

VERY RELIABLE
LOWER FIRST COST

LOWER EMISSIONS

ENVIRONMENTALLY FRIENDLY

LOWER ENERGY COST

BETTER HUMIDITY CONTROL

COLD AIR DISTRIBUTION

SMALLER CHILLERS-PUMPS

EMERGENCY COOLING

FLEXIBLE OPERATION

LARGE DELTA-T

THERMAL ICE STORAGE



APPLICATION & DESIGN GUIDE



GP - GLYCOL PUMP
Hs - CHILLED WATER PUMP
H-1 - ICE BUILD GLYCOL CHILLER

34°F (1.1°C)

36°F (2.2°C)



Thermal Ice Storage

Application & Design Guide

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Forward

The world's environmental health is directly linked to energy. The nations of the world are in a tug-of-war between adding new power plants to keep pace with their economies and reducing emissions that add to global warming. The solution to the energy crisis will be a combination of many factors - the biggest of which will be human ingenuity and desire!

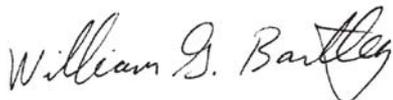
Many of the alternate energy sources being evaluated are in the early stages of development. Long range implementation plans often predict as many as twenty years before they will be fully effective on a significant scale.

Thermal Energy Storage (TES), on the other hand, is a proven, reliable, energy management technology that has been in use for over fifty years. TES is an energy management tool that transfers energy use from peak-hours to non-peak hours. In some areas of the world, TES is shifting hundreds of megawatts of power away from on-peak hours. Every major city in the world, by using thermal energy storage, could shift from 200 to 300 megawatts within ten years. Imagine the positive effect this would have on reducing emissions, lessening the need for more power plants and relieving the stress on transmission and distribution networks.

This Application and Design Guide focuses on one form of TES, Thermal Ice Storage. Specifically, the most popular "ice-on-coil" type as manufactured by Evapco, Inc. Thermal ice storage systems are explained in detail starting with various applications and continuing through to system commissioning.

Implementation of ideas focused on energy conservation, energy management, and the reduction of greenhouse gases all start with a desire to preserve our environment. It is in the spirit of learning ways to preserve our environment that Evapco freely offers this Ice Thermal Storage Application and Design Guide.

Sincerely,

A handwritten signature in black ink that reads "William G. Bartley". The signature is written in a cursive style with a large, stylized initial 'W'.

W. G. Bartley
President of Evapco, Inc.



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1. Introduction

A. History of Thermal Energy Storage

Thermal Energy Storage (TES) is the term used to refer to energy storage that is based on a change in temperature. TES can be hot water or cold water storage where conventional energies, such as natural gas, oil, electricity, etc. are used (when the demand for these energies is low) to either heat or cool the storage water. The energy is basically transferred, from conventional energy sources, to a temperature differential in the storage water that can be utilized during high energy demand periods. The typical domestic hot water heater is an example of thermal hot water storage that is popular throughout the world.

Thermal hot water storage and thermal chilled water storage applications are very common, and are used for both process and comfort heating and cooling systems.

In the 1930's, dairy farmers began using thermal ice storage to cool the daily batches of fresh milk. Normally, the milk cooling required large chillers that cooled for only a few peak hours (twice a day). Thermal ice storage offered the advantage of using much smaller refrigeration equipment that could build and store ice over a 10 to 12 hour period. Each batch of fresh milk could be cooled quickly using ice melt, and the thermal ice storage system could be recharged in time for the next milking. Thermal Ice storage still provides a considerable amount of milk cooling in the dairy industry.

Ice has played a major role in comfort cooling applications as well. Even the definition of a ton of cooling is derived using ice. The latent heat of fusion (phase change of water to ice or ice to water) is 144 Btu's per pound of water. One ton of ice is 2,000 pounds, Therefore, the energy required to change 2,000 pounds of water to ice would be $144\text{Btu/lb} \times 2000\text{ lb} = 288,000\text{ Btu's}$. To accomplish this in a 24 hour period, the hourly energy rate would be 12,000 Btu's per hour. This energy rate is defined as a ton of air conditioning.

In the late 1970's, a few creative engineers began to use thermal ice storage for air conditioning applications. During the 1980's, progressive electric utility companies looked at thermal energy storage as a means to balance their generating load and delay the need for additional peaking power plants. These utility companies offered their customers financial incentives to reduce their energy usage during selected on-peak hours. On-peak electric energy (kWh) and electric demand (kW) costs increased substantially, yet non-peak energy costs remained low.

B. Operating and Cost Benefits

Thermal energy storage was the perfect answer to the electric industries' needs. Creative and innovative owners and engineers applied the thermal ice storage concept to cooling applications ranging in size from small elementary schools to large office buildings, hospitals, arenas and district cooling plants for college campuses and downtown metropolitan developments. As the technology evolved, it became obvious to designers that thermal ice storage offered many additional installation, operational and cost benefits.

Thermal ice storage is a proven technology that reduces chiller size and shifts compressor energy, and condenser fan and pump energies, from peak periods, when energy costs are high, to non-peak periods, where electric energy is more plentiful and less expensive. The chiller operates during non-peak hours cooling a glycol solution to sub-freezing temperatures which is then circulated through the ice storage coils.



Ice forms around the external surfaces of the coils, and a full storage charge is reached when the ice is typically 1.1 to 1.5 inches thick. The ice is ultimately melted and used as a cooling agent. There are two different methods of ice melt and these will be explained in Section 3 - Methods of Ice melt.

The most significant benefit of thermal ice storage is the reduction of on-peak electric demand and the shift of energy use to non-peak hours. However, there are additional benefits that may not be as obvious to those designing a thermal ice storage system for the first time. Depending on the method of ice melt, the cooling fluid temperature can be substantially reduced when compared to a conventional chilled water system. Leaving temperatures are often as low as 34°F to 36°F (1.1°C to 2.2°C). This colder fluid offers many design benefits that reduce the overall system's first cost and improve HVAC and process cooling performance.

The benefits of the colder fluid are often overlooked when evaluating thermal ice storage systems. These benefits include:

First cost savings

- Reduced chilled water distribution flow - Colder supply water allows the designer to increase the system delta-T without effecting the components' performance. Rather than the conventional system's 10°F to 12°F (5.53°C to 6.63°C) delta-T, thermal ice storage systems typically are designed with an 18°F to 20°F (10.0°C to 11.1°C) delta-T distribution loop. A conventional design with a 12°F (6.63°C) delta-T (42°F - 54°F) (5.56°C - 12.2°C) will have an average fluid temperature of (48°F) (8.89°C). A thermal ice storage system designed with a 20°F (11.1°C) (38°F - 58°F) (3.33°C - 14.4°C) delta-T will have the same (48°F) (8.89°C) average water temperature. The 20°F (11.1°C) versus the 12°F (6.63°C) delta-T will reduce the chilled water flow approximately 40%, thus reducing the required distribution pipe sizes.
- Reduced chilled air distribution flow - The colder distribution fluid will allow the designer to use a larger air side delta-T as well. Conventional air-conditioning systems are designed for a leaving air temperature of 55°F (12.8°C) that result in a 50% relative humidity in the conditioned space. The colder fluid temperature available from the thermal ice storage system would allow for very cold air distribution temperatures (45°F) (7.22°C). Designing for the lowest possible air temperature will provide the most first cost and energy cost savings. However, these low temperatures would require a very tight (no leak) duct system, extra insulation and special terminal units. A more conservative 51°F (10.6°C) still offers considerable cost savings and results in 40% - 45% relative humidity in the conditioned space. By lowering the supply air temperature 4°F (55°F to 51°F) (2.2°C)(12.8°C - 10.6°C), the air flow can be reduced by 20%. This results in a corresponding 20% reduction in the distribution duct sizes. The cost of the duct system is often considered to be the largest single HVAC construction expense, and the first cost savings will be significant.
- Reduced fan motors and pump motors sizes - Designs using colder fluids and larger delta-Ts reduce air and water flow requirements. Therefore, fan and pump sizes, including the electric motor size, can be smaller, thus equipment and labor first cost savings can be substantial.
- Reduced electrical distribution - Smaller components such as chillers, fans and pump motors reduce the connected system's horsepower (kW) saving electrical distribution costs that may include the building's main transformer all the way to the starter panels. Reduced connected horsepower (kW) can also reduce the size of any emergency generation equipment that may be required.
- Building space savings - Smaller supply and return ducts require less floor area. Smaller air distribution ducts reduce ceiling plenum height which provides a shorter floor to floor dimension. The result is less construction costs and more usable/rentable floor space.

Long term benefits

- The combined electric demand of the fan and pump motors often exceed the electric demand of the chiller system. Low temperature fluid distribution designs will reduce the pump horsepower (kW) by approximately 40%. Low temperature air distribution designs will reduce the fan horsepower (kW) by approximately 50%. This is a substantial electric demand and energy use reduction that will provide operating energy cost savings for the life of the system.
- The chillers will always operate at or near 100% capacity when charging the storage system and typically at a higher capacity factor when compared with a conventional chilled water system during the daytime cooling. This reduces the amount of time chillers will operate at low load conditions, as well as on / off cycling based on cooling loads. When chillers are operated at or near full capacity most of the time, they require less maintenance. Any fluctuation in the cooling load will be satisfied by the ice storage.
- Process operations often have high cooling spikes of short duration. Chillers are not designed to load and unload quickly. Thermal ice storage can respond quickly and efficiently to load variations and can track rapid cooling spikes.
- Utility Electric Peak rate periods vary considerably. Demand periods may be 8 -10 hours or a series of shorter 2-3 hour segments. Thermal ice storage is very effective with any utility time-of day demand schedule and can be easily modified should rate periods change in the future.

Today, there are thousands of thermal ice storage systems installed and operating world wide and many of these have taken advantage of the benefits offered from lower temperatures.

2 Applications

A. Fundamental System

Any chilled water cooling system may be a good application for thermal ice storage. The system operation and components are similar to a conventional chilled water system. The main difference is that thermal ice storage systems are designed with the ability to manage energy use based on the time-of-day rather than the cooling requirements. The chiller is selected to cool a glycol solution to a temperature of 20°F-22°F (-6.7°C-5.6°C). The cold glycol is pumped through the ice storage coils which are located in the storage tank containing water. A ring of ice is formed around each coil tube. The ice build process occurs during the electric utility's off-peak time period, when energy and demand costs are very low. During the high price on-peak time period, the chiller, glycol and condenser water pumps and cooling tower fans are turned off. A chilled water pump circulates the cooling water through the ice storage tank where it is cooled to the desired temperature and distributed throughout the system. .

This describes the fundamental thermal ice storage system. There is no limit to the size of the cooling system. However, for small systems (less than 100 tons (352 kW)), thermal ice storage may be economically hard to justify. Large cooling systems with cooling capacities of several hundred or several thousand tons (kW) become easy to justify. In subsequent sections of this Application Guide, the fundamental system described above will be enhanced with:

- Choice of ice melt options
- Multiple operating modes
- Conventional chillers as well as ice build chillers



- Primary / secondary pumping loops
- Heat exchangers used to separate the different fluid loops (glycol, ice melt, chilled water)

B. HVAC Cooling:

Comfort air conditioning systems are ideal candidates for thermal ice storage. Large horsepower cooling compressors operate during peak summer energy periods. Thermal ice storage can transfer all or part of this energy to non-peak hours. Cooling may be required year round in some locations, while only seasonally in others. Typical applications are: office buildings, hospitals, large retail stores, schools (elementary - university), sports arenas and stadiums.

C. Process Cooling

This is a broad category with various applications including:

- Batch cooling where added heat must be removed (such as food processing)
- Batch cooling where internal heat is created that must be removed (such as chemical reactions or pharmaceutical processing)
- Cooling systems where a constant temperature must be maintained during all loads.
- Data centers where energy management plays a part along with multiple layers of equipment redundancy.

D. Turbine - Inlet Air Cooling

Peak turbine design efficiency occurs when the inlet air temperature is between 40°F & 50°F (4.44°C & 10.0°C). However, on hot summer days, when maximum generating capacity is essential, the ambient air temperature may be above 90°F (32.2°C) and the turbine efficiency may be substantially reduced. Many utilities have used thermal ice storage systems to lower the inlet air temperature entering the turbine. By building ice during off-peak hours, and using the thermal ice storage during on-peak hours, the inlet air, delivered by the air handling units, can be cooled below 50°F (10.0°C). Thus, the turbine efficiency and output can be maintained at design levels.

E. District Cooling Plants

District cooling plants for university campuses or metropolitan areas will have a variety of cooling applications: office buildings, hotels, dormitories, classrooms, labs, sports arenas and data centers to name a few. Thermal ice storage takes advantage of this diversity of cooling loads and enhances the performance of the entire cooling plant.

F. Developing Energy Sources - Solar & Wind

The technologies for both solar and wind energy are improving every year. These energy sources supply electric energy that can be used throughout the system, and are not limited to cooling. However, the creation of these energies often relies on weather conditions that may cause fluctuations in the energy flow. Thermal ice storage is a perfect complement for these systems. Ice storage will reduce the amount of solar or wind energy required by assuming the responsibility for a large portion of the air conditioning load. In addition, thermal ice storage / chiller cooling can be varied to offset the effect of any electric load irregularities caused by changing weather.

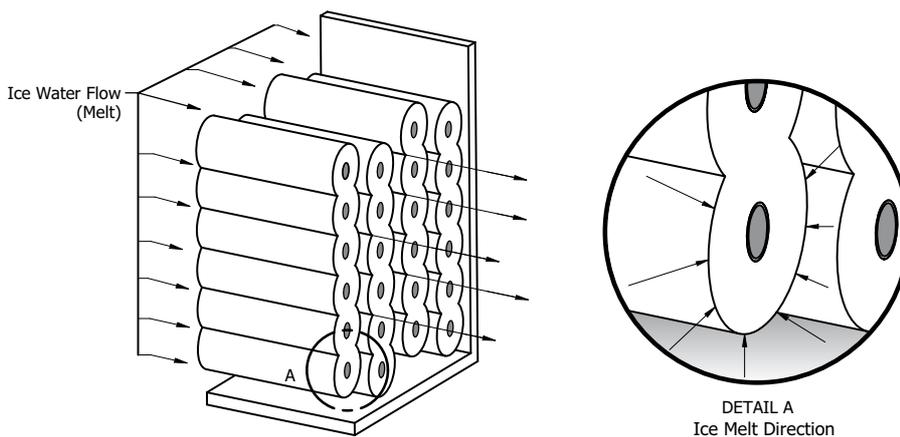
3. Methods of Ice melt

As explained earlier, a below freezing glycol fluid is pumped through the ice storage coils and a ring of ice is formed around each coil. Section 10 - Control Accessories, will describe the controls used to determine when a full charge is reached. This section will focus on the two (2) different types of ice melt.

A. External Melt

The ice build is complete when there is a ring of ice of the desired thickness around each coil circuit. At full build condition, the storage container will have approximately 65% ice and 35% water. The ice storage coils are spaced so that the warmer returning chilled water will circulate through the storage container and flow around and over these ice coil surfaces. The ice is melted from the outside of the ring, thus the term external melt. This resulting ice melt circulates to cool the chilled water system. External melt systems use two different fluids. Glycol is the ice build fluid and is circulated through the coil circuits, and water is the ice melt fluid providing the cooling to the system. Because there are two different fluids (glycol and ice water), more control components may be required for external versus internal melt systems.

Figure 3A: External Melt Method



The advantages of an external melt system are:

- Ice water supplied to the system is at a temperature of 34°F (1.1°C) or lower.
- Since there are no restrictions to the ice water flow, the rate of ice melt can vary greatly. The rate of ice melt can be constant (over 8-10 hours), rapid (melting all the ice in a short period of 1-2 hours), or fluctuating that satisfies the cooling requirements for air conditioning or process applications.
- The thermal ice storage cooling water is often the same as the cooling system fluid.
- Best overall system efficiency. Since the chiller and associated pumps are turned off during the on-peak hours, the only energy input is from the ice water pump. The on-peak system efficiency is often as low as 0.20 kW/ton.

The disadvantage of an external melt system is:

- The ice water in the storage container is exposed to atmospheric pressure. The cooling system loop must be designed as an open system with the ice water pump suction connection located below the water level of the storage container.

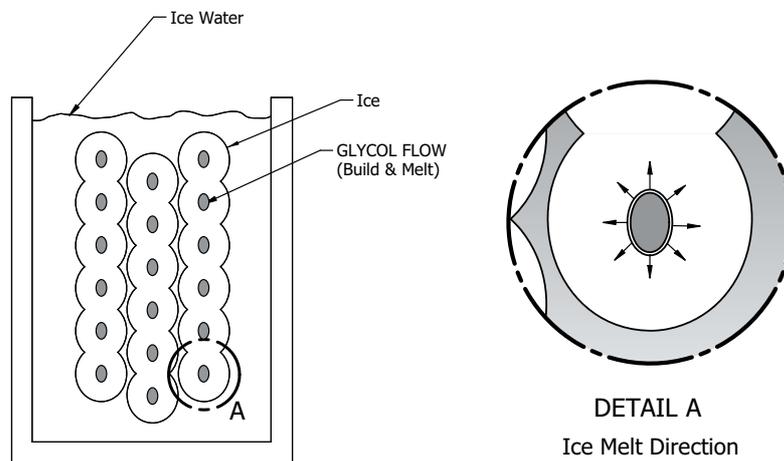
Examples of external melt system candidates are as follows:

- HVAC systems with short electric on-peak demand periods of 2 to 6 hours.
- Process cooling where the cooling requirement changes rapidly.
- Turbine - Inlet Air cooling where maximum cooling is required for 6 hours per day or less.
- Developing energy sources where rapid ice melt cooling is required to offset reductions in solar or wind power energy supply that result from changing weather conditions.
- District Cooling Plants where the lower fluid temperatures can reduce the system flow, pipe sizes and pump energy.

B. Internal Melt

The ice build is complete when the water in the storage container reaches a predetermined level. The volume in the storage container may be 65% to 80% ice. The ice thermal storage coils are located closer together, than for external melt designs, and the formation of ice on the coils is allowed to bridge from coil to coil. During the build cycle, the sub-freezing glycol solution is circulated through the ice coil circuits. During the ice melt cycle, the warmer returning glycol solution is circulated through the same ice coil circuits, and ice is melted from the inside of the ring. Thus the term internal melt.

Figure 3B: Internal Melt Method



Advantages of an internal melt system are:

- The cooling system is a closed loop.
- Water in the storage container remains static and goes through phase changes only. This water is not circulated in the cooling system.
- Since it is a closed loop, controls are simple.
- Minimum leaving glycol temperature is typically 37.4°F (3°C). Not as low a temperature as with external melt systems but still well below conventional chilled water system designs.

Disadvantages of an internal melt system are:

- The cooling fluid is the glycol solution.
- The glycol flow rate is limited due to the pressure drop through the ice storage coil. A limited flow rate also limits the rate of ice melt. The thermal ice storage system may not be able to track rapid cooling load fluctuations.

Examples of internal melt system candidates are as follows:

- HVAC cooling applications such as office buildings, schools, hospitals, retail stores, etc. where cooling requirements are relatively constant over a minimum 6 hour period and operating control systems should be very simple.
- Process cooling with relatively constant cooling loads.
- District cooling applications where the low temperature glycol (37.4°F / 3°C) can benefit the distribution system by decreasing pipe sizes and reducing pump horsepower.

4. Operating Strategy

With the total system cooling loads established as the basis of a design day, an operating strategy is the next step. Unlike conventional systems where the chillers load and unload to satisfy cooling requirements, thermal ice storage systems allow for the management of energy consuming components. The following items should be considered when developing an operating strategy.

A. Electric Cost and Rate Schedules

It is important to remember during this thought process that a kW \neq a kW. The energy units are the same, but time-of-use changes the value of the energy. Most electric utility companies have rate schedules that change based on seasons of the year and time of day. The cost of energy may fluctuate greatly with these changes. The lowest prices generally occur at night and on weekends, when system usage is light and energy is plentiful. This time period is referred to as off-peak. The highest prices occur during weekday hours, when energy usage is high and generating capacity and distribution may be limited. This time period is referred to as on-peak. The on-peak and off-peak periods may vary based on the particular utilities' needs. On-peak may be 8 to 12 hours during the day or only a few hours in the morning and evening. Typically, off-peak periods occur during the nighttime and early morning hours when electrical supply is plentiful. Some utilities have an intermediate rate period where a few hours separate the on-peak and off-peak time periods. During intermediate hours, energy cost may increase slightly, but demand costs are generally not applied. In some areas of the world, where electric energy supply is limited, the use of power for air-conditioning applications may be restricted.

B. Types of Ice Melt Systems

Both external melt and internal melt thermal ice storage systems are very effective when cooling loads are relatively constant over a minimum 6 hour period. External melt systems can provide the lowest leaving fluid temperature which can be a factor if the project design utilizes low temperature air and/or water. External melt systems are capable of satisfying rapid cooling spikes where all of the ice storage is available to be used in a few hours (Review Section 3 for the advantages and disadvantages of both types of ice melt systems).

C. Full or Partial Storage

The term Full Storage refers to systems where the entire system load is cooled from the ice storage. The term Partial Storage refers to systems where only a portion of the system cooling comes from the ice storage.

Full storage systems provide the largest amount of energy cost savings. Mechanical cooling components; compressors, condenser pumps and fans do not operate during on-peak hours. However, the system may also have the highest first cost. The amount of ice storage equipment required may be considerably more than required for a partial storage system. Also, in order to build sufficient ice for the full storage requirements, the capacity of the chiller may be larger than that required for a comparable conventional chilled water system. Both of these cost additions may offset the energy cost savings. Still, there are many areas of the world and conditions where on-peak energy is very limited and expensive, and full storage systems may be mandatory.

Partial storage systems reduce the first cost of the system components. Generally, the chiller size required is approximately 60% of that required for a comparable conventional chilled water system. This smaller chiller operates and maintains its portion of the cooling load through the on-peak time period. The ice storage / ice melt provides all of the additional cooling required. As seasonal cooling loads decrease, the percentage of chiller operation may be lowered. Partial storage systems often evolve into full storage systems in mild weather.

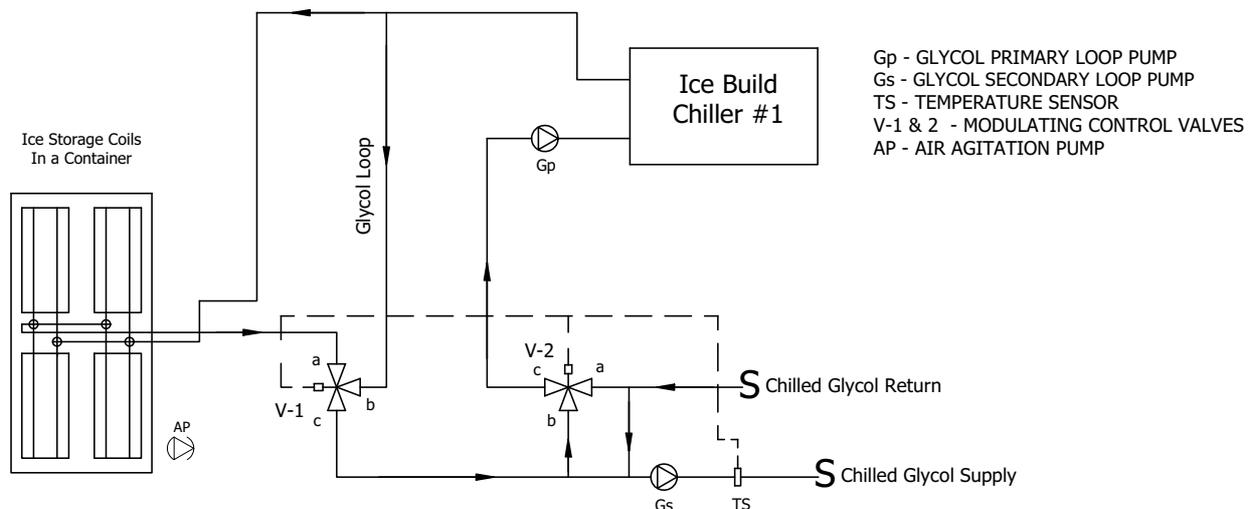
D. System Operating Modes

Depending on the method of ice melt (external or internal) selected, the control system will vary the modes of operation based on time-of-day or season of the year. Any or all of these operating modes could be used daily.

Internal Melt Systems

One of the advantages of an internal melt system is that the controls are simple. This basic flow diagram will be used to help explain each mode.

Figure 4D-1: Internal Melt Basic System



Ice Build Mode – Low temperature glycol is circulated through the storage coils creating the ice. Ice build will begin when the storage water temperature is below freezing and continue until a full build is reached. The leaving glycol temperature required from the chiller(s) will decrease throughout the build cycle. The chiller(s) capacity must be selected to meet the lowest temperature required based on the ice manufacturer's calculations. This may be 22°F (-5.56°C) or lower at the end of the build cycle. The chiller should operate at 100% capacity during the ice build period. To keep the chiller from unloading, it is a common practice to set the leaving temperature of the chiller at 2°F (1.1°C) below the final build temperature. In this case 20°F (-6.67°C). This will assure that the chiller remains fully loaded.

