ICE THERMAL STORAGE APPLICATIONS IN CHINA
CASE STUDY

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Abstract

While ice storage has long been recognized as an effective technology to shift electric demand to off-peak periods to take advantage of