Components Settings:

Chiller set to provide 20°F (-6.67°C) glycol. Glycol pump Gp (on) and GPs (off), Glycol flow valve V-1 (ports a > c), valve V-2 (ports b > c). Air agitation is not generally necessary for internal melt systems. However, if used, the air pump AP should operate the first 2 hours of the ice build mode.

Direct Cooling Mode (Chiller Only) – The direct cooling mode is intended to provide cooling directly from the chiller to the cooling loop. This mode would be used after the ice build is completed and prior to the on-peak period when energy prices are still low. All of the cooling requirements could be met by the chiller thus saving the ice inventory for use during the high price on-peak period. Depending on the cooling load, a small amount of ice storage may be required during this period. Ideally, this mode should maximize the chiller use and minimize the ice storage use.

Components Settings:

Chiller is reset to provide the desired system cooling loop temperature 42°F (5.56°C) for example. Glycol pumps Gp & GPs are on, Glycol flow valve V-1 (ports b > c) V-2 (ports a > c). If the chiller is unable to provide the entire cooling requirements, temperature sensor TS will modulate valve V-1 to provide additional cooling from storage.

Chiller and Ice Storage Mode – For partial storage systems, the chiller operates in conjunction with the ice storage to meet the cooling needs. Internal melt systems inherently have the chiller and ice storage piped in series. The chiller's leaving glycol set point can be reset to a temperature of say 47.4°F (8.55°C). For a system designed for a 20°F (11.1°C) delta-T, the chiller would provide the cooling from 57.4°F to 47.4°F (14.1°C to 8.55°C) and the ice storage would provide the final cooling to 37.4°F (3.0°C). Locating the chiller upstream of the ice storage allows for a higher chiller leaving set point of 47.4°F (8.55°C) and better chiller efficiency. The chiller may cycle off automatically when the return temperature approaches the 47.4°F (8.55°C) set point. When this occurs, the partial storage system becomes a full storage system.

Components Settings:

Chiller is reset to provide 47.4°F (8.55°C) Glycol pumps Gp & GPs are on. Valve V-1 modulates flow by TS to provide 37.4°F (3.0°C) & Valve V-2 flow (ports a > c). Air agitation is not generally necessary for internal melt systems. However, if used, the air pump AP should operate whenever the ice is being melted.

Locating the chiller down stream of the ice storage requires the chiller to be set at the final loop temperature. Using this same example, this could be 37.4°F (3.0°C). If the chiller is piped downstream of the ice storage, the chiller must run and operate at a lower efficiency. This piping arrangement can also be referred to as a chiller priority mode.

Ice Melt Only – As the name implies, all cooling is provided by the ice storage system. Chiller(s) and condensers components are turned off. Only the glycol pump and secondary loop pumps will operate.

Components Settings:

Chiller is off. Glycol pump GPp & GPs are on, Valve V-1 modulates flow by TS and valve V-2 flow (ports a > c). Air agitation is not generally necessary for internal melt systems. However, if used, the air pump AP should operate whenever the ice is being melted.

Ice Build with Cooling – Occasionally, there may be a small after-hours or nighttime cooling load. This load may be cooled during the ice build mode by modulating control valve V-2 to blend some of the glycol return fluid into the secondary loop. The secondary loop return fluid is mixed with the remainder of the glycol build fluid and returned to the chiller. The cooling load should be small, no greater than 10% of the design load, or the mixed return fluid to the chiller may be elevated to a level at which the chiller can no longer build ice.

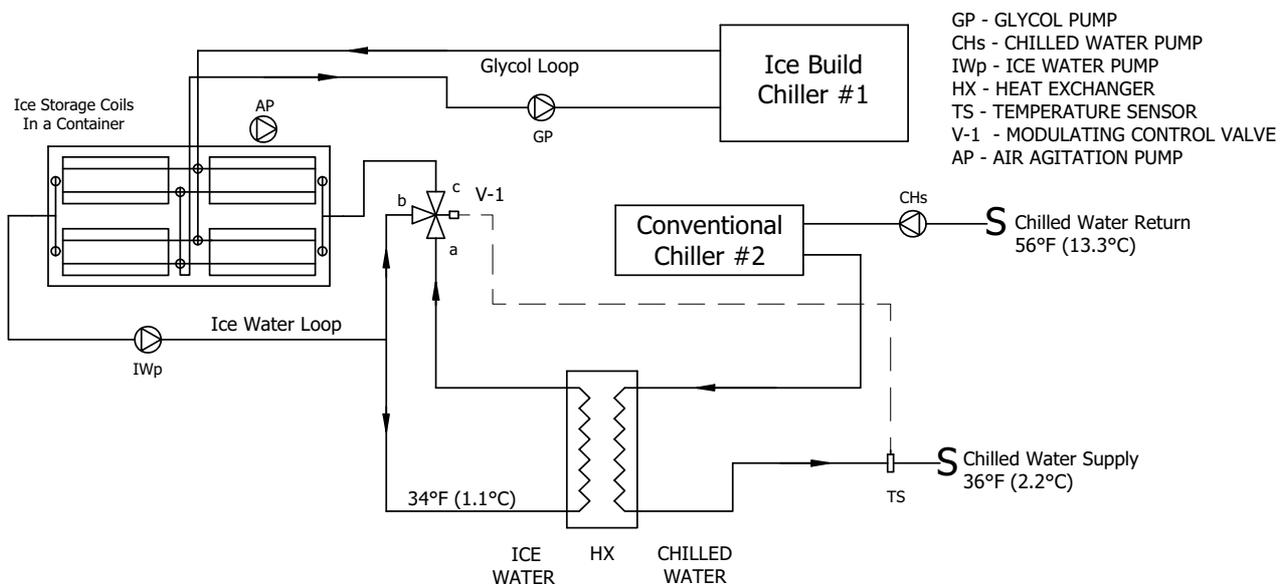
Components Settings:

The system components operate as described for the ice build mode except, glycol pump GPp (or a separate small zone loop pump) will operate and temperature sensor (TS) will modulate valve V-2 to maintain the desired system temperature.

External Melt Systems

This basic flow diagram will be used to help explain each mode.

**Figure 4D-2: External Melt
Conventional Chiller Piped in Series with Ice Water Heat Exchanger**



Ice Build Mode – Low temperature glycol is circulated through the storage coils creating the ice. Ice build will begin when the storage water temperature is below freezing and continues until a full build is reached. The leaving glycol temperature required from the chiller(s) will decrease throughout the build cycle. The chiller(s) capacity must be selected to meet the lowest temperature required based on the ice coil manufacturer's calculations. This may be 22°F (-5.56°C) or lower at the end of the build cycle. The chiller should operate at 100% capacity during the ice build period. To keep the chiller from unloading, it is a common practice to set the leaving temperature of the chiller at 2°F (1.1°C) below the final build temperature. In this case 20°F (-6.67°C). This will assure that the chiller remains fully loaded.

Components Settings:

Chiller set to provide 20°F (-6.67°C) glycol. Glycol pump GP is (on). Ice water pump IW is off. The air agitation pump AP operates for the first 2 hours of the ice build mode. .

Direct Cooling Mode (Conventional Chiller Only) – The direct cooling mode is intended to provide cooling directly from the conventional chiller to the cooling loop. This mode would be used at any time (before, during or after the ice build mode). During the ice build mode and prior to the on-peak period, when energy prices are still low, all of the cooling requirements could be met by the conventional chiller thus saving the ice inventory for use during the high price on-peak period.

Components Settings:

The ice build chiller can continue to operate based on the ice build mode time period. The conventional chiller is set to provide the desired system cooling loop temperature 42°F (5.56°C) for example. Chilled water pump CH is on and the ice water pump IW is off. There is no ice water flow through the heat exchanger and Valve V-1 is idle.

Chiller and Ice Storage Mode – For partial storage systems, the conventional chiller operates in conjunction with the ice storage to meet the cooling needs. The conventional chiller is piped in series with the ice water heat exchanger thus allowing for large delta T designs which reduce the system flow.

The conventional chiller is set to cool the returning 56°F (13.3°C) chilled water to 46°F (7.78°C). The ice water pump supplies 34°F (1.1°C) ice water to the heat exchanger where it cools the 46°F (7.78°C) chilled water to the 36°F (2.22°C) chilled water loop supply temperature.

Locating the conventional chiller upstream of the ice water heat exchanger allows for a higher chiller leaving set point of 46°F (7.78°C) and better chiller efficiency. The conventional chiller may cycle off automatically when the return temperature approaches the set point. Locating the conventional chiller downstream of the ice water heat exchanger requires the chiller to be set at the final loop temperature. Based on the system design, this could be 36°F (2.22°C) and the chiller would be operating at a very poor efficiency.

Components Settings:

The ice build chiller and glycol pump GP are turned off. The air agitation pump AP is on. The conventional chiller is set to provide 46°F (7.78°C) chilled water and chilled water pump CH is on. Ice water pump IW is on and Valve V-1 is modulated by temperature sensor TS to provide 36°F (2.22°C) on the leaving side of the heat exchanger.



Ice Melt Only Mode – As the name implies, all cooling is provided by the ice storage system.

Components Settings:

The ice build chiller and the conventional chillers and condenser components are turned off. Only the ice water pump IW, chilled water pump CH and air agitation pump AP are operating. Valve V-1 is modulated by temperature sensor TS to provide 36°F (2.22°C) on the leaving side of the heat exchanger.

E. Conventional Chiller Operation

The cooling capacity of most water cooled chillers can be accurately estimated using nominal conditions of 44°F leaving chilled water temperature and 85°F entering condenser water temperature (6.67°C / 29.4°C) as a base. For ice build duty, as a rule of thumb, de-rate the nominal capacity by 35% to estimate the chiller performance at 22°F (-5.56°C) leaving glycol temperature (25% glycol solution) and 80°F (26.7°C) entering condenser water temperature. For each additional 1°F (0.5°C) increase or decrease in the leaving water temperature, adjust the capacity by 1.5% accordingly. For conventional water chillers, the 1.5% adjustment factor can also be used. A chiller with a nominal capacity at 44°F (6.67°C) leaving water temperature will be de-rated by 12% (1.5% x 8°) and have only 88% of this capacity at 36°F (2.22°C) leaving water temperature.

The capacity of air-cooled chillers can also be accurately estimated using the same de-rate factors. However, the nominal capacity of an air-cooled chiller is based on 44°F leaving chilled water temperature and 95°F entering ambient air temperature (6.67°C / 35°C) as a base. For ice build duty, as a rule of thumb, de-rate the nominal capacity by 35% to estimate the chiller performance at 22°F (-5.56°C) leaving glycol temperature (25% glycol solution) and 75°F (23.9°C) entering ambient air temperature. Air-cooled chillers generally use screw type compressors. Their efficiency is greatly improved as the entering ambient air temperature drops and they work well in both ice build and conventional chiller modes.

Using this estimating technique will enable the designer to vary the chiller and ice storage capacities as necessary during the design process. Once the chiller and ice storage capacities are determined, the chiller manufacturers should be contacted to confirm the selections.

Ice Build Chillers:

The primary duty is to provide low temperature glycol to charge the storage system. However, these chillers can also be used during the Direct Cooling Mode and the Chiller and Ice Storage Mode. For external melt systems, reset the chiller's leaving glycol temperature to a point above the freeze point and divert the flow to a glycol / chilled water heat exchanger. (Refer to Chapter 6 - Figure 6A-4).

For internal melt systems, reset the chiller's leaving glycol temperature to a point above freezing and use control valve V-1 to direct the glycol flow to the cooling loop for direct cooling, or modulate valve V-1 and direct the flow through the ice storage coils for series cooling. (Refer to Chapter 6 - Figure 6B-3).

Conventional Chillers:

All cooling applications that operate 24 hours per day must use multiple chillers. Hospitals, data centers, district cooling plants, etc. have chillers that provide cooling while the ice storage system is being recharged. During on peak hours, they work in conjunction with the ice storage.

For external melt systems, conventional chillers can be piped in series or in parallel with the ice storage. One or more conventional chillers can be piped upstream of the ice storage. They can be set to supply 44°F (6.67°C) water, and the ice will provide the final cooling to 34°F (1.1°C). The chillers will operate at a very efficient level since they are providing higher fluid temperatures.

When piped in parallel with the ice storage, conventional chillers can be effective. The conventional chillers will operate with the same delta-T and the same temperature as the ice storage system. Typically the conventional chillers can operate at the larger delta-Ts (18°F - 20°) (10°C - 11.1°C) and supply chilled water temperatures of 34°-36°F (1.11° - 2.22°C) making them compatible with the ice storage system.

For internal melt ice systems that are traditionally designed with the chiller and ice storage piped in series, conventional chillers, when added, are piped in parallel with the ice storage. They generally will have the same delta-T and leaving temperature as the ice storage components. For high delta-T systems, it may be necessary to use sets of two chillers, piped in series with each other but piped in parallel with the storage components. (Refer to Figure 6B-3)

5. System Sizing and Design Day Performance

Whether the application is air conditioning, process cooling or district cooling, an accurate design day cooling load profile is recommended for sizing the various system components. Before selecting the system components, it is necessary to make decisions regarding the overall system operation. Consider the following:

1. Review the electric utility company's time-of-day rate schedule as these are needed in the thermal ice storage design process.
2. Select either external melt or internal melt as the basis of design of the thermal ice storage system.
3. Determine the chilled water system design flow and delta-T. Evaluate the use of glycol / chilled water or ice water / chilled water heat exchangers.
4. Most thermal ice storage system designs will be for partial storage. However, full storage should be considered in areas where energy supplies are limited or very expensive.
5. Review the design day cooling load profile and determine if conventional chillers will be necessary for cooling during non-peak and on-peak hours.

This information can be used to develop the design day performance spread sheet. The following example is a step by step method for developing this spread sheet.

A. Example: (External Melt System) (English Units)

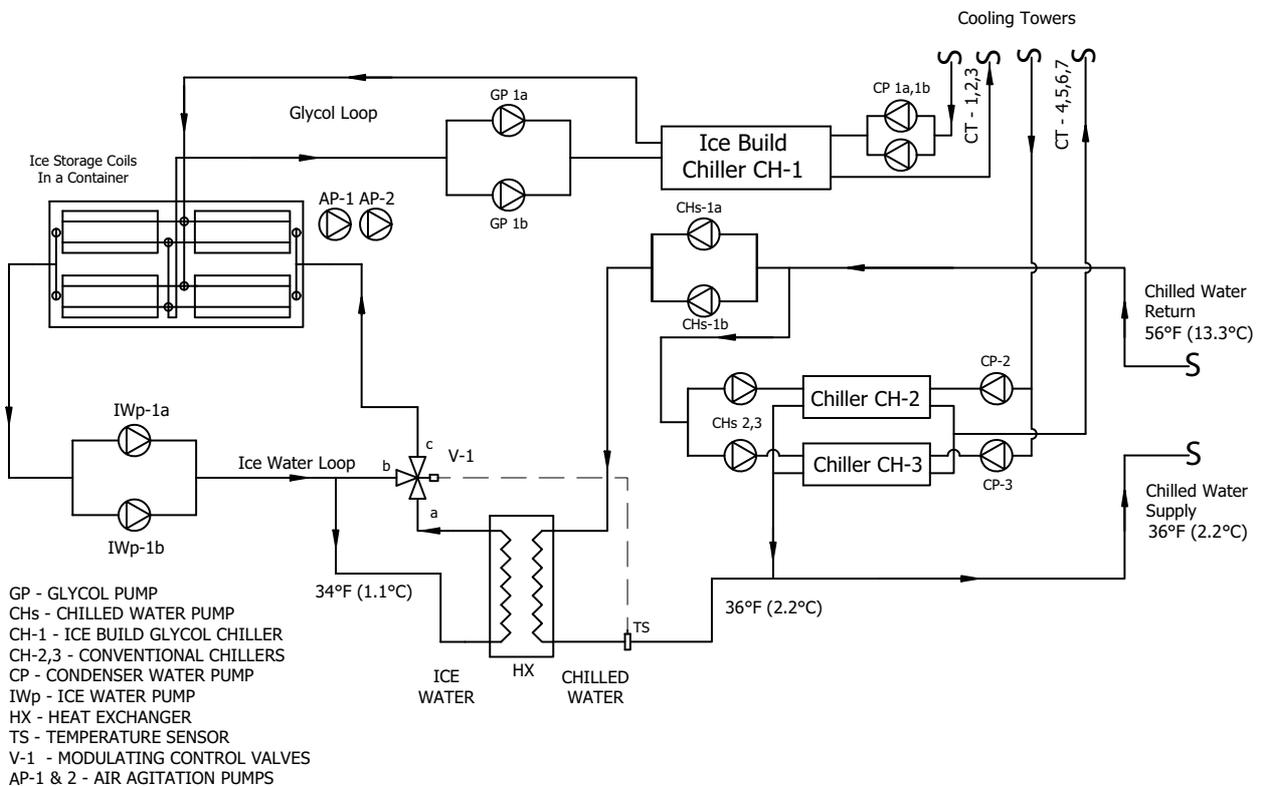
Information requested above -

1. The electric utility Company's time-of-day rate schedule is:
 - Summer - on-peak - 10:00 AM to 20:00 PM (10 hours)
 - Winter - on-peak - 6:00 AM to 11:00 AM and 16:00 PM to 20:00 PM
2. An external melt thermal ice storage system was selected.
3. The system chilled water loop is based on a 20°F delta-T (56°F to 36°F). An ice water / chilled water heat exchanger will be used to separate the ice water and chilled water loops.
4. The system will be a partial ice storage system.

- The design day cooling load profile has a cooling peak of 7,000 tons and a night cooling load of 3,000 to 4200 tons. Conventional chillers will provide 3,500 tons of the off-peak cooling and a maximum of 3,000 tons of the on-peak cooling.

Based on this information, the thermal ice storage / chilled water plant would have equipment components and a piping flow similar to the following:

Figure 5A-1: External Melt Example - Flow Schematic
Two Conventional Chillers Piped in Parallel with Ice Water Heat Exchanger



The *Total System Performance* spread sheet can be set up starting with columns for time-of day on the left with Electric Utility Rate Periods next to it. Continuing, left to right, add columns for:

- Design Day - Cooling Load Profile
- Conventional chiller load
- Chilled water flow (variable)
- Chilled water return and supply temperatures
- Ice melt load profile (design day load minus conventional chiller load)
- Ice water flow (variable)
- Ice water temperature (entering and leaving the heat exchanger)
- Chilled water flow (to heat exchanger)



- Chilled water temperature (entering and leaving the heat exchanger) - assume a 2°F cold side / hot side approach.

The last column should indicate the total system cooling load which is the hourly sum of the conventional chiller load and the ice melt load. This column should be identical to the design day cooling load column.

Before continuing with the development of the “*Thermal Ice Storage*” spread sheet, the “*Total System Performance*” spread sheet was completed and is shown below. The text that follows describes the development of the data for each column. Each of the 24 (time-of-day) rows will indicate the operation of each system component for that particular hour.

Figure 5A-Spread Sheet Example - External Melt (English Units)
Total System Performance

Time of Day	Electric Utility Rate Periods	Chilled Water Loop				Ice Water Loop		Ice Water / Chilled Water Heat Exc.		Chilled Water Flow (gpm)	Total System Cooling (tons)
		Design Day Cooling Load (tons)	Two Conv. Chillers CHs 2,3 (tons)	Chilled Water Flow (gpm)	Chilled Water Temp. Return / Supply (°F)	Ice Melt Cooling Profile (tons)	Ice Water Flow (gpm)	Cold Side (°F)	Hot Side (°F)		
0-1	3	3000	3000	3600	56 / 36						3000
1-2	3	3000	3000	3600	56 / 36						3000
2-3	3	3000	3000	3600	56 / 36						3000
3-4	3	3000	3000	3600	56 / 36						3000
4-5	3	3000	3000	3600	56 / 36						3000
5-6	3	3000	3000	3600	56 / 36						3000
6-7	3	3000	3000	3600	56 / 36						3000
7-8	3	3500	3500	4200	56 / 36						3500
8-9	3	3500	3500	4200	56 / 36						3500
9-10	3	4200	3500	4200	56 / 36	700	840	34 / 54	56 / 36	840	4200
10-11	1	5000	3000	3600	56 / 36	2000	2400	34 / 54	56 / 36	2400	5000
11-12	1	5000	3000	3600	56 / 36	2000	2400	34 / 54	56 / 36	2400	5000
12-13	1	6000	3000	3600	56 / 36	3000	3600	34 / 54	56 / 36	3600	6000
13-14	1	6500	3000	3600	56 / 36	3500	4200	34 / 54	56 / 36	4200	6500
14-15	1	7000	3000	3600	56 / 36	4000	4800	34 / 54	56 / 36	4800	7000
15-16	1	7000	3000	3600	56 / 36	4000	4800	34 / 54	56 / 36	4800	7000
16-17	1	6700	3000	3600	56 / 36	3700	4440	34 / 54	56 / 36	4440	6700
17-18	1	6400	3000	3600	56 / 36	3400	4080	34 / 54	56 / 36	4080	6400
18-19	1	6000	3000	3600	56 / 36	3000	3600	34 / 54	56 / 36	3600	6000
19-20	1	4200	3000	3600	56 / 36	1200	1440	34 / 54	56 / 36	1440	4200
20-21	3	3500	3500	4200	56 / 36						3500
21-22	3	3000	3000	3600	56 / 36						3000
22-23	3	3000	3000	3600	56 / 36						3000
23-0	3	3000	3000	3600	56 / 36						3000
Total		104500	74,000			30,500					104,500

Utility Rate Periods: 1= on peak; 2 = intermediate peak; 3 = off peak

Insert the design day cooling loads in their hourly slot. A review of the design day cooling loads indicates that, during the 14 hour off-peak period, one hour has a load of 4200 tons, three hours have a load of 3500 tons each and the remaining ten hours have a load of 3000 tons each. Using the chiller capacity de-rate factor shown in Section 4E-Chiller Operation, there will be a 1.5% reduction in chiller capacity for each degree (°F) below the nominal conditions. Since the system design water temperature is 36°F (8°F below 44 nominal) the de-rate factor



would be 12% ($1.5\% \times 8$) or 88% of its nominal capacity. The nominal chiller capacity for each of these tons is:

- 4200 tons divided by 88% = 4773 nominal tons
- 3500 tons divided by 88% = 3977 nominal tons (2 @ 2000 tons each)
- 3000 tons divided by 88% = 3409 Nominal tons

A conventional chiller selection of two (2) nominal 2000 ton chillers will provide all of the off-peak cooling except for 700 tons (4200 tons - 3500 tons) at hour 9-10 AM.

The system's chilled water flow through the conventional chillers may be variable and set to maintain a 56°F to 36°F temperature range. The ice melt cooling profile is the difference between the design day profile and the conventional chiller profile. The ice water flow is also variable and will maintain a 34°F to 54°F temperature to the heat exchanger. The system chilled water through the heat exchanger is variable and set to maintain a 56°F to 36°F temperature. The last column is a check to verify that the conventional chiller cooling and the ice melt cooling match the design day cooling.

Now continue with the development of the "*Thermal Ice Storage*" system spread sheet. Again start on the left and the first two columns are time-of-day and electric utility's rate periods. The next columns would be:

- Ice build chiller
- Glycol flow
- Glycol supply and return temperatures
- Ice coil pressure drop
- Ice build inventory
- Ice melt tons
- Ice melt inventory
- Ice water flow
- Ice water supply and return temperatures to the heat exchanger

The "*Ice Storage System Performance*" spread sheet has been completed and is shown below. The text that follows describes the development of the data for each column. Each of the 24 (time-of-day) rows will indicate the operation of each system component for that particular hour.



Figure 5A-Spread Sheet Example - External Melt (English Units)
Ice Storage System Performance

Time of Day	Electric Utility Rate Periods	Glycol Loop					Ice Water Loop			
		Ice Build Chiller CHS-1 (tons)	Glycol Flow (gpm)	Glycol Temp. In / Out (°F)	Ice Coil Pressure Drop (psi)	Ice Build Inventory (ton-hrs)	Ice Melt Inventory (ton-hrs)	Ice Melt (tons)	Ice Water Flow (gpm)	Ice Water Heat Ex Temp. Return / Supply (°F)
0-1	3	2377	11000	21.4 / 27.0	12.3	12816				
1-2	3	2345	11000	21.0 / 25.5	12.3	15166				
2-3	3	2318	11000	20.6 / 26.2	12.3	17479				
3-4	3	2297	11000	20.4 / 29.7	12.3	19776				
4-5	3	2280	11000	20.2 / 25.5	12.3	22056				
5-6	3	2270	11000	20 / 25.3	12.3	24326				
6-7	3	2254	11000	20 / 25.3	12.3	26580				
7-8	3	2243	11000	20 / 25.3	12.3	28823				
8-9	3	1955	11000	20 / 24.5	12.3	30778				
9-10	3	0					30078	700	840	54 / 34
10-11	1	0					28078	2000	2400	54 / 34
11-12	1	0					26078	2000	2400	54 / 34
12-13	1	0					23078	3000	3600	54 / 34
13-14	1	0					19578	3500	4200	54 / 34
14-15	1	0					15578	4000	4800	54 / 34
15-16	1	0					11578	4000	4800	54 / 34
16-17	1	0					7878	3700	4440	54 / 34
17-18	1	0					4478	3400	4080	54 / 34
18-19	1	0					1478	3000	3600	54 / 34
19-20	1	0					278	1200	1440	54 / 34
20-21	3	2626	11000	25.8 / 31.9	12.3	2904				
21-22	3	2608	11000	25.4 / 31.5	12.3	5512				
22-23	3	2501	11000	23.5 / 29.3	12.3	8013				
23-0	3	2426	11000	22.1 / 27.8	12.3	10439				
Total		30500						30500		

Utility Rate Periods: 1= on peak; 2 = intermediate peak; 3 = off peak

In order to size the ice build chiller, sum up the hour by hour ice melt profile. In this example, 30,500 ton -hours is the total ice-melt and ice storage required. Divide this total by the number of hours available to build ice (13 hours - 20:00 PM to 9:00 AM). The capacity of the ice build chiller (at 22°F / 80°F) is approximately 2350 tons. Applying the 35% de-rate factor (65% of nominal capacity) for ice build chillers refer to Section 4E Chiller Operation, the nominal ice build chiller size is estimated to be 3615 tons. This is an excellent method for estimating the ice build chiller size.

The glycol flow should be selected for a 5°F to 7°F delta-T (29°F to 22°F). The glycol temperature returning to the chiller must be below freezing. For this example, 11,000 gpm (2350 tons at 5.54°F delta-T) was used. At the start of the ice build mode, the chiller capacity and glycol supply temperature will be high. As the ice build process continues, the ice will become thicker requiring a lower glycol temperature resulting in less chiller capacity. The ice build will begin at 20:00 PM and continue to 9:00 AM (13 hours). The chiller capacity and glycol supply and return temperatures that are shown are typical for the ice build mode.

The ice inventory is simply the amount of ice storage (ton-hours) in the storage container. The inventory increases (hour by hour) during the ice build mode and decreases as ice is melted. There should always be a little ice



left in storage at the end of the ice melt cycle. The data shown on the spread sheet includes an estimated ice coil pressure drop.

The ice water flow is varied to maintain the 20°F Delta-T and 34°F supply temperature to the heat exchanger.

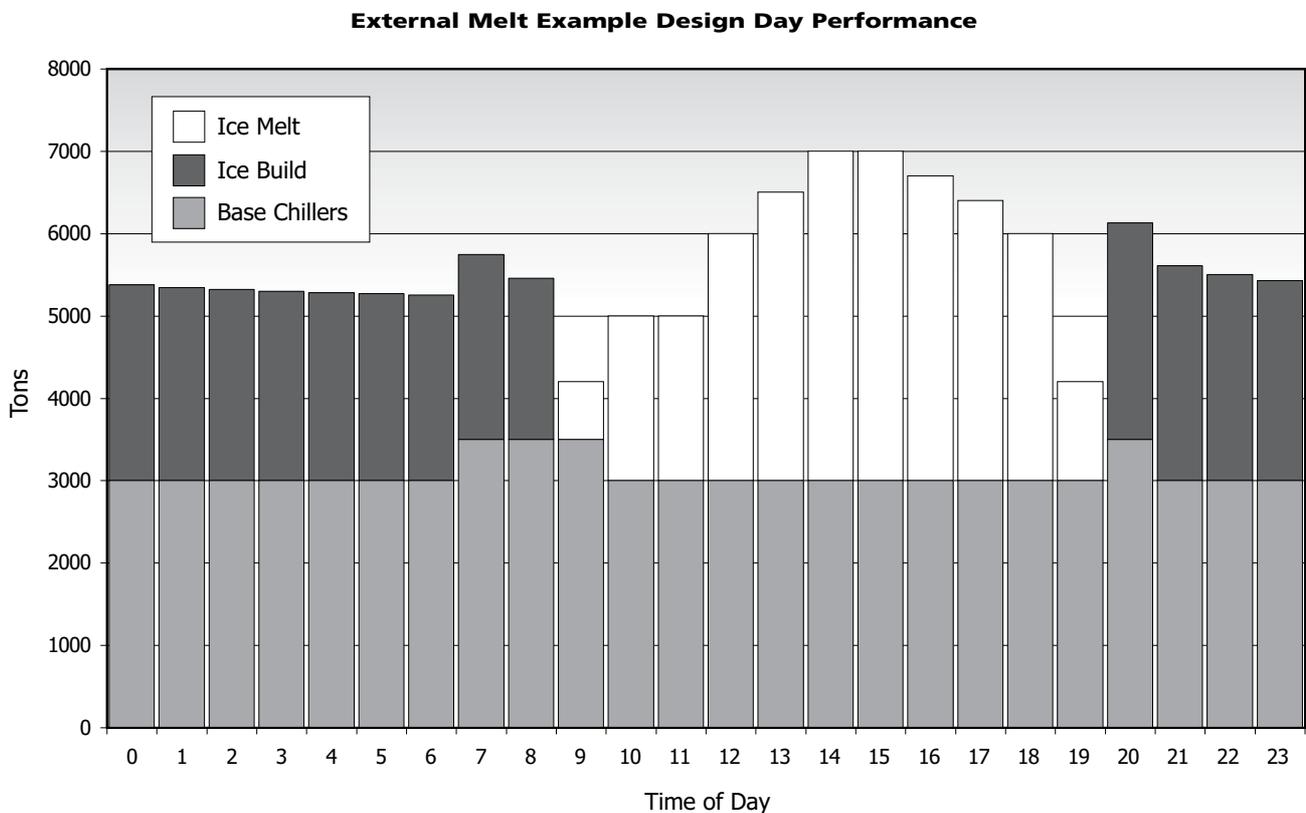
The preliminary planning for a thermal ice storage / chilled water plant takes only a few minutes and does not require involvement from the chiller manufacturer or the ice storage manufacturer. Modifications to the plant that may be considered are:

- Smaller or larger chilled water delta-T.
- Multiple chillers and pumps.
- Air-cooled or water cooled chillers or a mix of both.
- Changes in the electric utility rate schedule.

Both of these spread sheets should be completed before contacting the chiller manufacturer to verify the chiller capacity. Evapco has a Thermal Ice Storage Selection Program that can assist with the development of these spread sheets as well as thermal ice storage experts available to answer any questions.

The more data included in the spread sheet, the easier it is to evaluate the system's performance. We recommend that both completed spread sheets be included as part of all bid and contract documents.

Graph of the external melt example - Design Day Performance is shown here:



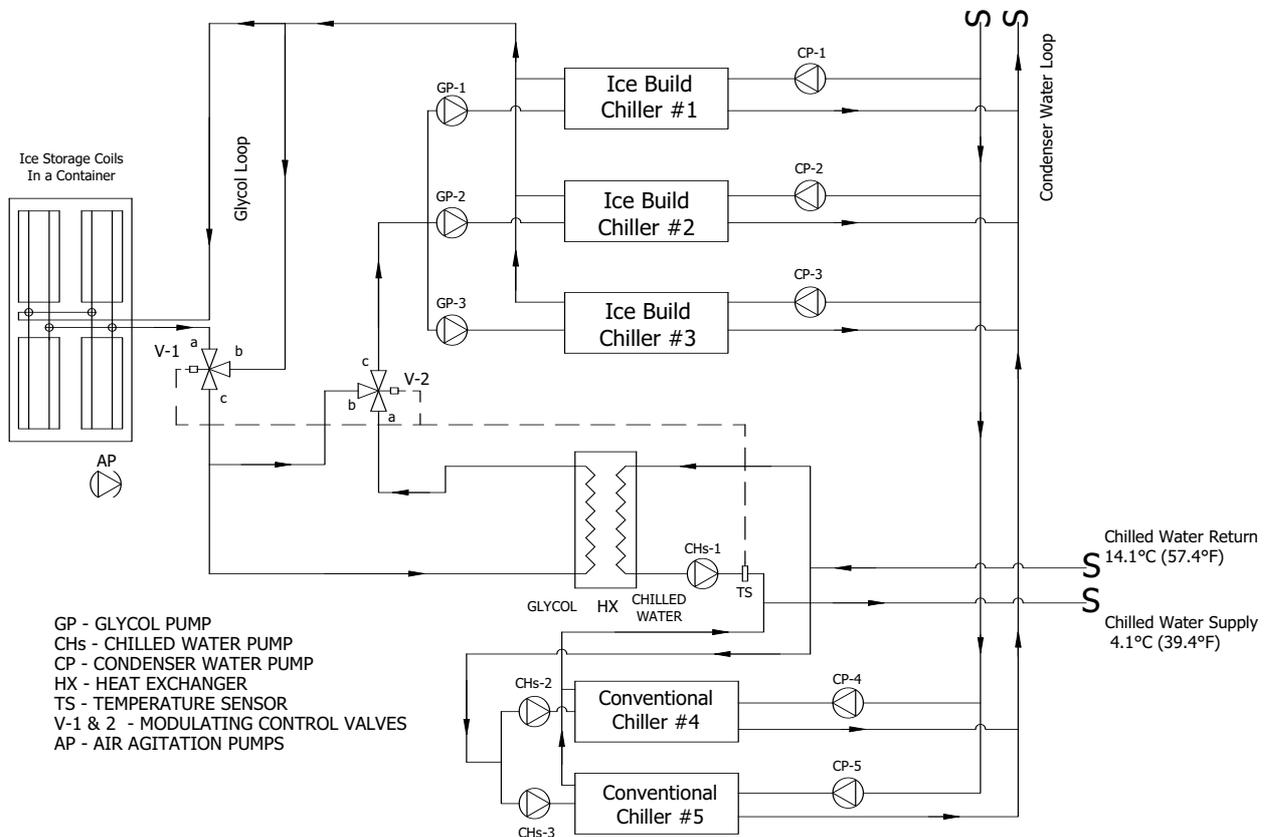
B. Example - Internal Melt (Metric Units)

Information requested above -

1. The electric utility Company's time-of-day rate schedule is:
 - Summer - On-peak - 10:00 AM to 20:00 PM (10 hours)
 Intermediate-peak - 07:00 AM - 10:00 AM; 20:00 PM - 23:00 PM (6 hours)
 Off-peak - 23:00 PM - 07:00 AM (8 hours)
 - Winter - On-peak - 6:00 AM to 11:00 AM; & 16:00 PM to 20:00 PM (9 hours)
 Intermediate-peak - 11:00 AM - 16:00 PM (5 hours)
 Off-peak - 20:00 PM - 07:00 AM (8 hours)
2. An internal melt thermal ice storage system was selected.
3. The system chilled water loop is based on a 10°C delta-T (14.1°C to 4.1°C). A glycol fluid / chilled water heat exchanger will be used to separate the glycol and chilled water loops.
4. The system will be a partial thermal ice storage system.
5. The design day cooling load profile has a cooling peak of 10,500 kW and a night cooling load of 1,100 kW to 1,800 kW. There will be two (2) conventional water chillers that will provide 1,800 kW of the off-peak cooling. One will operate to provide the 1,800 kW, and both will operate during intermediate and on-peak hours. There will be Three (3) glycol chillers. All three will build ice during the off-peak period. However, only two of these chillers will operate during the on-peak time period.

Based on this information, the thermal ice storage / chilled water plant would have equipment components and a piping flow similar to the following:

Figure 5B-1: Internal Melt Example - Flow Schematic





The *Total System Performance* spread sheet can be set up starting with columns for time-of day on the left with Electric Utility Rate Periods next to it. Continuing, left to right, add columns for:

- Design Day - Cooling Load Profile
- Conventional chiller load #4 & #5
- Chilled water flow (variable)
- Chilled water supply and return temperatures
- Ice storage system cooling load profile (design day load minus conventional chiller load)
- Glycol fluid flow (variable)
- Glycol fluid temperature (entering and leaving the heat exchanger)
- Chilled water system flow (to the heat exchanger) (assume a 1.1°C cold side to hot side approach)
- Chilled water temperature (entering and leaving the heat exchanger)

The last column should indicate the total system cooling load which is the hourly sum of the conventional chiller load and the ice storage system (glycol chiller and ice melt) load. This column should be identical to the design day cooling load column.

Before continuing with the development of the “*Thermal Ice Storage*” spread sheet, the “*Total System Performance*” spread sheet was completed and is shown below. The text that follows describes the development of the data for each column. Each of the 24 (time-of-day) rows will indicate the operation of each system component for that particular hour.

Figure 5B-Spread Sheet Example - Internal Melt (Metric Units)
Total System Performance

Time of Day	Electric Utility Rate Periods	Chilled Water Loop				Glycol Loop			Chilled Water Loop			
		System		Conventional Chillers		Ice Storage System			Chilled Water System			
		Cooling Load Profile	Conv. Chillers #4 & #5	Chilled Water Flow	Chilled Water Temp Return / Supply	Cooling Load Profile	Glycol Fluid Flow	Glycol/Chilled Water Heat Exchanger Temp Cold Side / Hot Side	Chilled Water Flow	Supply Temp	Cooling Load Profile	
		kW	kW	L/s	(°C)	kW	L/s	(°C)	(°C)	L/s	(°C)	kW
0-1	3	1100	1100	26	14.1 / 4.1						4.1	1100
1-2	3	1100	1100	26	14.1 / 4.1						4.1	1100
2-3	3	1100	1100	26	14.1 / 4.1						4.1	1100
3-4	3	1400	1400	33	14.1 / 4.1						4.1	1400
4-5	3	1400	1400	33	14.1 / 4.1						4.1	1400
5-6	3	1800	1800	43	14.1 / 4.1						4.1	1800
6-7	3	1800	1800	43	14.1 / 4.1						4.1	1800
7-8	2	5200	3500	84	14.1 / 4.1	1700	228	3.0 / 4.9	14.1 / 4.1	40.6	4.1	5200
8-9	2	5600	3500	84	14.1 / 4.1	2100	228	3.0 / 5.4	14.1 / 4.1	50	4.1	5600
9-10	2	6300	3500	84	14.1 / 4.1	2800	228	3.0 / 6.2	14.1 / 4.1	67	4.1	6300
10-11	1	7700	3500	84	14.1 / 4.1	4200	228	3.0 / 7.8	14.1 / 4.1	100	4.1	7700
11-12	1	9200	3500	84	14.1 / 4.1	5700	228	3.0 / 9.5	14.1 / 4.1	136	4.1	9200
12-13	1	10500	3500	84	14.1 / 4.1	7000	228	3.0 / 11.0	14.1 / 4.1	167	4.1	10500
13-14	1	10500	3500	84	14.1 / 4.1	7000	228	3.0 / 11.0	14.1 / 4.1	167	4.1	10500
14-15	1	10500	3500	84	14.1 / 4.1	7000	228	3.0 / 11.0	14.1 / 4.1	167	4.1	10500
15-16	1	9200	3500	84	14.1 / 4.1	5700	228	3.0 / 9.5	14.1 / 4.1	136	4.1	9200
16-17	1	8500	3500	84	14.1 / 4.1	5000	228	3.0 / 8.7	14.1 / 4.1	119	4.1	8500
17-18	1	7000	3500	84	14.1 / 4.1	3500	228	3.0 / 7.0	14.1 / 4.1	84	4.1	7000
18-19	1	5200	3500	84	14.1 / 4.1	1700	228	3.0 / 4.9	14.1 / 4.1	41	4.1	5200
19-20	1	4200	3500	84	14.1 / 4.1	700	228	3.0 / 3.8	14.1 / 4.1	17	4.1	4200
20-21	2	1800	1800	43	14.1 / 4.1						4.1	1800
21-22	2	1800	1800	43	14.1 / 4.1						4.1	1800
22-23	2	1400	1400	26	14.1 / 4.1						4.1	1400
23-0	3	1400	1400	26	14.1 / 4.1						4.1	1400
Total		115,700	61,600			54,100						115,700

Utility Rate periods: 1 = on peak; 2 = intermediate period; 3 = off peak

Insert the design day cooling loads in their hourly slot. Each of the conventional water chillers will be selected to have an 1800 kW capacity at 4.1°C leaving chilled water temperature / 29.4°C entering condenser water temperature. One of these chillers will handle the night load, but both will operate during the intermediate and on-peak time periods. Using the chiller de-rate factor shown in Section 4E Chiller Operation, there will be a 1.5% reduction in capacity for each 0.5°C below the nominal conditions. Since the system design water temperature is 4.1°C (2.5°C below the 6.67°C nominal), the de-rate factor is 7.7% (1.5% x 2.57°C) or 92.3% of its nominal capacity. The nominal capacity for each of the conventional water chillers is 1800 divided by 92.3% = 1950 kW. The system chilled water flow through the conventional chillers may be variable and set to maintain a 14.1°C to 4.1°C temperature range.

The thermal ice storage system cooling profile, including the capacity of the two glycol chillers and ice melt, is the difference between the design day profile and conventional chiller profile. The glycol fluid flow will be determined when the ice build chillers are selected. The glycol will be constant flow and there will be two chillers operating between 07:00 AM and 20:00 PM. The glycol fluid temperature entering the heat exchanger will be 3.0°C. Based on the hour by hour cooling load and constant flow rate, the glycol heat exchanger delta-T can be calculated. Since the chilled water side of the heat exchanger is piped in parallel with the conventional chillers, the delta-T will be the same (14.1°C to 4.1°C). The chilled water flow will be variable to hold this delta-T and final 4.1°C supply temperature. The last column is a check to verify that the sum of the conventional chiller cooling and the ice storage system cooling is equal to the design day cooling.

Now continue with the development of the “*Thermal Ice Storage*” system spread sheet. Again start on the left and the first two columns are time-of day and electric utility's rate periods. The next columns would be:

- Ice build glycol chillers (#1,#2,#3)
- Glycol flow
- Glycol supply and return temperatures
- Ice coil pressure drop
- Ice build inventory
- Cooling load profile (glycol chillers & ice melt)
- Glycol chillers #1 and #2
- Glycol flow
- Ice melt inventory
- Ice melt cooling load
- Glycol fluid supply and return temperatures to the heat exchanger

The “*Ice Storage System Performance*” spread sheet has been completed and is shown on the next page. The text that follows describes the development of the data for each column. Each of the 24 (time-of-day) rows will indicate the operation of each system component for that particular hour.



Figure 5B-Spread Sheet Example - Internal Melt (Metric Units)
Ice Storage System Performance

Electric		Glycol Loop									
Time of Day	Utility Rate Periods	Ice Build System					Ice Melt & Glycol Chillers in Series				
		Ice Build Chillers # 1,2,3	Glycol Fluid Flow	Glycol Fluid Temp Supply / Return	Ice Coil Pressure Drop	Ice Build Inventory	Cooling Load Profile	Chillers # 1,2	Glycol Fluid Flow	Ice Melt Inventory	Ice Melt Cooling Load
		kW	L/s	(°C)	(kPa)	kW-Hrs	kW	kW	L/s	kW-Hrs	kW
0-1	3	3552	342	-3.7 / -0.8	127	10342					
1-2	3	3535	342	-4.2 / -1.4	127	13877					
2-3	3	3509	342	-4.5 / -1.8	127	17386					
3-4	3	3483	342	-4.8 / -2.1	127	20869					
4-5	3	3458	342	-5.1 / -2.3	127	24327					
5-6	3	3432	342	-5.2 / -2.5	127	27759					
6-7	3	2241	342	-5.3 / -2.6	127	30000					
7-8	2						1700	1700	228	30000	
8-9	2						2100	2100	228	30000	
9-10	2						2800	2800	228	30000	
10-11	1				58	4200	*2288	228	30000	1912	
11-12	1				58	5700	*2288	228	28088	3412	
12-13	1				58	7000	*2288	228	24676	4712	
13-14	1				58	7000	*2288	228	19964	4712	
14-15	1				58	7000	*2288	228	15252	4712	
15-16	1				58	5700	*2288	228	10540	3412	
16-17	1				58	5000	*2288	228	7128	2712	
17-18	1				58	3500	*2288	228	4416	1212	
18-19	1					1700	1700	228	3204		
19-20	1					700	700	228	3204		
20-21	2								3204		
21-22	2								2304		
22-23	2								3204		
23-0	3	3586	342	-3.1 / -0.2	127	6790					
Total							54,100	27,304			26,796

Utility Rate periods: 1 = on peak; 2 = intermediate period; 3 = off peak
 (*) Chillers #1 & #2 are 65% demand limited during the on-peak period

In order to size the ice build chiller, sum up the hour by hour ice melt profile. In this example, 26,796 kW -hours is the total ice-melt and ice storage required. Divide this total by the number of hours available to build ice (8 hours - 20:00 PM to 07:00 AM). The total capacity of the ice build chillers (at -5.56°C / 26.7°C) is approximately 3350 kW. This is an excellent method for estimating the ice build chiller size. There are three chillers so the capacity of each is 1120 kW. Increase this estimated chiller size by 2% (1144 kW) for safety should the final fluid build temperature be below - 5.56°C. Applying the 35% de-rate factor (65% of nominal capacity) for ice build chillers, refer to Section 4E Chiller Operation, the nominal ice build chiller size is estimated to be 1760 kW each.

The glycol flow should be selected for a 2.5°C to 3.9°C delta-T (-1.67°C to -5.56°C). The glycol temperature returning to the chiller must be below freezing. For this example, the glycol for each chiller is 114 L/s (1144 kW at 2.5°C delta-T).

The pressure drop through the ice storage coils was estimated. Note, during the ice build period (23:00 PM - 07:00 AM) there are three chillers in operation and the flow is 342 L/s. However, when the ice is being melted (10:00 AM - 18:00 PM) there are only two chillers operating and the glycol flow is 228 L/s. There is no glycol flow through the ice storage coils between 07:00 AM - 10:00 AM and 18:00 PM - 23:00 PM).

At the start of the ice build mode, the chiller capacity and glycol supply temperature will be high. As the ice build process continues, the ice will become thicker requiring a lower glycol temperature resulting in less chiller capacity. The ice build will begin at 23:00 PM and continue to 7:00 AM (8 hours). The chiller capacity, and glycol supply and return temperatures that are shown are typical for the ice build mode.

The ice inventory is simply the amount of ice storage (kW-hours) in the storage container. The inventory increases (hour by hour) during the ice build mode and decreases as ice is melted. There should always be a little ice left in storage at the end of the ice melt cycle.

The glycol chiller #1 and #2 column indicates the hourly capacity supplied by these chillers. Each of these chillers has a nominal capacity of 1760 kW and they can supply all of the storage system cooling requirements between 07:00 AM -10:00 AM and 18:00 PM - 20:00 PM. These chillers can be capacity demand limited during the on-peak hours of 10:00 AM to 18:00 PM. This will maximize the ice melt and minimize the chiller compressor electric load during the on-peak period. For this example, the conventional chiller capacity was held constant at 3,500 kW for the hours between 07:00 AM and 20:00 PM.

The ice melt inventory shows the storage at the beginning and at the end of the ice build cycle. The inventory decreases as ice melt cooling is extracted from the storage container. The fully charged system will have 30,000 kW-hours in storage. At the end of the ice melt period, there is 2,874 kW-hours left in the container. The difference (27,126 kW-hours) is the actual amount of ice storage used.

The glycol return and supply temperatures are the heat exchanger cold side temperatures indicated on the *Total System Performance* spread sheet.

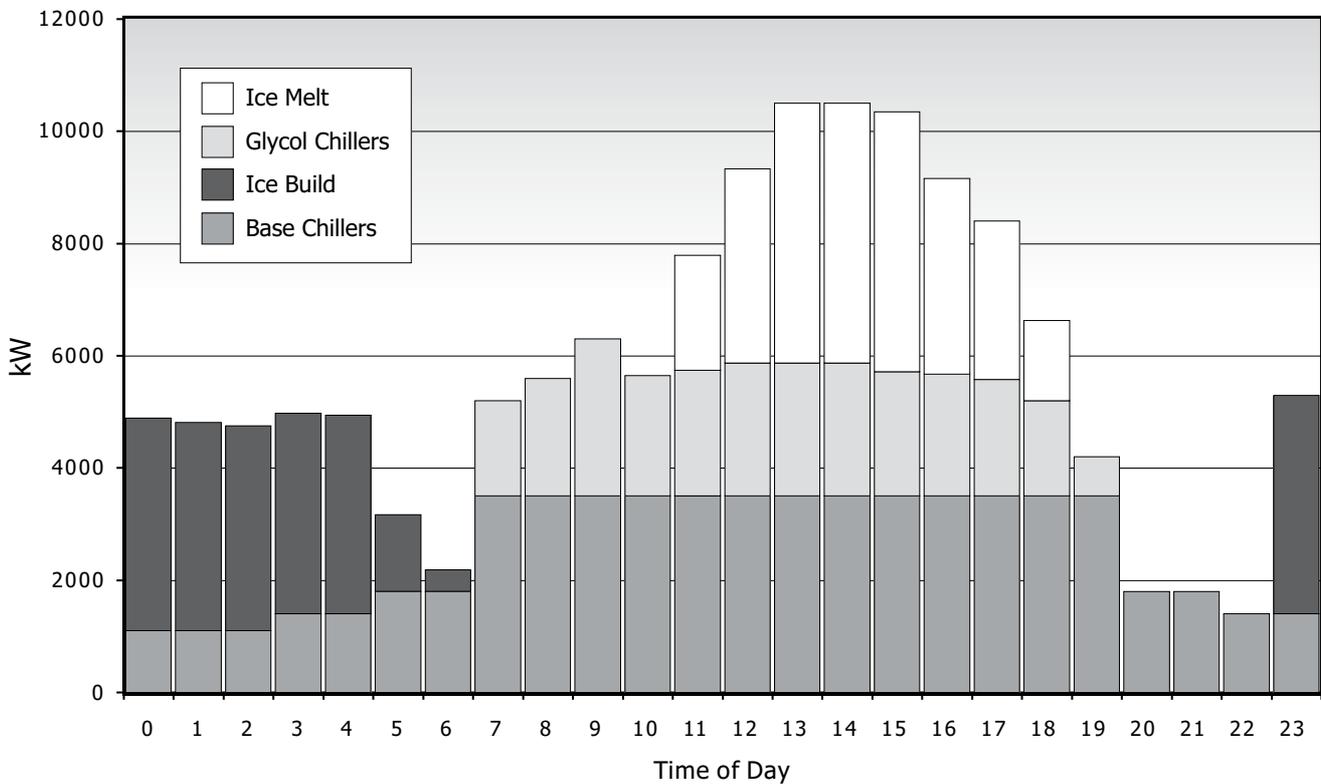
The preliminary planning for a thermal ice storage / chilled water plant takes only a few minutes and does not require involvement from the chiller manufacturer or ice storage manufacturer. Modifications to the plant that may be considered are:

- Smaller or larger chilled water delta-T.
- Multiple chillers and pumps.
- Air-cooled or water cooled chillers or a mix of both.
- Changes in the electric utility rate schedule.

Both of these spread sheets should be completed before contacting the chiller manufacturer to verify the chiller capacity. Evapco has a Thermal Ice Storage Selection Program that can assist with the development of these spread sheets as well as thermal ice storage experts available to answer any questions.

The more data included in the spread sheet, the easier it is to evaluate the system's performance. We recommend that both completed spread sheets be included as part of all bid and contract documents.

Internal Melt Example Design Day Performance
 Conventional Chillers Demand Limited "On Peak"



6. Schematic Flow Diagrams and System Control Strategy

The design options for ice storage systems are unlimited. These basic flow schematics and control strategies are fundamental guidelines that can be applied to 99% of thermal ice storage projects. Individual projects with unique characteristics may require more creative designs.

Varying equipment operation based on time-of-day electric rates can optimize energy cost savings. The following series of flow schematics and control strategies are intended to offer the owner / designer a variety of components, piping and control options for cooling systems. Please note that all control strategies include the operation of an air agitation pump. Air agitation is used, for external melt systems, during the first 2 hours of the ice build mode and whenever cooling is provided from the ice melt. Internal ice melt systems do not usually use air agitation. Section 10 "Ice Storage Control Accessories" has a full description of the air pump and other control accessories.

Chillers may be air cooled or water cooled. To simplify the flow diagrams and control strategies, the condenser fans, condenser pumps and cooling tower fans are not shown. Their operations are tied to their respective chillers.

Again, we emphasize that, in order for external melt systems to function successfully, particular attention must be directed to the plant layout. The ice water storage container is an open system; therefore, the ice water pump (IWp) must be located below the container water level in order to maintain a suction head. The ice water piping must be designed so that only a minimum amount of ice water will drain back to the storage container when the pump is shut off. Another solution would be to elevate the ice water container so that the water level is the high point in the system or integrate the use of a plate and frame heat exchanger to separate the loops.

During the ice melt mode, the water level in the storage container should be no more than 1 to 2 inches (25.4 to 50.8 cm) above the top of the ice coil.

A. External Melt

Figure 6A-1: External Melt Basic System

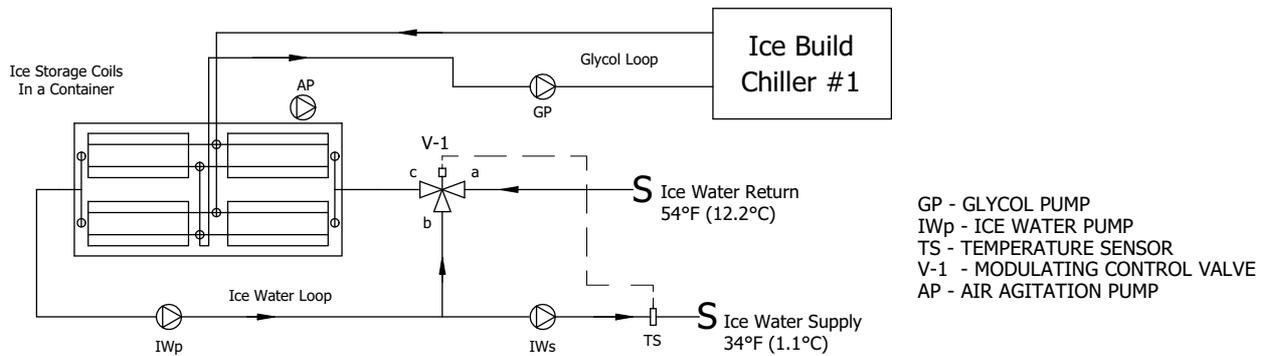


Figure 6A-1: External Melt Basic System

System Modes	Glycol Loop			Ice Water Loop				
	Ice Build Chiller #1	Pumps		Valve	Pump			
	Status	Set Point	Air	Glycol GP	Water IWp	V-1 Flow	Water IWs	Temp Sensor
Ice Build								
8 PM - 6 AM	on	20°F (-6.7°C)	on *	on	off	no flow	off	x
Ice Melt								
6 AM - 8 PM	off	x	on	off	on	a-b / c Mod	on	34°F (1.1°C)

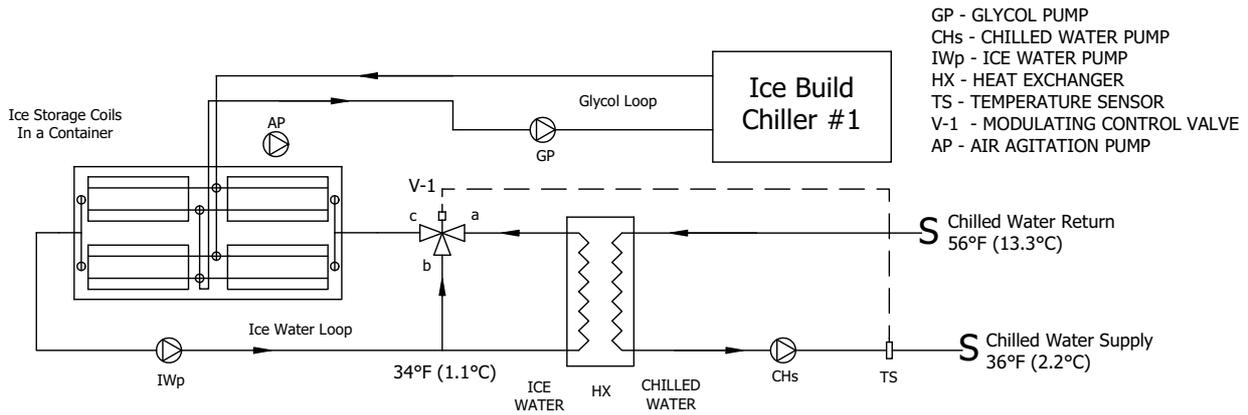
Note: Temperature sensor controls valve V-1

(*) Air agitation pump operates for the first two (2) hours of ice build and whenever ice is melted

Variable frequency drives (VFD) may be used on the secondary loop pump

The external melt figures and control strategies that follow are all applications where the ice water loop is separated from the chilled water loop by a heat exchanger.

**Figure 6A-2: External Melt
Basic System with Ice Water Heat Exchanger**

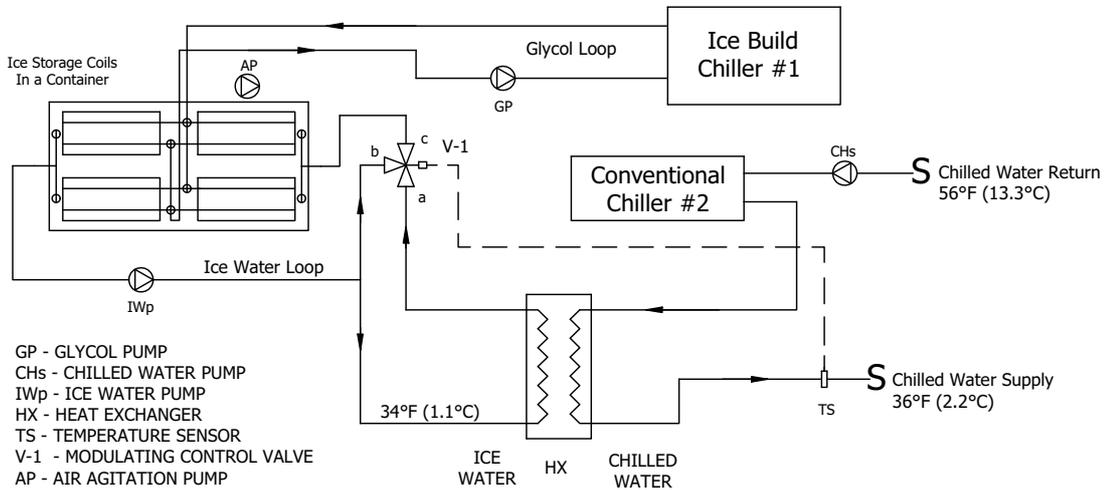


**Control Strategy -Fig. 6A-2 - External Melt
Basic System with Ice Water Heat Exchanger**

System Modes	Ice Build Chiller #1		Pumps			Valve	Ice Water HX		Pump		Temp Sensor
	Status	Set Point	Air	Glycol GP	Water IWp	V-1 Flow	Cold Side	Hot Side	Water CHs		
Ice Build											
8 PM - 6 AM	on	20°F (-6.7°C)	on *	on	off	no flow	no flow	no flow	off	x	
Ice Melt											
6 AM - 8 PM	off	x	on	off	on	a-b / c Mod	34°F - 44°F	56°F - 36°F	VFD on	36°F (2.2°C)	
							(1.1°C-6.7°C)	(13.3°C-2.2°C)			

Note: Temperature sensor controls valve V-1
 (*) Air agitation pump operates for the first two (2) hours of ice build and whenever ice is melted
 Variable frequency drives (VFD) may be used on the secondary loop pump

Figure 6A-3: External Melt
Conventional Chiller Piped in Series with Ice Water Heat Exchanger



Control Strategy -Fig. 6A-3 - External Melt
Conventional Chiller Piped in Series with Ice Water Heat Exchanger

System Modes	Ice Build Chiller #1		Pumps			Valve	Ice Water HX		Pump	
	Status	Set Point	Air	Glycol GP	Water IWp	V-1 Flow	Cold Side	Hot Side	Water CHs	Temp Sensor
Ice Build										
8 PM - 6 AM	on	20°F (-6.7°C)	on *	on	off	no flow	no flow	no flow	off	x
Ice Melt										
10 AM - 8 PM	off	x	on	off	on	a-b / c Mod	34°F - 44°F (1.1°C- 6.7°C)	56°F - 36°F (13.3°C- 2.2°C)	VFD ON	36°F (2.2°C)

System Modes	Conv. Chiller #2		Pump	Pumps		Valve	Ice Water HX		Pump
	Status	Set Point	Water CHs	Air IWp	V-1 Flow	Cold Side	Hot Side	Water CHs	Temp Sensor
Series Cooling - Conv. Chiller #2 & Ice Water / Chilled Water HX									
10 AM - 8 PM	on	46°F (7.8°C)	VFD ON	on	a-b / c Mod	34°F - 44°F (1.1°C- 6.7°C)	46°F - 36°F (7.8°C- 2.2°C)	VFD ON	36°F (2.2°C)

Direct Cooling - Conventional Chiller #2 Only

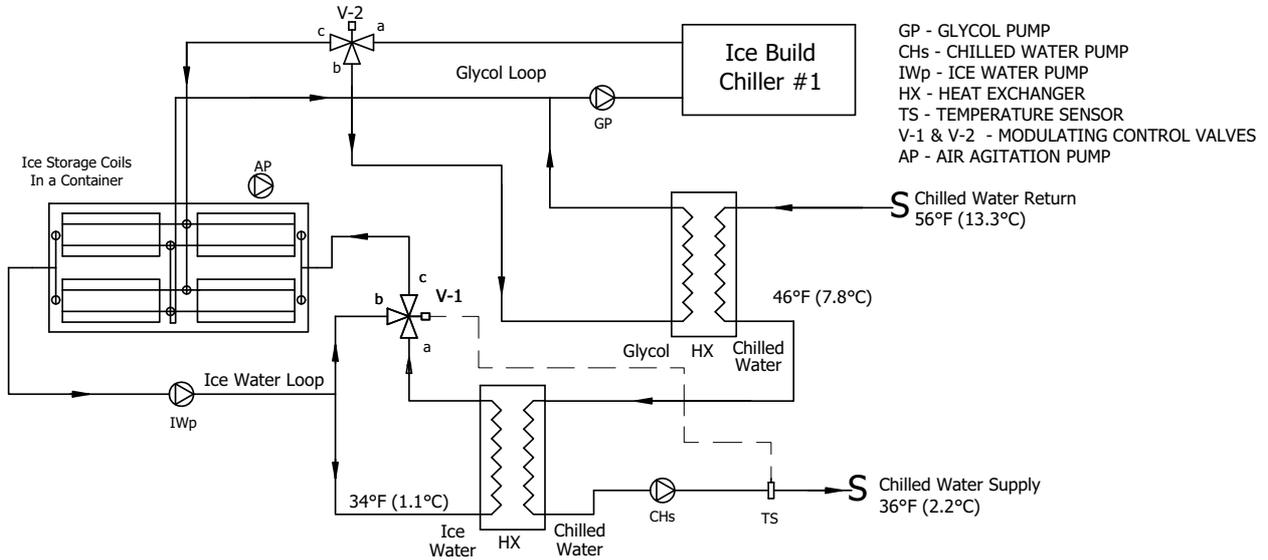
6 AM - 10 AM	on	36°F - (2.2°C)	VFD ON	off	on flow	no flow	56°F - 36°F (13.3°C- 2.2°C)		
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Note: Temperature sensor controls valve V-1

(*) Air agitation pump operates for the first two (2) hours of ice build and whenever ice is melted

Variable frequency drives (VFD) may be used on the secondary loop pump

Figure 6A-4: External Melt
Glycol / Water Heat Exchanger Piped in Series with Ice Water Heat Exchanger



Control Strategy -Fig. 6A-4 - External Melt

Glycol Heat Exchanger Piped in Series with Ice Water Heat Exchanger

System Modes	Glycol Loop				Ice Water Loop			Chilled Water Loop			
	Valve	Ice Build Chiller #1	Pumps		Valve	Ice Water HX	Pump				
	V-2 Flow	Status	Set Point	Air	Glycol GP	Water IWp	V-1 Flow	Cold Side	Hot Side	Water CHs	Temp Sensor
Ice Build											
8 PM - 6 AM	a-c	on	20°F (-6.7°C)	on *	on	off	no flow	no flow	no flow	off	x
Ice Melt											
10 AM - 8 PM	no flow	off	x	on	off	on	a-b / c Mod	34°F - 44°F (1.1°C- 6.7°C)	56°F - 36°F (13.3°C- 2.2°C)	VFD ON	36°F (2.2°C)

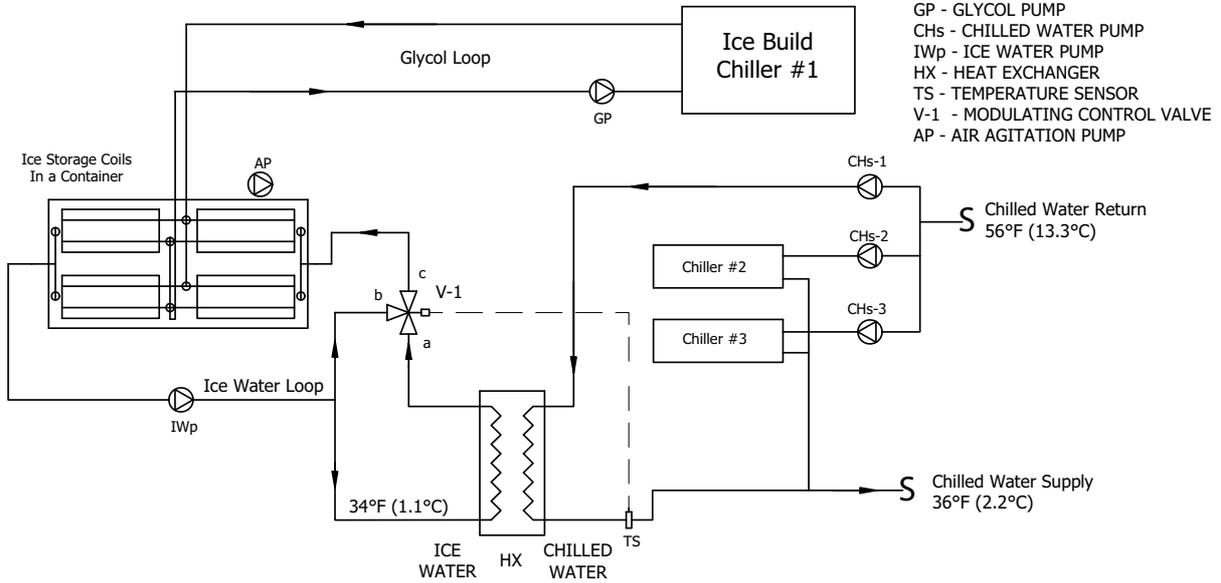
System Modes	Glycol Loop			CW Loop		Ice Water loop		Chilled Water Loop			
	Valve	Ice Build Chiller #1	Glycol/Water HX	Valve	Pumps	Ice Water HX	Pump				
	V-2 Flow	Status	Set Point	Cold Side	Hot Side	V-1 Flow	Air IWp	Cold Side	Hot Side	Water CHs	Temp Sensor
Series Cooling - Glycol HX & Ice Water HX											
10 AM - 8 PM	a-b	on	44°F (6.7°C)	44°F - 54°F (6.7°C - 12.2°C)	56°F - 46°F (13.3°C- 7.8°C)	a-b / c Mod	on	34°F - 44°F (1.1°C- 6.7°C)	46°F - 36°F (7.8°C- 2.2°C)	VFD ON	36°F (2.2°C)
Direct Cooling - Chiller #1 & Glycol HX Only											
6 AM - 10 AM	a-b	on	34°F - (1.1°C)	34°F - 44°F (1.1°C- 6.7°C)	56°F - 36°F (13.3°C- 2.2°C)	no flow	off	no flow	no flow	VFD ON	36°F (2.2°C)

Note: Temperature sensor controls valve V-1

(*) Air agitation pump operates for the first two (2) hours of ice build and whenever ice is melted

Variable frequency drive (VFD) may be used on the secondary loop pump

Figure 6A-5: External Melt
Two Conventional Chillers Piped in Parallel with Ice Water Heat Exchanger



Control Strategy -Fig. 6A-5 - External Melt
Two Conventional Chillers Piped in Series with Ice Water Heat Exchanger

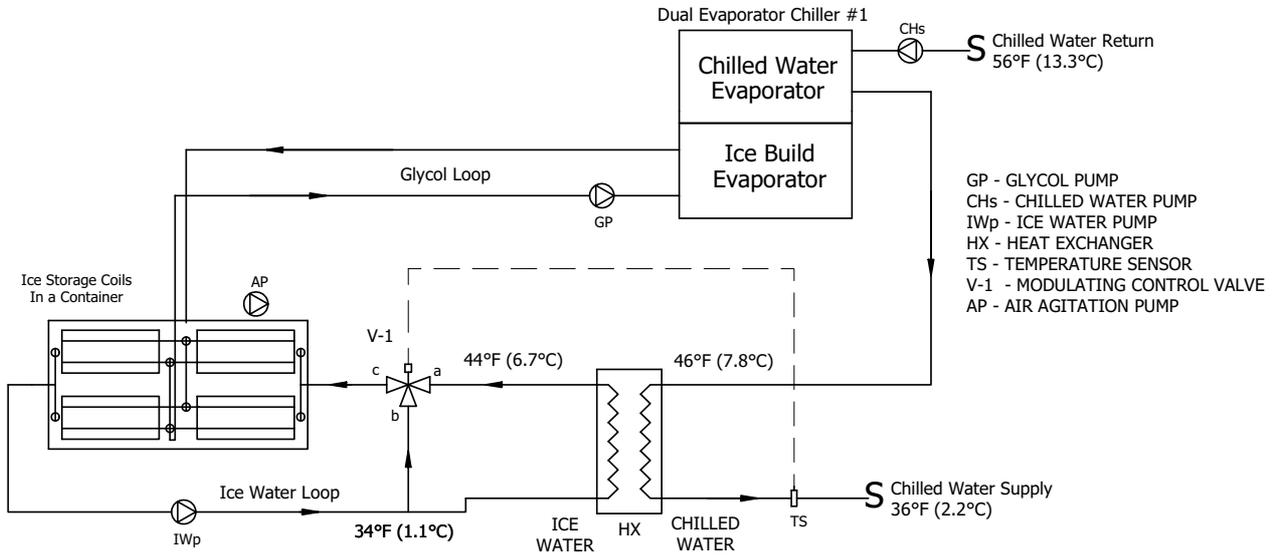
System Modes	Glycol Loop			Ice Water Loop			Chilled Water Loop			
	Ice Build Chiller #1	Pumps		Valve	Ice Water HX		Pump			
	Status	Set Point	Air	Glycol GP	Water IWp	V-1 Flow	Cold Side	Hot Side	Water CHs-1	Temp Sensor
Ice Build										
8 PM - 6 AM	on	20°F (-6.7°C)	on *	on	off	no flow	no flow	no flow	off	x
Ice Melt										
10 AM - 8 PM	off	x	on	off	on	a-b / c Mod	34°F - 54°F (1.1°C-12.2°C)	56°F - 36°F (13.3°C-2.2°C)	VFD ON	36°F (2.2°C)

System Modes	Chilled Water Loop		Ice Water Loop			Chilled Water Loop				
	Conv Chiller #2, #3	Pump	Pump	Valve	Ice Water HX		Pump			
	Status	Set Point	Water CHs-1&2	Water IWp	V-1 Flow	Cold Side	Hot Side	Water CHs-1	Temp Sensor	
Cooling - Conventional Chillers and Ice Water HX in Parallel										
10 AM - 8 PM	on	36°F (2.2°C)	on	on	a-b / c Mod	34°F - 54°F (1.1°C-12.2°C)	56°F - 36°F (13.3°C-2.2°C)	VFD ON	36°F (2.2°C)	

Direct Cooling - Conventional Chillers Only										
6 AM - 10 AM	on	34°F (1.1°C)	on	off	no flow	no flow	no flow	off	x	

Note: Temperature sensor controls valve V-1
 (*) Air agitation pump operates for the first two (2) hours of ice build and whenever ice is melted
 Variable frequency drive (VFD) may be used on the secondary loop pump

**Figure 6A-6: External Melt - Dual Evaporator Chiller
Chilled Water Evaporator Piped in Series with Ice Water Heat Exchanger**



**Control Strategy -Fig. 6A-6 - External Melt - Dual Evaporator Chiller
Conventional Evaporator Piped in Series with Ice Water Heat Exchanger**

System Modes	Glycol Loop			Ice Water Loop			Chilled Water Loop				
	Ice Build Evaporator		Air	Pumps		Valve	Ice Water HX		Pump		Temp Sensor
	Status	Set Point		Glycol GP	Water IWp		Cold Side	Hot Side	Water CHs		
Ice Build											
8 PM - 6 AM	on	20°F (-6.7°C)	on *	on	off	no flow	no flow	no flow	off	x	
Ice Melt											
10 AM - 8 PM	off	x	on	off	on	a-b / c Mod	34°F - 44°F (1.1°C- 6.7°C)	56°F - 36°F (13.3°C- 2.2°C)	VFD on	36°F (2.2°C)	

System Modes	Chilled Water Loop			Ice Water Loop			Chilled Water Loop				
	Chilled Water Evaporator		Water CHs	Pumps		Valve	Ice Water HX		Pump		Temp Sensor
	Status	Set Point		Water IWp	V-1 Flow		Cold Side	Hot Side	Water CHs		
Series Cooling - Conv. Chilled Water Evaporator in series with Ice Water											
10 AM - 8 PM	on	46°F (7.8°C)	VFD on	on	a-b / c Mod	34°F - 44°F (1.1°C- 6.7°C)	46°F - 36°F (7.8°C- 2.2°C)	VFD on	36°F (2.2°C)		

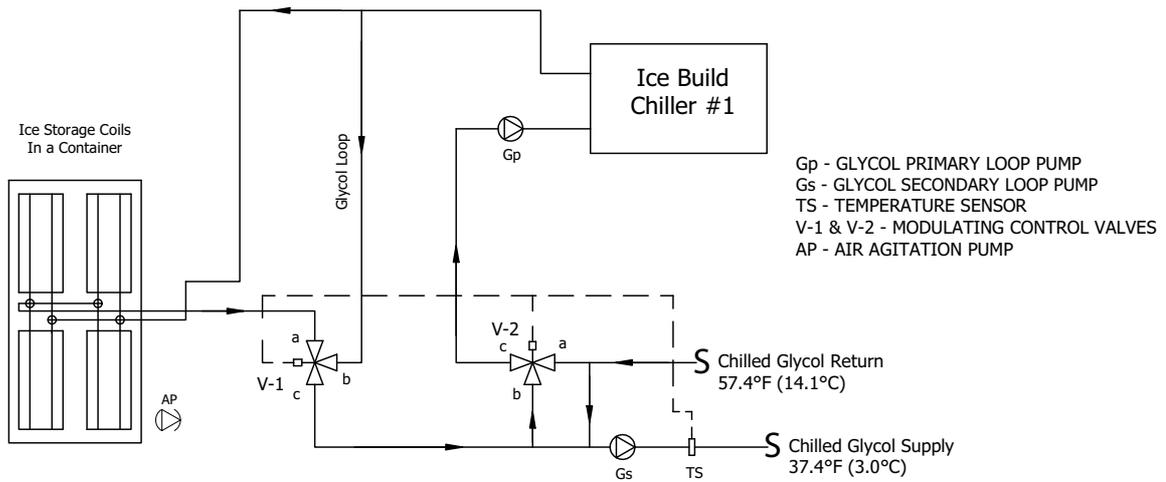
Direct Cooling - Conventional Chiller Water Evaporator Only											
System Modes	Chilled Water Evaporator		Water CHs	Pumps		Valve	Ice Water HX		Pump		Temp Sensor
	Status	Set Point		Water IWp	V-1 Flow		Cold Side	Hot Side	Water CHs		
6 AM - 10 AM	on	36°F - (2.2°C)	VFD on	off	on	no flow	36°F (2.2°C)	VFD on	36°F (2.2°C)		

Note: Temperature sensor controls valve V-1
 (*) Air agitation pump operates for the first two (2) hours of ice build and whenever ice is melted
 Variable frequency drive (VFD) may be used on the secondary loop pump

B. Internal Melt

Piping and control for internal melt thermal ice storage system are different from external melt systems. The ice water remains in the storage container and is not circulated through the distribution piping. The temperature of the glycol is varied, based on the operating mode, to provide the desired cooling.

Figure 6B-1: Internal Melt Basic System

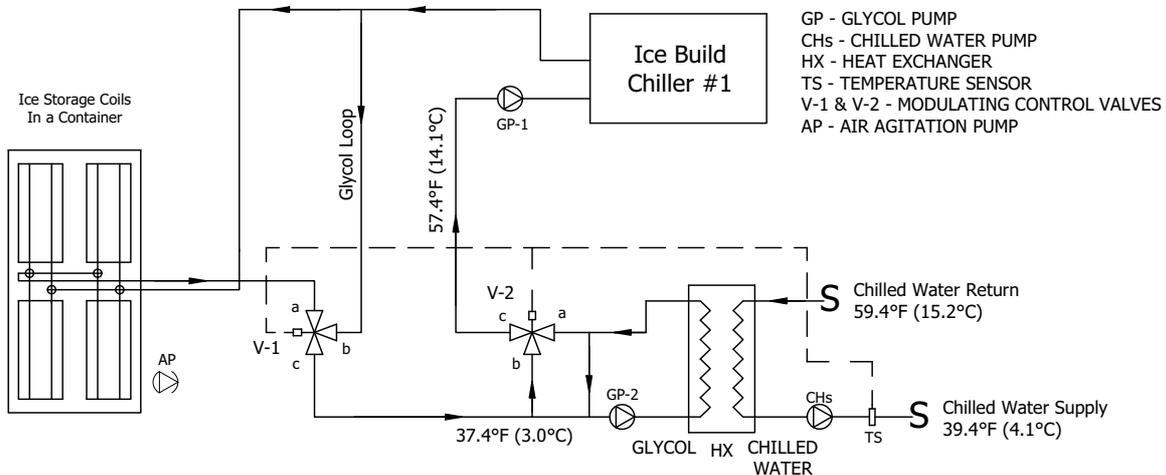


Control Strategy -Fig. 6B-1 - Internal Melt Basic System

System Modes	Glycol Loop							
	Chiller # 1		Pump		Control Valve		Pump	Temp Sensor
	Status	Set Point	Air *	Glycol Gp	V-1 Flow	V-2 Flow	Glycol Gs	
Ice Build								
8 PM - 6 AM	on	20°F (-6.7°C)	on *	on	a-c	b-c	off	x
Direct Cooling Chiller Only								
6 AM - 10 AM	on	37.4°F (3.0°C)	off	on	b-c	a-c	VFD on	37.4°F (3.0°C)
Chiller and Ice Melt in Series								
10 AM - 8 PM	on	44°F (6.7°C)	on *	on	a-b / c Mod	a-c	VFD on	37.4°F (3.0°C)
Ice Melt Only								
10 AM - 8 PM	off	x	on *	on	a-b / c Mod	a - C	VFD on	37.4°F (3.0°C)
Ice Build with Cooling								
8 PM - 6 AM	on	20°F (-6.7°C)	on *	on	a-c	a-b / c Mod	VFD on	37.4°F (3.0°C)

(*) Optional - Air agitation is generally used only to meet specific project ice melt temperature
 Note: Temperature sensor controls valve V-1, except, in Ice Build with Cooling Mode, when it controls valve V-2
 Variable frequency drive (VFD) may be used on the secondary loop pump

**Figure 6B-2: Internal Melt
Basic System with Glycol / Water Heat Exchanger**

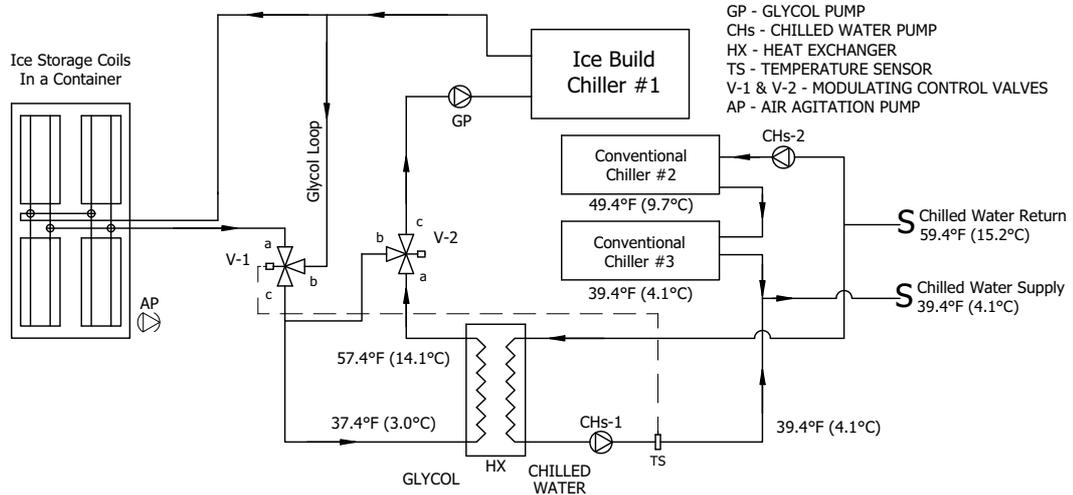


**Control Strategy -Fig. 6B-2 - Internal Melt
Basic System with Glycol Loop / Chilled Water Heat Exchanger**

System Modes	Glycol Loop							Chilled Water Loop			
	Chiller # 1		Pump		Control Valve		Pump	Glycol/Water HX		Pump	
	Status	Set Point	Air *	Glycol GP-1	V-1 Flow	V-2 Flow	Glycol GP-2	Cold Side	Hot Side	Water CHs	Temp Sensor
Ice Build											
8 PM - 6 AM	on	20°F (-6.7°C)	on *	on	a-c	b-c	off	no flow	no flow	off	X
Direct Cooling Chiller Only											
6 AM - 10 AM	on	37.4°F (3.0°C)	off	on	b-c	a-c	VFD ON	37.4°F - 47.4°F (3.0°C - 8.6°C)	49.4°F - 39.4°F (9.7°C - 4.1°C)	VFD ON	39.4°F (4.1°C)
Chiller and Ice Melt in Series											
10 AM - 6 PM	on	47.4°F (8.6°C)	on *	on	a-b / c Mod	a-c	VFD ON	37.4°F - 57.4°F (3.0°C - 14.1°C)	59.4°F / 39.4°F (15.2°C - 4.1°C)	VFD on	39.4°F (4.1°C)
Ice Melt Only											
10 AM - 6 PM	off	x	on *	on	a-b / c Mod	a - c	VFD on	37.4°F - 47.4°F (3.0°C - 8.6°C)	49.4°F - 39.4°F (9.7°C - 4.1°C)	VFD ON	39.4°F (4.1°C)
Ice Build with Cooling											
8 PM - 6 AM	on	20°F (-6.7°C)	on *	on	a-c	a-b / c Mod	VFD on	> 32°F (> 0.0°C) Entering	39.4°F (4.1°C) Leaving	VFD ON	39.4°F (4.1°C)

(*) Optional - Air agitation is generally used only to meet specific temperature requirements.
 If used, Air agitation pump operates the first two (2) hours of ice build and whenever ice is melted.
 Note: Temperature sensor controls valve V-1, except in Ice Build with Cooling Mode, when it controls valve V-2.
 Variable frequency drives (VFD) may be used on pumps Gp2 and CHs.

**Figure 6B-3: Internal Melt
Two Conventional Chillers Piped in Series with Each Other and in Parallel with Glycol / Water Heat Exchanger**



**Control Strategy -Fig. 6B-3 - Internal Melt
Basic System with Two Conventional Chillers Piped in Series with Each Other
and Piped in Parallel with Glycol / Water Heat Exchanger**

System Modes	Glycol Loop						Chilled Water Loop			
	Chiller #1		Pumps		Valve		Glycol / Water HX		Pump	Temp
	Status	Set Point	Air *	Glycol GP	V-1 Flow	V-2 Flow	Cold Side	Hot Side	Water CHs-1	Sensor
Ice Build										
8 PM - 6 AM	on	20°F (-6.7°C)	on *	on	a-c	b-c	no flow	no flow	off	x
Direct Cooling Chiller Only										
6 AM - 10 AM	on	37.4°F (3.0°C)	on *	on	b-c	a-c	37.4°F - 47.4°F (3.0°C - 8.6°C)	49.4°F - 39.4°F (9.6°C - 4.1°C)	VFD on	39.4°F (4.1°C)
Chiller and Ice Melt In Series										
10 AM - 6 PM	on	46°F (7.8°C)	on *	on	a-b / c Mod	a-c	37.4°F - 57.4°F (3.0°C - 14.1°C)	59.4°F / 39.4°F (15.2°C - 4.1°C)	VFD on	39.4°F (4.1°C)
Ice Melt Only										
10 AM - 6 PM	off	x	on *	on	a-b / c Mod	a - c	37.4°F - 47.4°F (3.0°C - 8.6°C)	49.4°F - 39.4°F (9.6°C - 4.1°C)	VFD on	39.4°F (4.1°C)

(*) Optional - Air agitation is generally used only to meet specific project ice melt temperature requirements.

Note: Temperature sensor controls valve V-1.

Variable frequency drive (VFD) may be used on chilled water pump CHs-1.

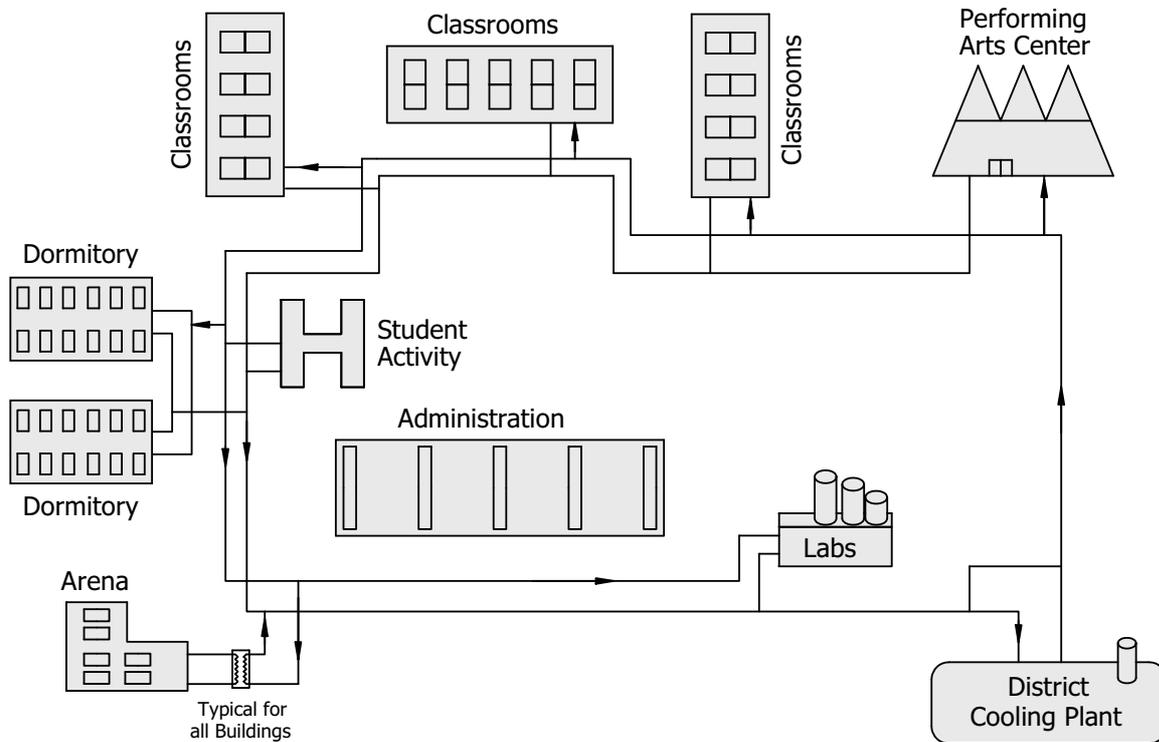
System Modes	Chiller #2 & #3		Pump
Conventional Chillers #2 & #3	Status	Set - Point	Water CHs-2
At Any Time	on	39.4°F (4.1°C)	on

C. District Cooling

District cooling plants utilizing thermal ice storage provide both first cost and energy cost savings. The distribution cooling pipes are typically sized for a delta-T of 20°F (11.1°C). This reduces the chilled water flow volume, thus enabling the use of smaller pipes and pumps. The ice storage provides the energy management ability to shift energy use to lower cost periods of time.

Heat exchangers, located at each building, are often used to separate the distribution fluid from the build cooling loop. The supply cooling fluid for external melt systems may be 34°F (1.11°C) if ice water is used directly or 36°F (2.22°C) if an ice water heat exchanger is used in the district plant. The supply fluid for internal melt systems can be as low as 37.4°F (3°C) to the district cooling heat exchanger.

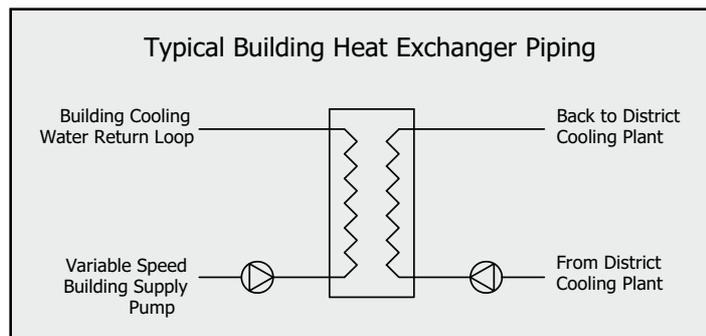
Typical University District Cooling Plant



Older Buildings can maintain their original design cooling flow, temperatures and delta-T, 54°F - 44°F (12.2°C - 6.7°C).

New buildings can be designed for lower temperatures, 36°F or 38°F (2.2°C or 3.3°C) and larger delta-Ts when they are added to the distribution loop.

Variable speed building pumps can maintain the distribution loop at a minimum return temperature, thus assuring a high plant chiller efficiency.



7. Storage Containers

A. Design Considerations

Materials of Construction:

Ice storage containers may be constructed of any material that can be waterproofed and support the weight of the coils and water. Common construction materials are reinforced concrete and steel.

Location:

Ice storage containers may be located totally below grade, partially buried or completely above grade. They can be designed as an integral part of the cooling plant or placed in a remote location. Due to the physical size and weight of the container when filled with the coils and water, locations on firm grade are often mandatory. Some below grade locations that should be considered include: below the chiller plant, under parking lots and beneath walkways, patios and park areas. Above grade locations can be anywhere that space and firm grade support is available.

Access:

Poured concrete containers, above and below grade, can be designed with removable top panels for coil installation and service. These panels can have waterproof seals. Designs where the container top is poured, at the same time as the base and walls, may have some structural and cost advantages. A removable top section (the size of a single or double wide coil) would provide installation and service access for the entire container. Steel containers are generally above grade and typically cylindrical. Coil and service access is through a top removable hatch. They can be taller than concrete and are typically less expensive.

Civil and structural engineers should be involved in all storage container locations and designs.

B. Waterproofing

Waterproofing is an important part of the storage container design. All construction joints and pipe penetrations must be sealed to withstand the hydraulic pressure of the water. While steel surfaces are waterproof, concrete surfaces may be porous. There are several methods that can be used to seal concrete surfaces:

- A waterproofing chemical additive can be included when the concrete is mixed.
- An EPDM liner can be installed internally on the container floor and walls.
- A sprayed-on or troweled -on cement base waterproofing compound applied to interior and exterior surfaces (depending on ground conditions).
- Sprayed on asphaltic liner similar to CIM 1000.

C. Insulation

The minimum temperature possible for the ice water in the container is 32°F (0.0°C). The air temperature in the container may approach freezing and will be close to 100% saturation. Any fibrous exposed insulation installed on surfaces or piping within the container will not hold up over time. If insulation is required within the container, it must be of a closed cell spray foam type. Typically 1-2 inches (25 - 50 mm) thickness is sufficient. Insulation can also be applied between the EPDM liner, if used, and the container wall or on exposed external container surfaces.



1. Container surfaces: The base of the container, assuming it is installed on grade, will not require any insulation. Also, storage container walls located below grade in a vault type of arrangement need not be insulated. External container walls exposed to ambient air should be insulated as they will sweat. Any traditional construction insulation, indoor or outdoor, can be applied to these external surfaces. Exposed exterior surfaces of the container roof will also sweat. The insulation for this type of application should be installed, in a sandwiched fashion, in a tank cover or between the container roof and the working floor area.
2. Interior Piping: The steel piping that supplies low temperature glycol to the coils should not be insulated within the container. These pipes should be protected from rusting by applying a rust proof epoxy coating after installation. If the ice water supply and return piping is steel, the epoxy coating should be applied to these as well. However, the ice water piping within the container is often PVC, and no coating is required. The same is true for the PVC air agitation pipes within the container.

D. Ice Storage Coils Physical Size

A typical ice storage coil will have the following approximate dimensions:

- 60" to 72" (1.52 M to 1.83M) - Width
- 186" to 240" (4.72 M to 6.1 M) - Length including header
- 72" to 84" (1.83 M to 2.13M) - Height
- 6" (0.15 M) - Mounting Foot

Coils are often preassembled and shipped in groups that are two coils wide). The overall dimensions of a two coil assembly would be:

- 120"to 144" (3.05 M to 3.66M) - Width
- 186" to 240" (4.72 M to 6.1 M) - Length including header
- 72"to 84" (1.83 M to 2.13M) - Height
- 6" (0.15 M) - Mounting Foot

Once received at the construction site, the coils are often installed on top of each other. It is common for ice storage coils to be stacked from 2 to 6 coils high. A coil assembly two high will typically have a height of 150" (3.81 M), four high 294" (7.47 M) and six high 438" (11.13 M).

Ice storage coil dimensions may vary as they are manufactured in multiple facilities throughout the world with different manufacturing limitations.

E. Coil Spacing Within the Container

To establish the inside length and width of the container, use the coil dimensions and allow the following coil spacing:

- 6" (0.15 M) between the container wall and the side of the coil.
- 24"- 30" (0.60 M - 0.76M) between the end of the coil (where the ice water supply and return pipes enter, and the container wall. (External Melt Systems).
- 6" (0.15 M) between the end of the coil (opposite to the side with the connections) and the container wall. - (Internal Melt System).



- 42" - 60" (1.07 M - 1.5M) for service clearance on the header end of the coil. A common practice is to locate rows of coils so that the service clearance is shared between alternate rows.
- 6" (0.15 M) between end to end coils.
- 3" - 6" (.08M - .15 M) between side to side coils.

To estimate the inside height of the container, use the typical coil heights described above and add 6" (0.15M) for the coil mounting foot, an estimated 3" (0.08M) per coil ice water rise and space for the coil piping.

	<u>2 coils high</u>	<u>4 coils high</u>	<u>6 coils high</u>
Coil height with foot:	174" (4.42 M)	342" (8.69 M)	510" (13.0 M)
Estimated water rise:	6" (0.15 M)	12" (0.30 M)	18" (0.46 M)
Piping space:	<u>38" (0.91 M)</u>	<u>42" (1.07 M)</u>	<u>48" (1.22 M)</u>
Estimated container height:	218" (5.53 M)	396" (10.06 M)	576" (14.6 M) ^b

(Add additional height if the design includes a large volume of drain back water)

Figures 8A & 8C (Section 8 - Storage Container Layout) can be used to estimate the plan area of external and internal melt storage containers. Assume each coil is 216" (5.49 M) long, 66" (1.67 M) wide and apply the clearances described above.

The plan area dimensions for the container shown in Figure 8A (external melt) are 1038" (26.37 M) long and 428" (10.67 M) wide. The ice water flow baffles shown in Figure 8B are connected to the side of the coils and will not change the overall dimensions.

The plan area dimensions for the tank shown in Figure 8C (internal melt) are 1028" (26.06 M) long and 428" (10.67 M) wide.

8. Storage Container Ice Coil Layout

A. External Melt

During external melt applications, the ice water flows through the storage container. The warm return ice water enters the container and passes over the first group of coils. This water is warm, so ice will melt rapidly cooling the water before it reaches the next group of coils. Most of the ice will be depleted from the first group of coils before any warm water reaches the second group and so on through all of the coil groups. On a design day, the warm water proceeds across all of the coils melting the entire storage charge. However, most days have less than the design loads and some ice will remain on the final coil groups. When the ice build cycle begins, the first coils groups may be depleted of ice while latter groups may still have a partial or full ice charge. In order to fully charge each coil group, automatic zone valves are used to direct the cold glycol to the desired groups. Each of these valves will close when the ice thickness sensor is satisfied. (See Chapter 10-A: Accessories)

Figure 8A: Storage Container Layout - External Melt - Ice Water Flow - One Pass

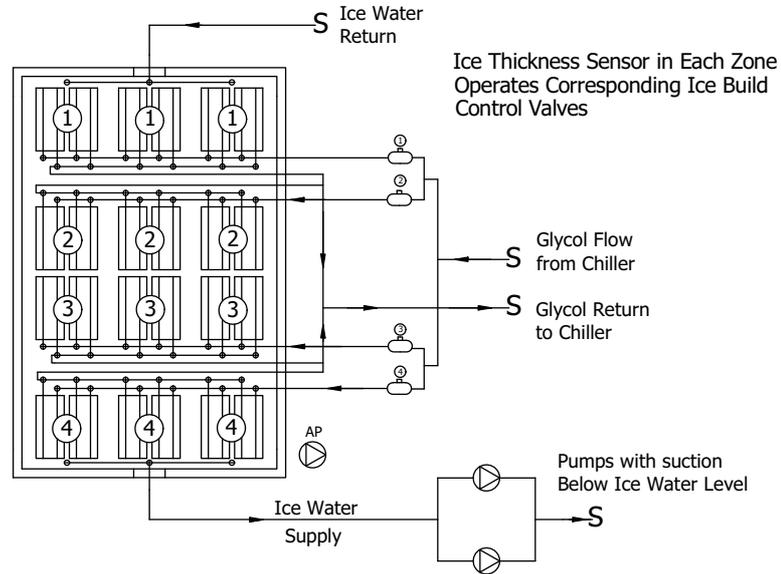
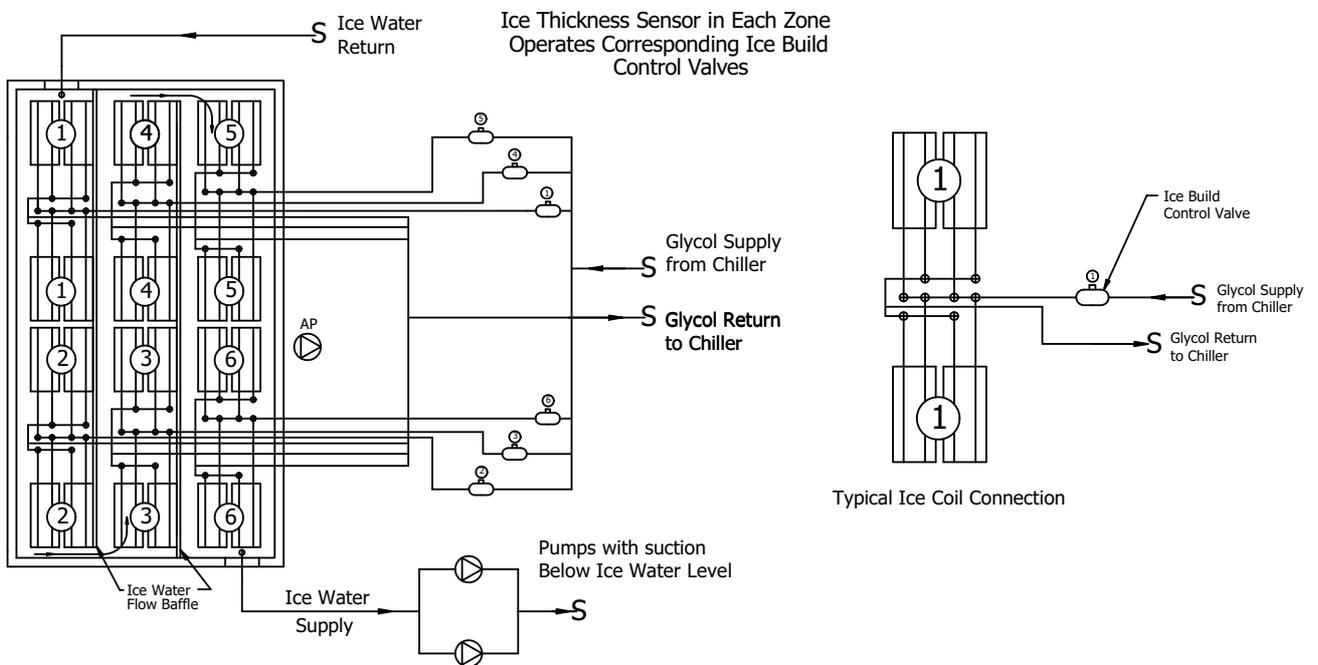


Figure 8B: Storage Container Layout - External Melt - Ice Water Flow - Three Pass

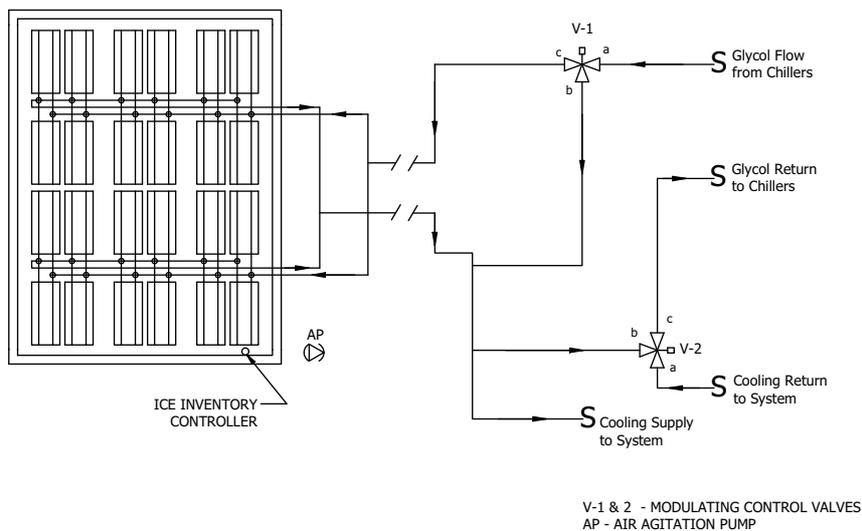


Note: Water flow baffles are simply sheet metal or flat plastic panels that channel the ice water flow.

B. Internal Melt

During internal melt applications, the glycol flow through the ice coils melts the ice. The warmer glycol begins melting the ice from the inside of each ice coil ring, thus cooling the glycol. As more ice is melted, the ice ring begins to crack exposing the ice coil tubes to the cold container water. When the ice build cycle begins on a design day, all of the ice coils are free of ice and the ice will form evenly around each coil. However, on other days, there will be ice remaining in the container. When recharging the system, all of the ice in the container must be considered in order to get a complete charge. An ice inventory device, see Chapter 10 B Accessories, is used to determine the amount of ice in the container. The inventory device operates on the principal that as ice is formed, the water level will rise. For a predetermined amount of ice storage and a known container plan area, the water level rise can be calculated. All of the ice, whether loose or attached to the coil, will contribute to the water rise. The inventory device measures the difference in water level, resulting from the water rise, and transmits a corresponding milli-amp signal to terminate the ice build mode when a full charge is obtained.

Figure 8C: Storage Container Layout - Internal Melt - Ice Water Flow



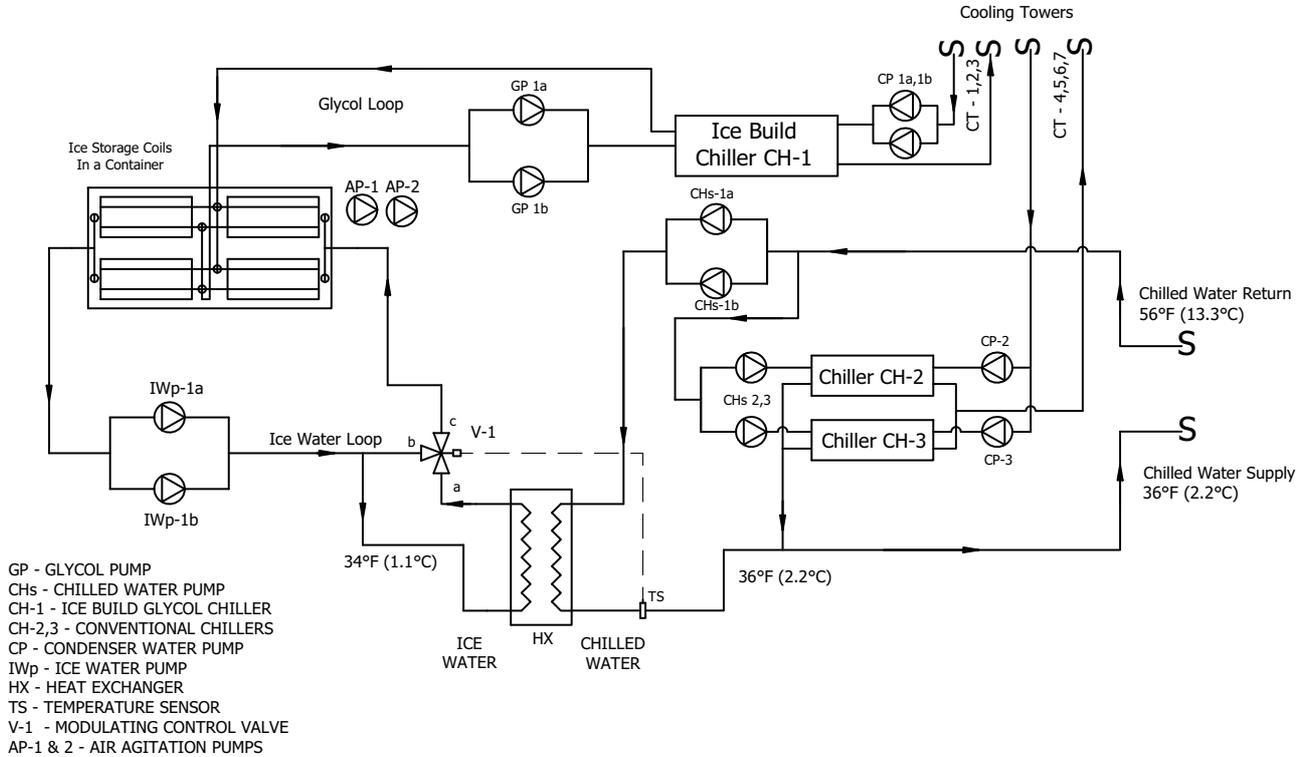
9. Examples: Equipment Selection, Flow Diagram, and On-Peak Demand Comparison

A. External Melt Example (English Units)

For this example, the flow schematic and spread sheet developed in Section 5A - System Sizing and Design Day Performance are used. The design day peak cooling load is 7,000 tons, and the electric on-peak demand period is 10 hours (10:00 AM to 20:00 PM). The ice storage capacity is 30,500 ton-hrs. The ice build chiller and its accessories do not operate during the demand period. The conventional chillers provide cooling for the non-peak hours. They also operate during on-peak hours along with the ice melt to meet the total cooling requirements. The distribution system is designed with a 20°F delta-T (36°F to 56°F).

The thermal ice storage system flow schematic is shown again for convenience.

**Figure 9A-1: Thermal Ice Storage - External Melt - 7000 Ton Flow Schematic - Example
Two Conventional Chillers Piped in Parallel with Ice Water Heat Exchanger**



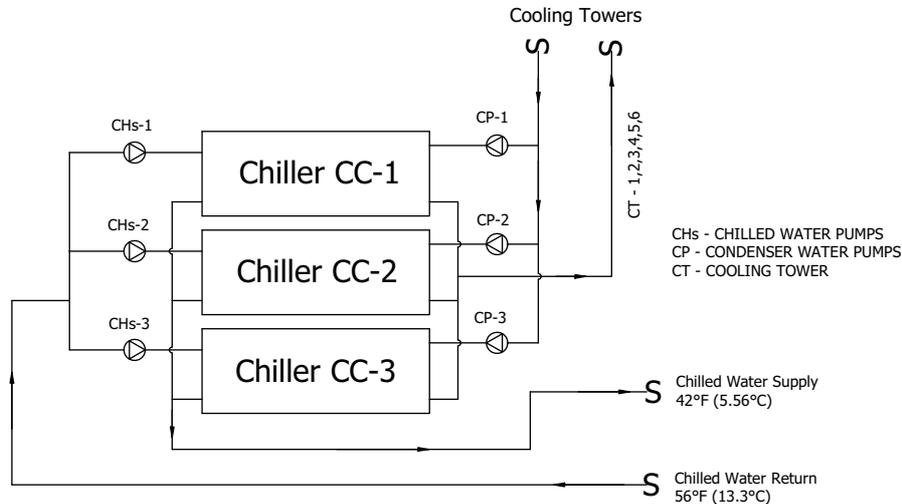
The thermal ice storage equipment, size and performance are indicated below.

Ice Storage System Components and Performance:

- Ice build chiller (CH-1)
 - Nominal capacity – 3600 tons (44°F / 85°F)
 - Ice Build capacity – 2362 tons (22°F / 80°F) (2,008 kW)
- Glycol pumps (GP-1a, 1b): Two (2) @ 5500 gpm, 25 % EG solution, 103 Ft., @ 200 hp each
- Condenser water pumps (CP-1a, 1b): Two (2) @ 5400 gpm, 75 ft, @ 150 hp each
- Cooling towers (CT-1, 2, 3): Evapco Model AT: Three (3) fans @ 75 hp each
- Air agitation pumps (AP-1, 2): Two (2) @ 40 hp each
- Ice water pumps (IWp-1a, 1b): Two (2) @ 2400 gpm, 100 ft, @ 100 hp each
- Heat exchanger: ice water (34°F) / chilled water (36°F)
- Chilled water pump (CHs-1a, 1b): Two @ 2400 gpm, 105 ft, @ 125 hp each
- Conventional chillers (CH-2, 3): Two (2) @ 1750 tons (36°F / 85°F), (.66 kW/ton) - 1155 kW each Capacity limited to 1500 tons On-Peak - 990 kW
- Chilled water pumps (CHs-2, 3): Two (2) @ 2100 gpm, 125 ft, @ 100 hp each
- Condenser water pumps (CP-2, 3): Two (2) @ 5250 gpm, 75 ft, @ 150 hp each
- Cooling towers (CT-4, 5, 6, 7) Evapco Model AT: Four @ 75 hp each
- Ice storage coils: Evapco Model IPCB - 266 (120 coils) (30,500 ton-hours)

The conventional chilled water system flow schematic is shown here.

Figure 9A-2: Conventional Chilled Water 7,000 Tons Flow Schematic Example



The conventional chilled water plant equipment, size and performance are indicated below.

Conventional Chilled Water System

The design day cooling load and electric utility demand period are identical. The distribution loop is based on a 14°F delta -T, (42°F / 56°F).

- Conventional chillers (CC-1, 2, 3): 2400 tons each, 42F leaving temp., 0.60 kW/ton (4320 kW)
- Chilled water pumps (CHS-1, 2, 3): Three (3) @ 4000 gpm, 125 ft, @ 200 hp each
- Condenser water pumps (CP-1, 2, 3): Three (3) @ 7000 gpm, 75 ft, @ 200 hp each
- Cooling towers (CT-1-6) Evapco Model AT: Six @ 100 hp each

On-peak Electric Demand Comparison

Ice Storage System

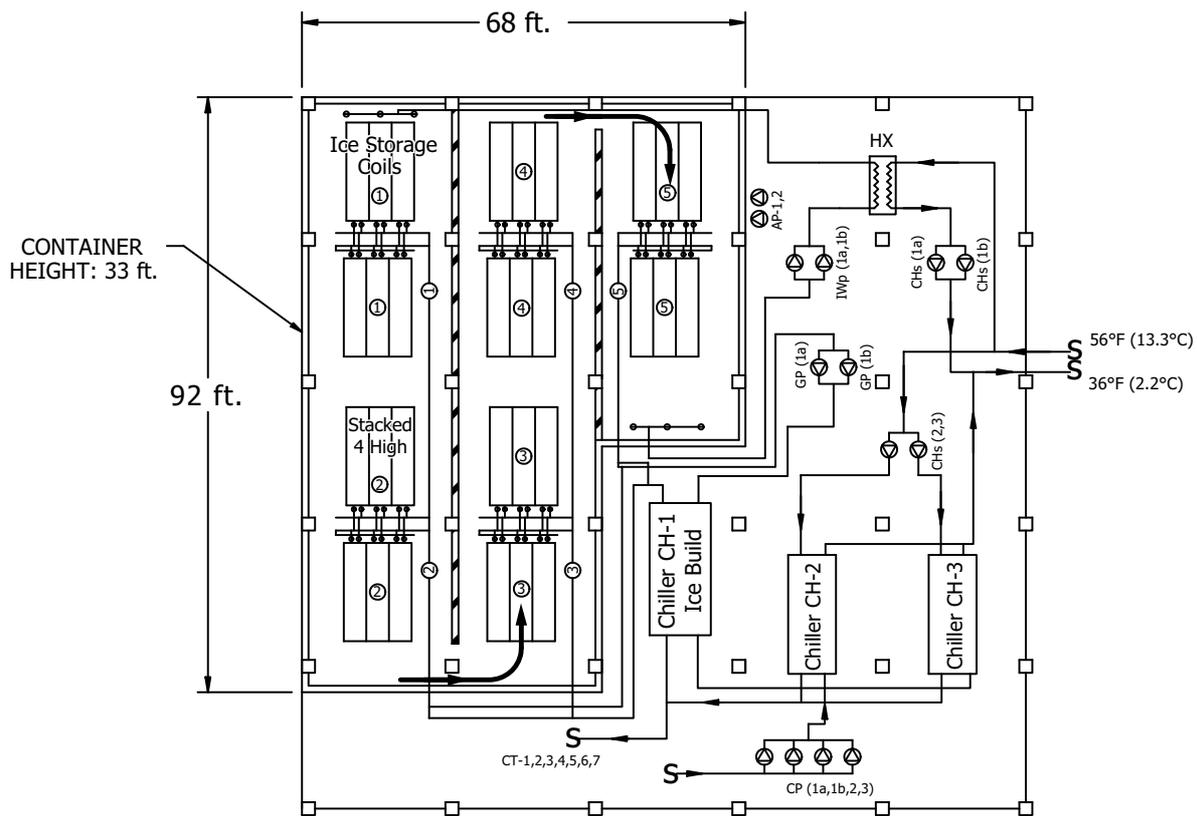
Ice Build Chiller CH-1	off
Glycol pumps GP 1a,1b	off
CP 1a, 1b,	off
CT 1, 2, 3	off
IWp 1a, 1b: Two @ 100 hp	168 kW
CHs 1a, 1b: Two@ 125 hp	210 kW
CH 2, 3: Two 1500 tons	1980 kW
CP 2, 3: Two @ 150 hp	252 kW
CHs 2, 3: Two@ 100 hp	168 kW
CT 4, 5, 6, 7: Four @ 75 hp	252 kW
AP- 1, 2: Two @ 40 hp	67 kW
Estimated Total	<u>3097 kW</u>

Conventional Chilled Water System

Chillers 7000 tons @ 0.617 kW/ton	4320 kW
Chiller water pumps 3 @ 4000 gpm, 125 ft.	
3 @ 200 hp.....	504 kW
Condenser pumps 3 @ 7000 gpm, 75 ft.	
3 @ 200 hp.....	504 kW
Cooling tower fans	
6 @ 100 hp	<u>504 kW</u>
	<u>5832 kW</u>

The estimated on-peak demand avoidance is 2735 kW per month. In addition, thermal ice storage system designs that take advantage of the larger fluid delta-T (20°F) (reduced pump hp) and lower temperature air (51°F or lower) (reduced fan hp) not only provide additional energy cost savings, but they reduce the HVAC construction first cost of the project.. Refer to Section 1B - "Operating and Cost Benefits".

9A & 9B External Melt Example Layout

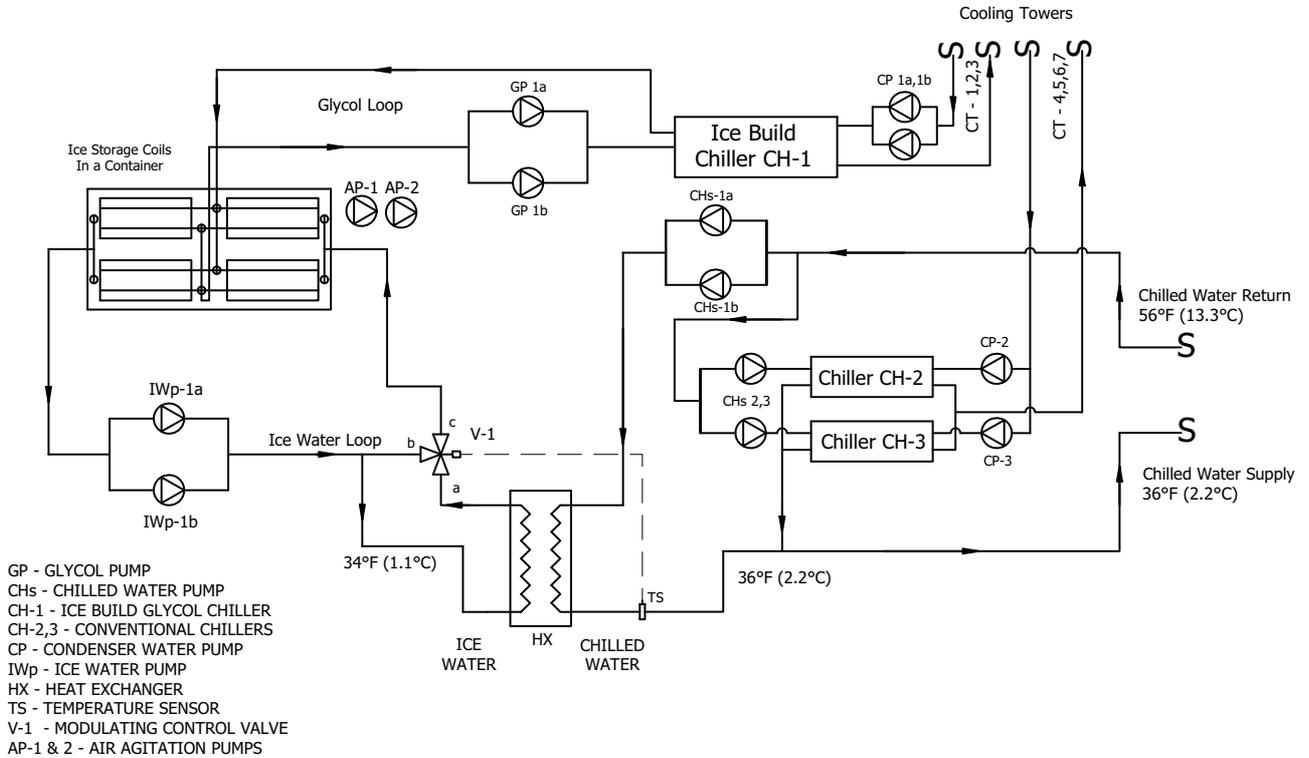


B. External Melt Example (Metric Units)

For this example, the flow schematic and spread sheet developed in Section 5A - System Sizing and Design Day Performance are used. The design day peak cooling load is 24,640 kW and the electric on-peak demand period is 10 hours (10:00 AM to 20:00 PM). The ice storage capacity is 107,360 kW-hrs. The ice build chiller and its accessories do not operate during the demand period. The conventional chillers provide cooling for the non-peak hours. They also operate during on-peak hours along with the ice melt to meet the total cooling requirements. The distribution system is designed with a 11.1°C delta-T (2.22°C to 13.3°C).

The thermal ice storage system flow schematic is shown again for convenience.

**Figure 9B-1: Thermal Ice Storage - External Melt
24,640 kW Flow Schematic - Example**



The thermal ice storage equipment, size and performance are indicated below.

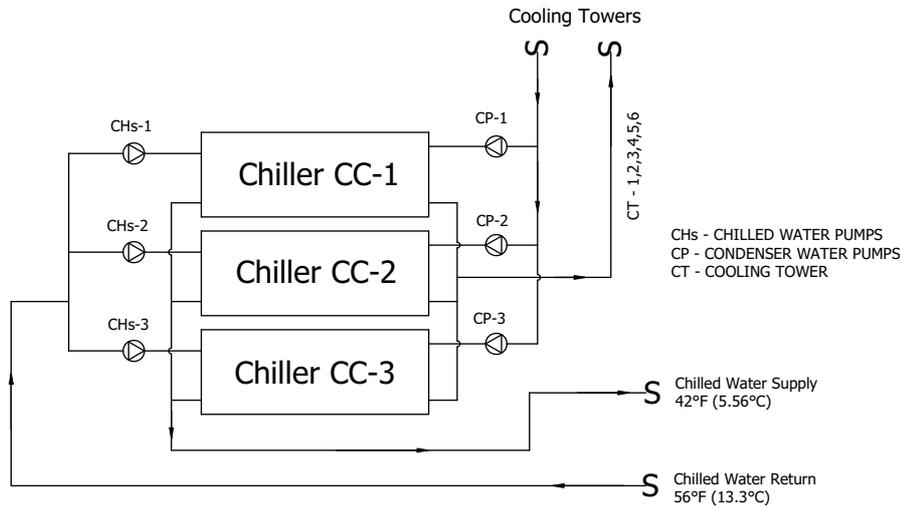
Ice Storage System Components and Performance:

- Ice build chiller (CH-1)
Nominal capacity – 12,672 kW (6.67°C / 29.4°C)
Ice build capacity – 8314 kW (-5.56°C / 26.7°C) (2,173 kW)
- Glycol pumps (GP-1a, 1b): Two (2) @ 346.5 L/s, 25 % EG solution, 710 kPa, @ 168 kW each
- Condenser water pumps (CP-1a, 1b): Two (2) @ 340 L/s, 517 kPa, @ 126 kW each
- Cooling towers (CT-1, 2, 3) Evapco Model AT: Three (3) fans @ 63 kW each
- Air agitation pumps (AP-1, 2): Two (2) @ 34 kW each
- Ice water pumps (IWp-1a, 1b): Two (2) @ 151 L/s, 689 kPa, @ 84 kW each
- Heat exchanger: ice water (1.11°C) / chilled water (2.22°C)
- Chilled water pump (CHs-1a, 1b): Two @151 L/s, 723 kPa @ 105 kW each
- Conventional chillers (CH-2, 3): Two (2) @ 6160 kW (2.22°C / 29.4°C), 5.53 COP, 1155 kW each capacity limited to 5280 kW On-Peak - 990 kW
- Chilled water pumps (CHs-2, 3): Two (2) @) 132.3 L/s, 861 kPa, @ 84 kW each
- Condenser water pumps (CP-2, 3): Two (2) @ 331 L/s, 517 kPa, @ 126 kW each
- Cooling towers (CT-4, 5, 6, 7) Evapco Model AT: Four @ 63 kW each
- Ice storage coils: Evapco Model IPCB - 266 (120 coils) (107,360 kW-hrs)



The conventional chilled water system flow schematic is shown here.

**Figure 9B-2: Thermal Ice Storage - External Melt
24,640 kW Flow Schematic - Example**



The conventional chilled water plant equipment, size and performance are indicated below.

Conventional Chilled Water System

The design day cooling load and electric utility demand period are identical. The distribution loop is based on a 7.74°C delta -T, (5.56°C / 13.3°C)

- Conventional chillers (CC-1, 2, 3): 25344 kW, 5.56°C leaving temperature, 5.87 COP, 4320 kW
- Chilled water pumps (CHs-1, 2, 3): Three (3) @ 252 L/s, 861 kPa, @ 168 kW each
- Condenser water pumps (CP-1, 2, 3): Three (3) @ 4.41 L/s, 517 kPa, @ 168 kW each
- Cooling towers (CT-1 - 6) Evapco Model AT: Six (6) @ 84 kW each

On-peak Electric Demand Comparison

Ice Storage System

Ice build chiller CH-1	off
Glycol pumps GP 1a,1b	off
CP 1a, 1b,	off
CT 1, 2, 3	off
IWp 1a, 1b: Two @ 84 kW	168 kW
CHs 1a, 1b, 2: Two@ 105 kW	210 kW
CH 2, 3: Two 5280 kW	1980 kW
CP 2, 3: Two @ 126 kW	252 kW
CHs 2, 3: Two@ 84 kW	168 kW
CT 4, 5, 6, 7: Four @ 63 kW	252 kW
AP- 1, 2: Two @ 33.5 kW	67 kW
Estimated Total	<u>3097 kW</u>

Conventional Chilled Water System

Chillers 24670 kW @ 5.71 COP	4320 kW
Chiller water pumps 3 @ 252 L/s, 861 kPa	
3 @ 168 kW.....	504 kW
Condenser pumps 3 @ 441L/s, 516 kPa	
3 @ 168 kW.....	504 kW
Cooling tower fans	
6 @ 84 kW	<u>504 kW</u>
	<u>5832 kW</u>

The estimated on-peak demand avoidance is 2735 kW per month. In addition, thermal ice storage system designs that take advantage of the larger fluid delta-T (11.1°C) (reduced pump hp) and lower temperature air (10.6°C or lower) (reduced fan hp) not only provide additional energy cost savings, but they reduce the HVAC construction first cost of the project. Refer to Section 1B - "Operating and Cost Benefits".

C. Internal Melt Example (Metric units)

For this example, the flow schematic and spread sheet developed in Section 5B - System Sizing and Design Day Performance are used. The design day peak cooling load is 10,500 kW and the utility on peak period is 10 hours (10:00 AM to 20:00 PM). The ice storage / glycol loop is separated from the chilled water distribution loop by a heat exchanger. Two conventional chillers are piped in parallel with the ice storage heat exchanger.

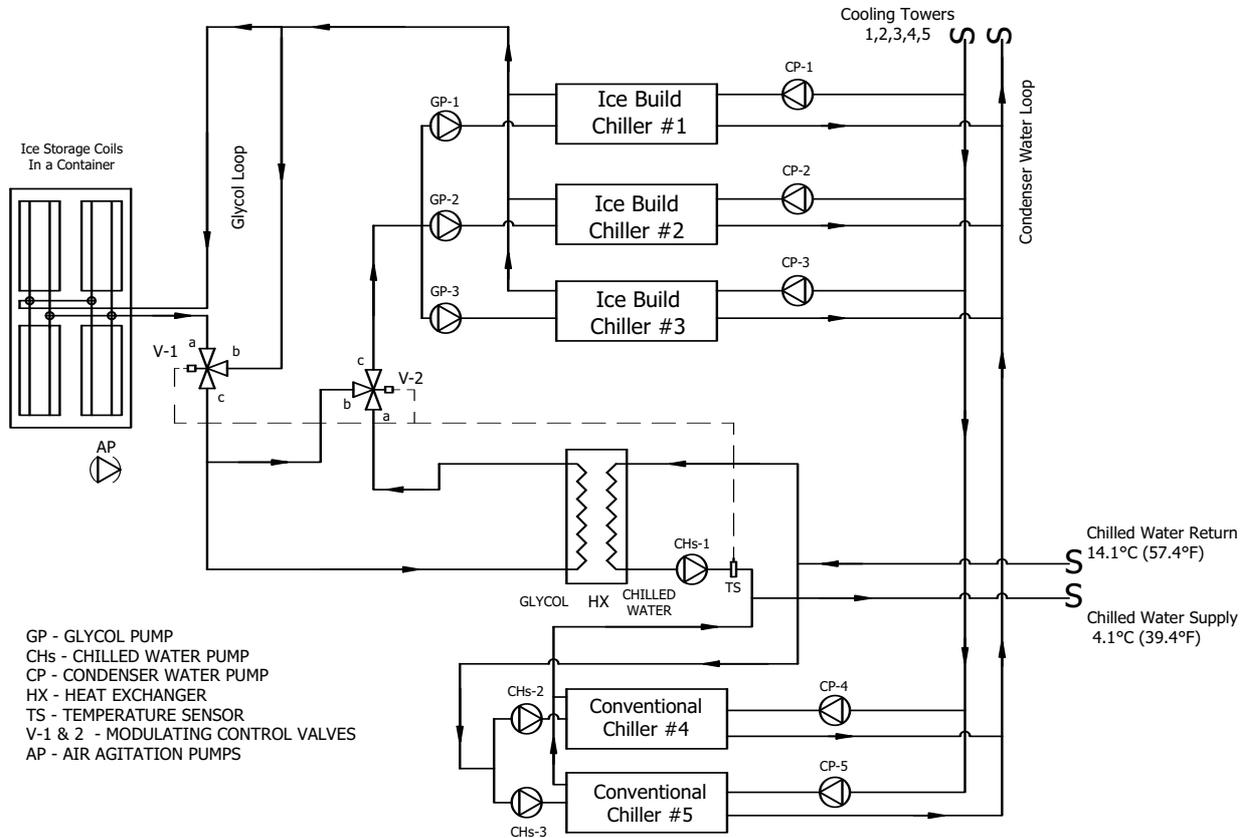
This example has built-in equipment redundancy and would be ideal for any typical air conditioning application or for a 24 hour cooling applications such as: data centers, hospitals, or a district cooling plant for a college campus or office complex. After reviewing this example, some modification options are described for your consideration.

Electric utilities often limit the off peak hours available to recharge the ice storage system. For this example, the ice build mode is limited to 8 hours (23:00 PM to 7:00 AM). The third glycol ice build chiller was added specifically to accomplish this.

During the 7:00 AM to 10:00 AM utility intermediate period, two of the glycol chillers provide the 3.0°C cooling directly to the heat exchanger. These two chillers are demand limited to 65% capacity and provide cooling, in series with the ice melt, during the 10:00 AM to 20:00 PM on peak period. The distribution system is designed with a 10°C delta-T (5.0°C to 15.0°C).

The thermal ice storage system flow schematic is shown again for convenience.

**Figure 9C-1: Thermal Ice Storage - Internal Melt
10,500 kW Flow Schematic - Example**



The thermal ice storage equipment, size and performance are indicated below.

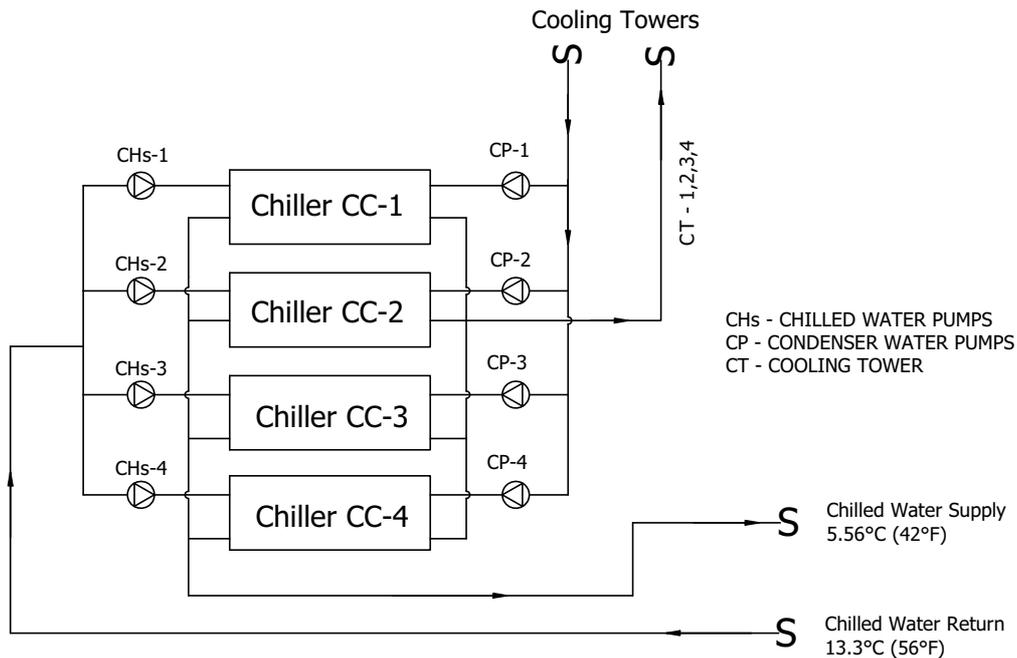
Ice Storage System Components and Performance:

- Ice build chiller (CH-1, 2, 3)
 - Nominal capacity – 1760 kW (6.7°C / 29.4°C)
 - Ice build capacity – 1176 kW (-5.6°C / 26.7°C), 4.14 COP (284 kW)
 - Direct cooling capacity – 1627 kW (3.0°C / 29.4°C), 5.28 COP (306 kW)
 - In series with ice melt – 1760 kW (6.7°C / 29.4°C) (5.77 COP) Demand Limited to 65% capacity (1144 kW) (199 kW)
- Glycol pumps (GP-1 ,2, 3): Three (3) @ 114 L/s, 25 % EG solution, 352 kPa, @ 84 kW each
- Condenser water pumps (CP-1, 2, 3): Three (3) @ 94.5 L/s, 239 kPa, 42 kW each
- Cooling towers (CT-1, 2, 3) Evapco Model AT: Three (3) fans @ 25.2 kW each
- Heat exchanger: glycol (3.0°C) / chilled water (4.1°C)
- Chilled water pump (CHs-1): one 167 L/s, 372 kPa, 105 kW
- Conventional chillers (CH-4, 5): Two (2) @ 1760 kW (5.0°C / 29.4°C), 5.41 COP (325 kW) each
- Chilled water pumps (CHs-2, 3): Two (2) @ 42 L/s, 125 ft, 358 kPa, @ 22.6 kW each

- Condenser water pumps (CP-4, 5): Two (2) @ 99.2 L/s, 239 kPa, @ 42 kW each
- Cooling towers (CT-4, 5) Evapco Model AT: Two (2) @ 25.2 kW each
- Ice storage coils: Evapco Model ICE - 1000 (30 coils) (30,000 kW-hours)

The conventional chilled water system flow schematic is shown here.

**Figure 9C-2: Thermal Ice Storage - Internal Melt
10,500 kW Flow Schematic - Example**



The conventional chilled water plant equipment, size and performance are indicated below.

Conventional Chilled Water System

The design day cooling load and electric utility demand period are identical. The distribution loop is based on a 6.63°C delta -T, (13.3°C / 6.67°C)

- Conventional chillers (CC-1, 2, 3, 4): 2625 kW:
Four (4) @ 5.56°C leaving temperature, 5.58 COP (470 kW)
- Chilled water pumps (CHs-1, 2, 3, 4): Four (4) @ 94 L/s, 358 kPa, @ 42 kW each
- Condenser water pumps (CP-1, 2, 3, 4): Four (4) @ 141 L/s, 239 kPa, @ 63 kW each
- Cooling towers (CT-1, 2, 3, 4) Evapco Model AT: Four (4) @ 42 kW each



On-peak Electric Demand Comparison

Ice Storage System

Chiller CH- 1, 2: Two @ 199 kW ..	298 kW
GP 1a, 1b: Two @ 84 kW	168 kW
CP 1a, 1b: Two @ 42 kW	84 kW
CT 1, 2: Two @ 25.2 kW	50.4 kW
CHs 1: One @ 105 kW	105 kW
CH 4, 5: Two @ 325 kW	650 kW
CHs 2, 3: Two @ 22.6 kW	45.2 kW
CP 3, 4: Two @ 42 kW	84 kW
CT 3, 4: Two @ 25.2 kW	50.4 kW
Estimated Total	1535 kW

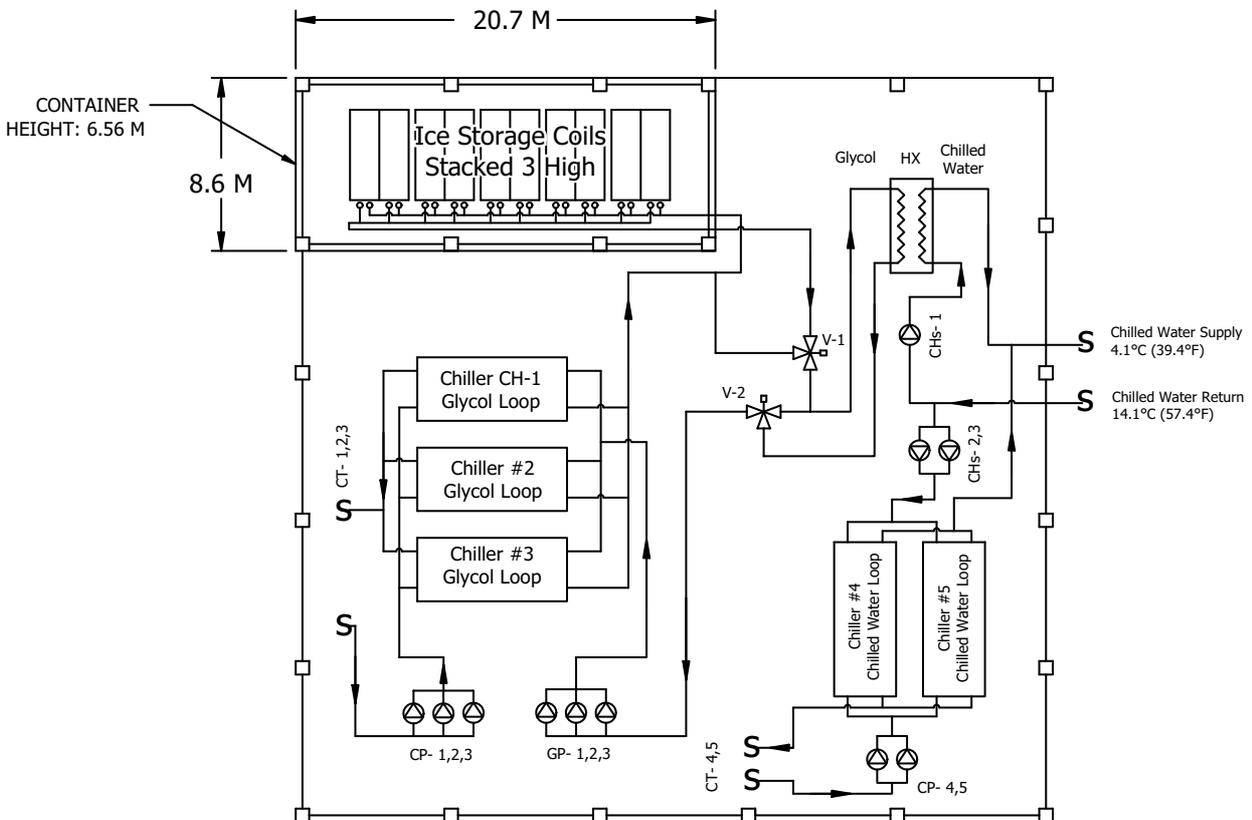
Conventional Chilled Water System

Chillers 10500 kW @ 5.58 COP	1880 kW
Chilled water pumps 4 @ 42 kW	168 kW
Condenser pumps 4 @ 63 kW	252 kW
Cooling tower fans: 4 @ 42 kW	168 kW

2468 kW

The estimated on-peak demand avoidance is 933 kW per month. In addition, thermal ice storage system designs that take advantage of the larger fluid delta-T (11.1°C) (reduced pump hp) and lower temperature air (10.6°C or lower) (reduced fan hp) not only provide additional energy cost savings, but they reduce the HVAC construction first cost of the project. Refer to Section 1B - "Operating and Cost Benefits".

9C & 9D - Example - Internal Melt Layout



The following options are offered for consideration where applicable with the project design:

- Omit one of the ice build chillers. A full ice charge can be obtained by operating two chillers from 19:00 PM to 7:00 AM.
- Locate all chillers in the glycol loop. This would improve chiller, pump and cooling tower redundancy.
- For new installations: eliminate the glycol / chilled water heat exchanger. Circulate the glycol solution throughout the cooling loop. The distribution fluid supply temperature can be lowered from 4.1°C to 3.0°C and the delta-T can be increased to 11.1°C.

D. Internal Melt Example (English units)

For this example, the flow schematic and spread sheet developed in Section 5B - System Sizing and Design Day Performance are used. The design day peak cooling load is 3000 tons and the utility on peak period is 10 hours (10:00 AM to 20:00 PM). The ice storage / glycol loop is separated from the chilled water distribution loop by a heat exchanger. Two conventional chillers are piped in parallel with the ice storage heat exchanger.

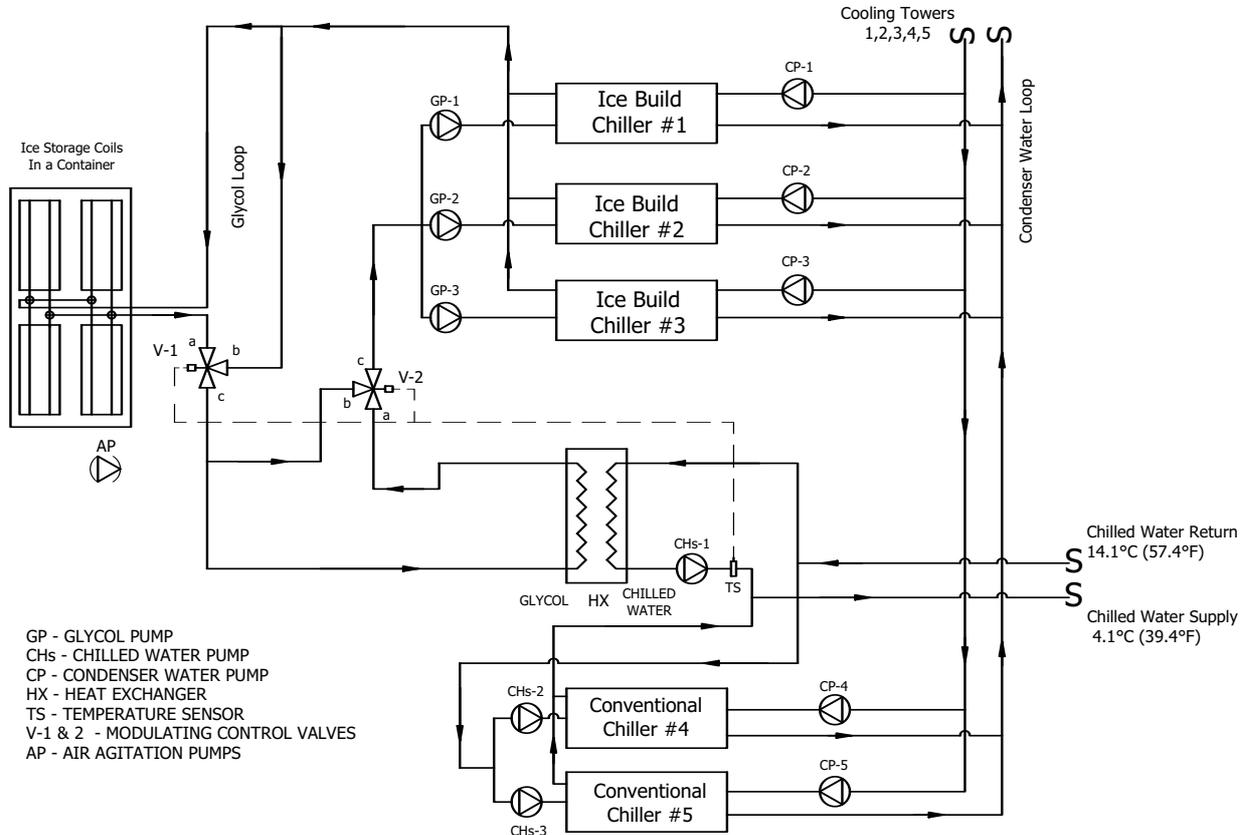
This example has built-in equipment redundancy and would be ideal for any typical air conditioning application or for a 24 hour cooling applications such as: data centers, hospitals, or a district cooling plant for a college campus or office complex. After reviewing this example, some modification options are described for your consideration.

Electric utilities often limit the off peak hours available to recharge the ice storage system. For this example, the ice build mode is limited to 8 hours (23:00 PM to 7:00 AM). The third glycol ice build chiller was added specifically to accomplish this.

During the 7:00 AM to 10:00 AM utility intermediate period, two of the glycol chillers provide the 39°F cooling directly to the heat exchanger. These two chillers are demand limited to 65% capacity and provide cooling, in series with the ice melt, during the 10:00 AM to 20:00 PM on peak period. The distribution system is designed with an 18°F delta-T (41°F to 59°F).

The thermal ice storage system flow schematic is shown again for convenience.

**Figure 9D-1: Thermal Ice Storage - Internal Melt
3,000 Tons Flow Schematic - Example**



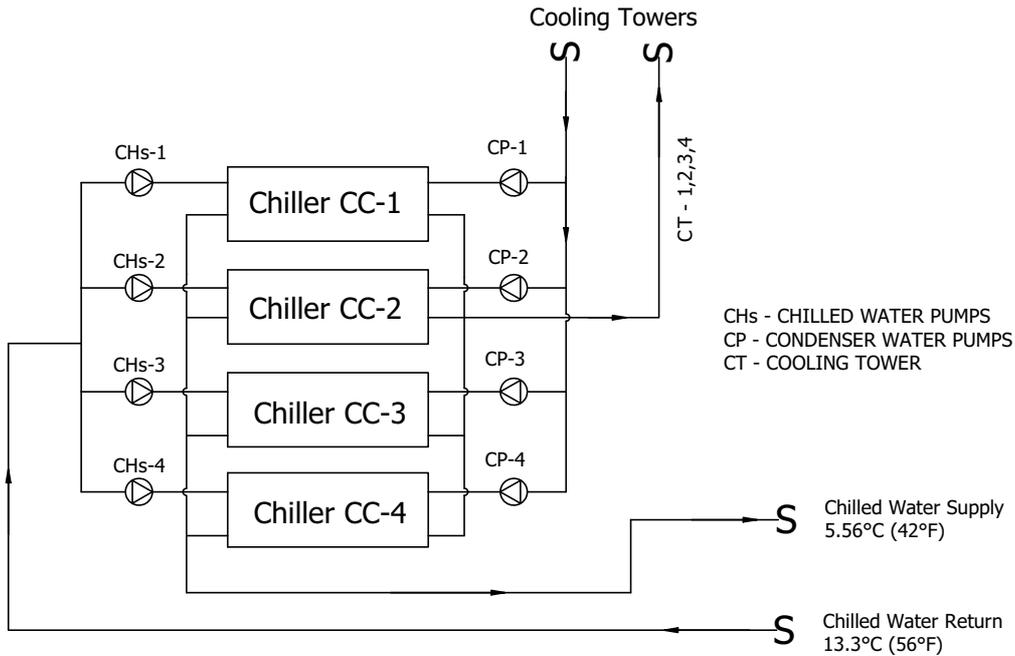
The thermal ice storage equipment, size and performance are indicated below.

Ice Storage System Components and Performance:

- Ice build chiller (CH-1, 2, 3)
 - Nominal capacity – 500 tons (44°F / 85°F)
 - Ice build capacity – 325 tons (22°F / 80°F), 0.85 kW / ton (276 kW)
 - Direct cooling capacity – 462 tons (39°F/ 85°F), 0.66 kW / ton (306 kW)
 - In series with ice melt – 500 tons (44°F / 85°F), 0.61 kW / ton demand limited to 65% capacity (325 tons) (199 kW)
- Glycol pumps (GP-1, 2, 3): Three (3) @ 1809 gpm, 25 % EG solution, 120 ft, @ 100 hp each
- Condenser water pumps (CP-1, 2, 3): Three (3) @ 1500gpm, 80 ft, @ 50 hp each
- Cooling towers (CT-1, 2, 3) Evapco Model AT: Three (3) fans @ 30 hp each
- Heat exchanger: glycol (39°F) / chilled water (41°F)
- Chilled water pump (CHs-1): one 2650 gpm, 125 ft, 125 hp
- Conventional chillers (CH- 4, 5): Two (2) @ 500 tons (41°F / 85°F), 0.65 kW / ton (325 kW) each
- Chilled water pumps (CHs- 2, 3): Two (2) @ 667 gpm, 125 ft, @ 40 hp each
- Condenser water pumps (CP- 4, 5): Two (2) @ 1575 gpm, 80 ft, @ 50 hp each
- Cooling towers (CT-4, 5) Evapco Model AT: Two (2) @ 30 hp each
- Ice storage coils: Evapco Model ICE - 284 (30 coils) (8522 ton / hours)

The conventional chilled water system flow schematic is shown here.

**Figure 9D-2: Conventional Chilled Water Plant
3,000 Ton Flow Schematic - Example**



The conventional chilled water plant equipment, size and performance are indicated below:

Conventional Chilled Water System

The design day cooling load and electric utility demand period are identical. The distribution loop is based on a 18°F delta -T, (41°F / 59°F).

- Conventional chillers (CC-1, 2, 3, 4): 750 tons:
 Four (4) @ 41°F leaving temperature, 0.63 kW / ton (470 kW)
- Chilled water pumps (CHs-1, 2, 3, 4): Four (4) @ 1000 gpm, 120 ft, @ 50 hp each
- Condenser water pumps (CP-1, 2, 3, 4): Four (4) @ 2250 gpm, 80 ft, @ 75 hp each
- Cooling towers (CT-1, 2, 3, 4) Evapco Model AT: Four (4) @ 50 hp each



On-peak Electric Demand Comparison

Ice Storage System

Chiller CH- 1, 2: Two @ 199 kW ..	298 kW
GP 1a, 2a: Two @ 100 hp	168 kW
CP 1a, 1b: Two @ 50 hp	84 kW
CT 1, 2: Two @ 30 hp	50.4 kW
CHs 1: One @ 125 hp	105 kW
CH 4, 5: Two @ 325 kW	650 kW
CHs 2, 3: Two @ 25 hp	45.2 kW
CP 4, 5: Two @ 59 hp	84 kW
CT 4, 5: Two @ 30 hp	50.4 kW
Estimated Total	<u>1535 kW</u>

Conventional Chilled Water System

Chillers 3000 tons @ 0.63 kW/ton	1880 kW
Chilled water pumps 4 @ 50 hp	168 kW
Condenser pumps 4 @ 75 hp	252 kW
Cooling tower fans: 4 @ 50 hp	168 kW
	<u>2468 kW</u>

The estimated on-peak demand avoidance is 933 kW per month. In addition, thermal ice storage system designs that take advantage of the larger fluid delta-T (20°F) (reduced pump hp) and lower temperature air (51°F or lower) (reduced fan hp) not only provide additional energy cost savings, but they reduce the HVAC construction first cost of the project.. Refer to Section 1B - "Operating and Cost Benefits".

The following options are offered for consideration where applicable with the project design:

- Omit one of the ice build chillers. A full ice charge can be obtained by operating two chillers from 19:00 PM to 7:00 AM.
- Locate all chillers in the glycol loop. This would improve chiller, pump and cooling tower redundancy.
- For new installations: eliminate the glycol / chilled water heat exchanger. Circulate the glycol solution throughout the cooling loop. The distribution fluid supply temperature can be lowered from 41°F to 39°F and the delta-T can be increased to 20°F.

10. Ice Storage System Control Accessories

A. Air agitation pumps (primarily external melt systems)

Air agitation pumps are generally positive displacement, rotary compressors (normally 5 to 40 hp) (4.2 - 33.6kW) with a discharge air capacity of 0.1 cfm per square foot (1.9M³/HR per M²) of the tank plan area and of sufficient pressure to overcome the static water column head in the storage container. Air is pumped through the perforated PVC pipe attached to the underside of the bottom coil. The bubbling action through the coil bundle assures an even water temperature throughout the container.

Air agitation adds turbulence to the ice water in the container. Turbulence during the first 2 hours of the ice build mode will assure that all the water in the container is at 32°F (0°C). After the first two hours, the air agitation pump can be turned off since the ice will now build evenly. Turbulence during the ice melt mode assures that the ice water flow does not establish any channels that might bypass the flow around some coil areas.

For external melt systems, air agitation is required for all projects. Air agitation is seldom used on internal melt systems.

The air pump assembly includes a muffler to reduce the compressor noise. The discharge air will be heated due to compression. To dissipate this heat, steel discharge piping should be used for the initial 10 feet (3M). PVC pipe can be used to continue the piping to the perforated pipe. A PVC check valve must be installed in the discharge piping. When the air agitation pump stops, the check valve will prevent ice water from siphoning back into the pipe and back into the compressor discharge chamber. This check valve should be installed in a horizontal section of pipe located above the container water level.

Air from the surrounding area, such as the mechanical equipment room, will contain humidity (water vapor). If this air was used for the agitation pump suction, the water vapor would condense as it bubbles through the ice water and, over time, increase the water level in the container. Operating controls that use the water level in the container as a reference point may have to be recalibrated more frequently. It is a common practice to draw the pump suction air from inside of the container, above the water level. This assures that no additional moisture is introduced into the container and any recalibration of the controls will be minimized.

Figure 10A-1: Typical Ice Storage Coil

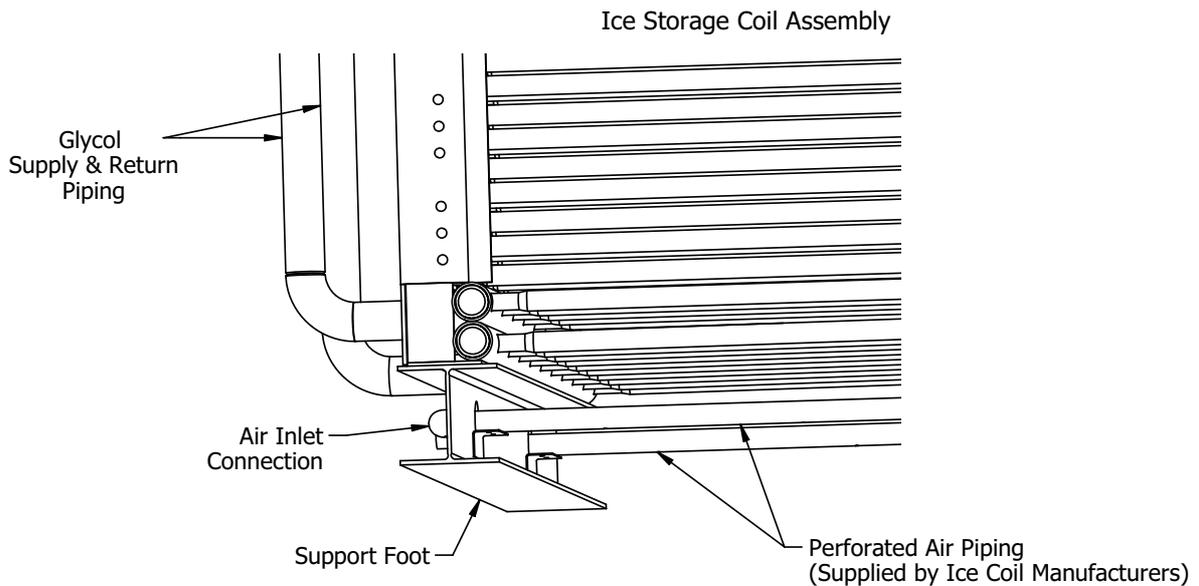
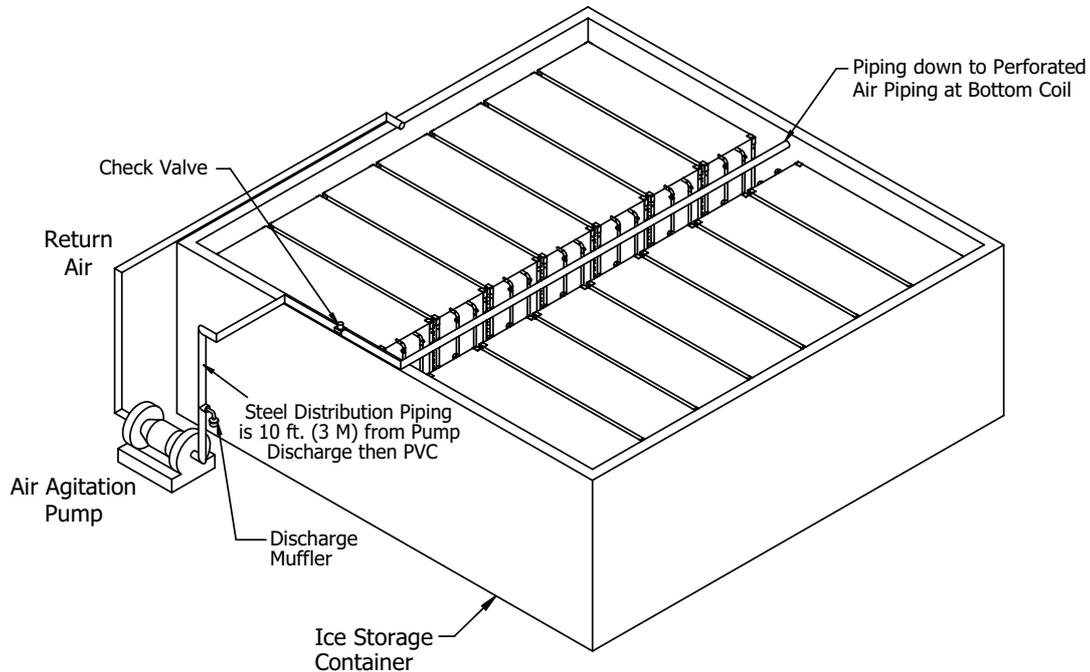


Figure 10A-2: Air Piping Schematic



B. Ice thickness sensor (external melt systems)

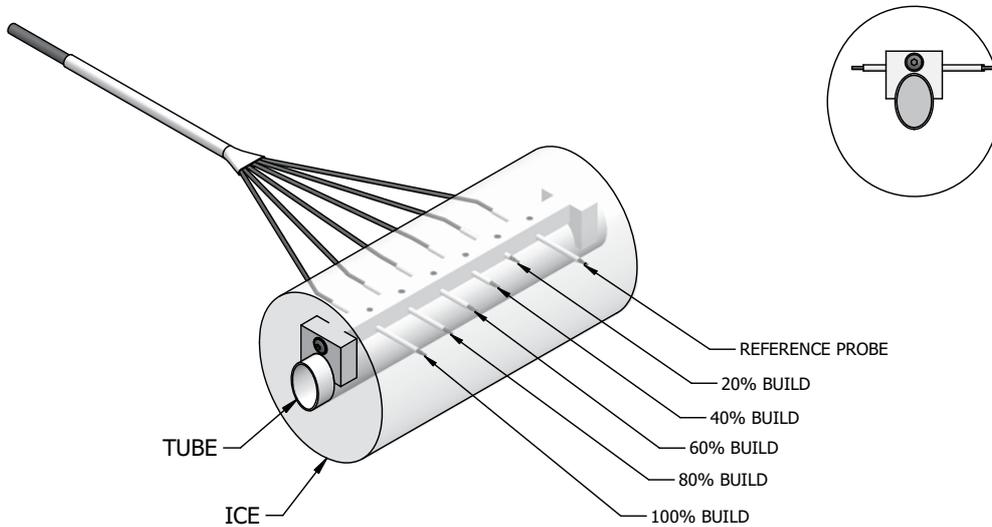
The ice thickness sensor is a device with a set of probes. The probes are of different lengths and measure the thickness of the ice on the coils. The probe assembly will generate a milliamp signal that is used by the ATC system. The ice thickness sensor is attached to one of the ice coils. As the ring of ice forms around the coil, the shortest probe becomes embedded in the ice ring. As ice continues to form, all of the probes will be embedded in the ice. The longest probe will signal the controls that a full ice charge has been obtained. The different length of the probes will approximate the amount of ice remaining on the coil (80%, 60%, 40%, 20%) as the ice is melted and each probe becomes exposed to the ice water again. The control system processes this information to estimate the amount of ice remaining on the coils.

The ice thickness sensor distinguishes the resistance between ice and water. When a full build of ice is reached, the sensor opens a contactor thus signaling the Automatic Temperature Control (ATC) system to terminate the ice build mode.

On small ice storage systems, only one ice thickness sensor is used and its signal may stop the chiller directly. Larger systems with ice build zones use multiple ice thickness sensors that close their respective glycol zone valve.

During the cooling modes, the ice will melt exposing the probes in order of their length. However, the contactor will remain open until sufficient ice is melted to expose the no-ice probes. This will enable the ice build mode to start when the ATC system schedule calls for it. The ice build mode can also be initiated based on the time-of-day.

Figure 10B: Ice Thickness Sensor (External Melt)



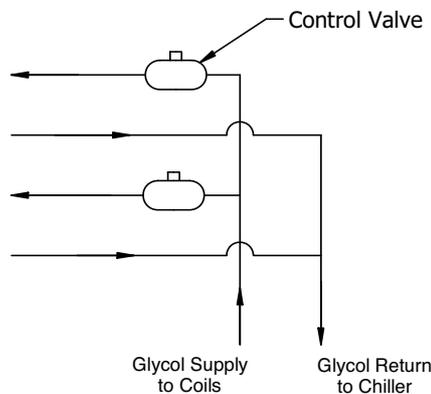
C. Automatic glycol zone valves

As explained in Section 8 “Storage Container Ice Coil Layout” (Figures 8A & 8B), the ice water flow is directed through the ice storage coils. Based on the coil layout, the ice water will flow longitudinally with the length of the coils and the coils will be arranged end to end. The flow is in series over the coils and the ice will be depleted from the coils, in the order that the water flows over them, starting with the initial coil in the series.

When the ice build mode begins, the initial group of coils will contain no ice and subsequent groups of coils may have a partial or full charge of ice. Automatic glycol zone valves and multiple ice thickness sensors allow the system to recharge the different zones according to the amount of ice depleted. As each thickness sensor reaches the full charge level, its glycol zone valve closes ending the ice build mode for those coils. The ice build mode is terminated when all glycol zone valves are closed.

These zone valves are normally two position solenoid valves furnished by the installing contractor.

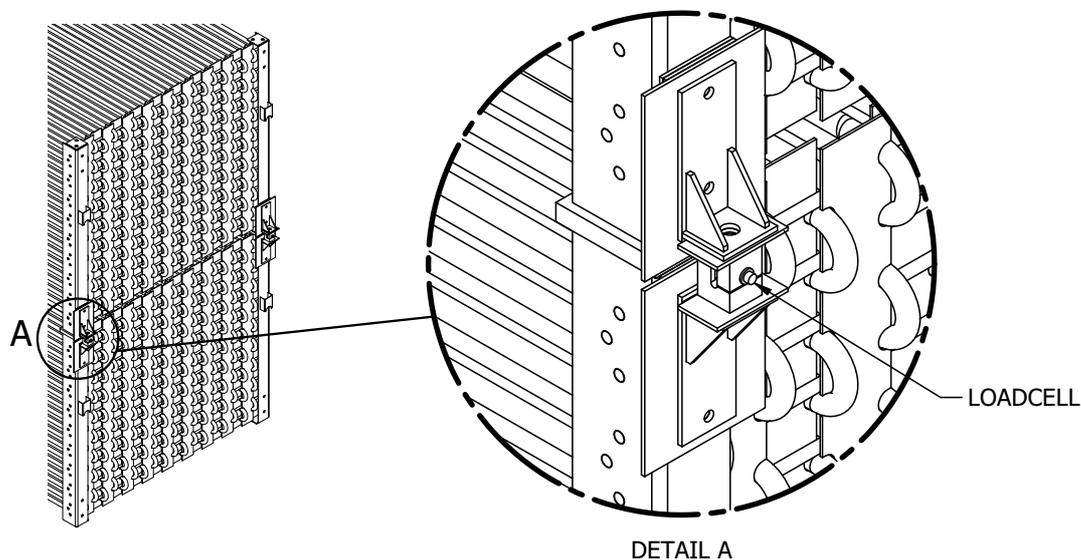
Figure 10C: Automatic Zone Control Valves



D. Ice inventory sensor (external melt systems)

The ice water is circulated through the storage container during the ice melt modes. Therefore, the water level in the container will not remain constant and should not be used to estimate the amount of ice in inventory. Instead, a load cell is used to measure the ice buoyancy. The load cell is mounted between the top two ice storage coils. Generally, brackets are installed on one end of these coils and the load cell is installed between these brackets. The load cell measures the small strain changes between these coils resulting from the ice build-up buoyancy effect. This strain factor is converted to a 4-20 ma signal that can be used by the ATC system as a part of an operating strategy or it can simply be displayed as the amount of inventory remaining in the container (ton-hours, kW-hours or a percentage).

Figure10D: Load Cell (External Melt)



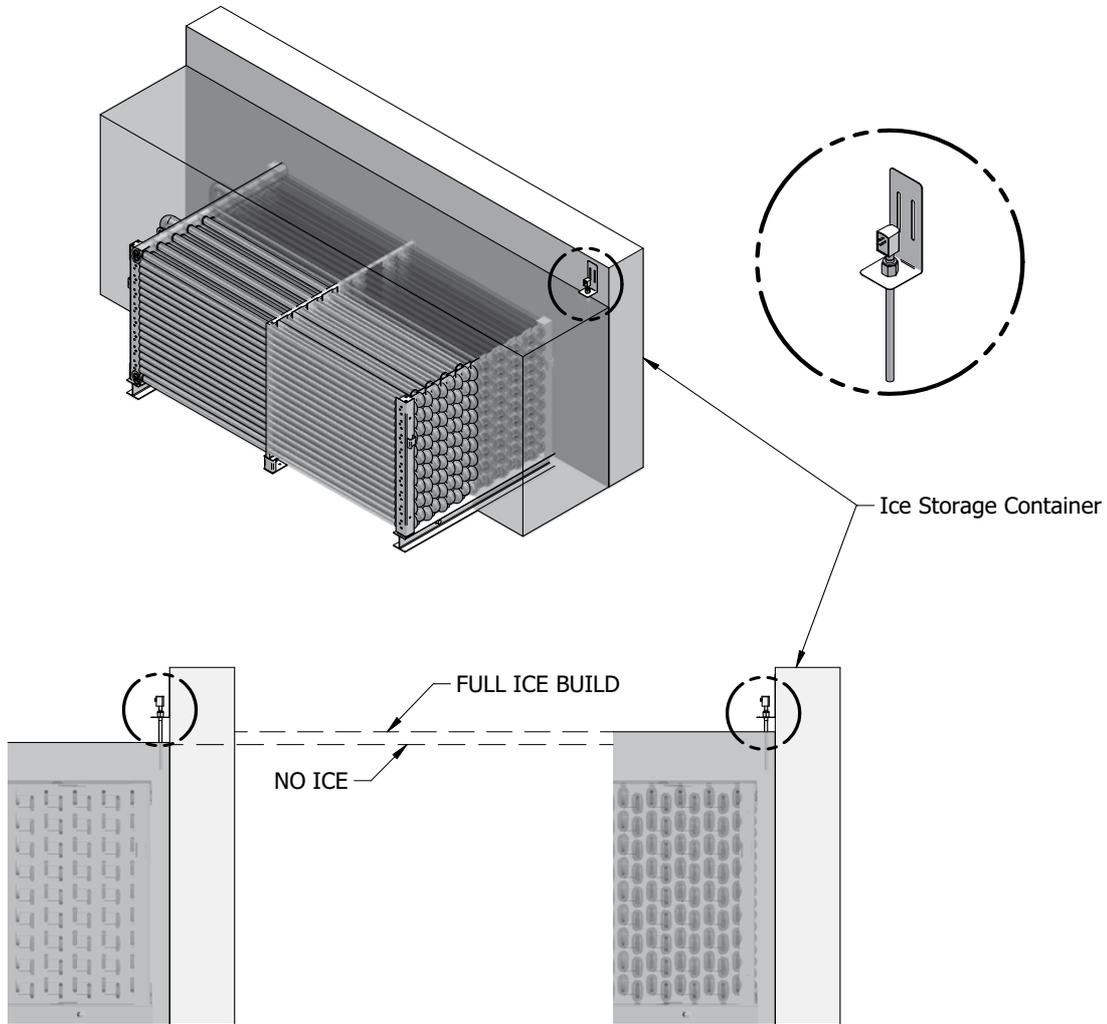
E. Ice inventory sensor (internal melt systems)

The ice water for internal melt systems is not circulated through the container and therefore, the ice water level is not effected. As ice is either formed or melted, the water level will change. With the plan area dimensions of the container known and the full storage amount of ice established, the water level rise from no ice to full ice can be calculated.

The ice inventory sensor measures the water rise resulting from this changing level. This is converted to a 4-20 ma signal that can be used by the ATC system as a part of an operating strategy, or it can simply be displayed as the amount of inventory remaining in the container (ton-hours, kW-hours, or a percentage).

The ice build mode will be terminated when the full build level is reached and should not begin again until scheduled by the ATC system. The ATC system can also use this signal for a safety alarm.. A low water alarm can alert the operator, should the signal indicate that the water level is below the no-ice setting.

Figure 10E: Ice Inventory Sensor (Internal Melt System)



11. Commissioning

After the testing and balancing of the entire HVAC system is completed, the commissioning process can begin. Commissioning is the process by which operation and performance of every system component and control is verified and documented. Commissioning an ice storage system is very similar to commissioning a conventional chilled water system. The major components (chillers, pumps, cooling towers and controls) are all basically the same. Ice storage systems have a few additional operating controls and almost always adhere to a time-of-day schedule.

External melt thermal ice storage systems always use air pumps to agitate the ice water in the container to assure that there is no temperature stratification. Uniform air agitation throughout the container should be observed. The ice water flow through the container, should also be verified. The ice water flow, especially along the sides



and corners of the container should be observed. The glycol piping divides the ice coils into zones. Each zone will have an automatic valve controlled by an ice thickness sensor. The sensor closes the valve when the desired amount of ice is formed around the coil. The data verifying the status from each zone is sent to the ATC system. Also within each zone, an ice inventory load cell may be used to transmit ice inventory data to the ATC system. The operation and calibration of these devices shall be verified during commissioning.

Internal melt thermal ice storage systems generally do not require the air agitation pump. However, if air agitation is used, the commissioning of the system will be the same as described for external melt. Internal melt systems also do not use zone valves in the ice build mode or load cells to estimate the ice inventory. Instead, they use a water level measuring device that monitors the ice water level in the container to determine the amount of ice in inventory. This data is sent to the ATC system. The operation and calibration of these devices shall be verified during commissioning.

For either type of thermal ice storage system, commissioning aids should be installed that will enable the operator to both manually and electronically verify the status of every component (on/off, open/closed, etc). Verifying fluid temperature and pressure at the inlet and outlet of each component is essential. These components include: chillers, pumps (glycol, chilled water and ice water), ice storage container, ice build zone valves, modulating control valves, primary and secondary loops, and heat exchangers.

Time of day operation of these components is critical for ice storage systems to avoid high demand costs. Depending on the time of day, different modes require different operation. The chiller leaving fluid set points may change. Chillers may be cycled off or demand limited. Pumps may be cycled on or off and control valve functions may be altered. Like conventional chilled water systems, there may be seasonal changes initiated by a monthly date or ambient temperature. The ice storage control system may be interconnected to other large electric energy using equipment to provide energy management beyond just the HVAC components. The time operation for every component should be verified for each operating mode and each season of the year.

Using traditional commissioning procedures, all installed equipment must be verified to confirm specification compliance and capacity. The operation of each component in each operating mode must be verified to perform at the temperature and capacity specified. ATC response for each component and time period must be confirmed.

Ice storage systems operate 24 hours a day and there may not be an operator on duty at all times, therefore, component commissioning is essential to assure reliable ATC operation.

12. Water Quality and Types of Glycol

A. Water Quality

Because water quality varies throughout the world, the quality of the water in an ice storage system is very important. After the initial ice build mode, the temperatures of the water in the storage container will remain near the freezing point. At these temperatures there are no biological elements and little or no scale formation. Also, there is very little loss of water due to evaporation, so make-up water is at a minimum.

Established water treatment programs are often used to adjust and maintain the water quality within a desired limit. Good water quality limits to strive for are:

- 6.5 to 8.5 pH level and mineral levels at or below: 100 ppm chlorides, 250 ppm sulfates, 500 ppm alkalinity and 1000 ppm dissolved solids.

Care must be taken when selecting the water treatment additives to avoid changing the freezing properties of the water.

Automatic water treatment programs should not be used. Once the initial water charge is treated and is within the recommended limits, the quality of the water should be monitored only periodically (once or twice a year). Depending on the type of thermal ice storage system and flow design, annual monitoring is usually sufficient. However, more frequent monitoring may be required due to water quality or project circumstances. A chemical analysis of the water will determine if additional treatment is necessary.

B. Types of Glycol

The glycol solution should consist of either ethylene or propylene glycol mixed with good quality water for freeze protection. Both types of glycol are available as industrial grade products with corrosion inhibitors for the materials found in HVAC systems (copper, brass & steel). The glycol should have a useful life expectancy of 20 years or more, while the inhibitors should last approximately 7 to 10 years.

Dow Chemical Company products DOWTHERM SR-1 (ethylene glycol) and DOWFROST HD (propylene glycol) are both acceptable for steel ice storage coils. Other manufactures that meet the requirements described above may also be acceptable and should be submitted to the ice coil manufacturer for approval.

The glycol solution can be purchased as a pre-mixed solution of the desired concentration or as a 97% concentration with inhibitors for mixing at the site. Pre-mixed solutions generally consist of glycol, inhibitors and deionized water. When field mixing is necessary, deionized water is always acceptable but not always available. Good quality potable water, similar to the ice water described above, can be used to mix with the glycol.

13. Maintenance

The ice coils have no moving parts and require no maintenance. Visual observation is generally all that is required for these coils.

The ice water in the container should be approximately 1" (2.5 cm) above the top coil when there is no ice. As mentioned in Chapter 12 - Water Quality & Types of Glycol, the quality of the water in the container is important, so a water sample should be analyzed by a laboratory annually.

The glycol solution should have a long useful life expectancy, however, a glycol sample should be analyzed annually to assure that the concentration, fluid properties and inhibitors are unchanged.

A stand alone glycol make-up unit should be connected to the glycol loop. All make-up solution should be furnished from a pre-mixed container of the desired system concentration level. The make-up unit will have self



contained controls and should be inspected periodically.

The air agitation pump required for external melt systems will require routine maintenance such as: checking oil level, relief valve operation, air filter cleaning, and belt tension and wear.

For external melt systems, the operation of the ice thickness sensors and automatic zone valves are monitored by the ATC system. The ice inventory load cells are also monitored by the ATC system. Visual inspections of these control devices are recommended, as necessary.

For internal melt systems, the ice inventory sensor is monitored by the ATC system. This sensor should be inspected several times during the season. Ice storage containers may accumulate humidity condensation that might increase the water level slightly over time. The controls should be recalibrated periodically to assure the zero ice level point is correct.

The major system components, chillers, cooling towers, pumps, control valves, etc, have the same maintenance requirements whether they are connected to a conventional system or ice storage system. The manufacturer's published maintenance guidelines for each component should be followed.

Finally, operating logs are recommended to be used regularly. The logs should monitor the whole system and will show the operator how well the thermal ice storage system is operating. Over time, the logs will show any system or component operating trends, alerting the operator to whenever preventative maintenance is required. The ice storage control accessories should be included as Operating Log entries. Finally, operating logs should include outside ambient temperature as well as the date and time the log was entered.



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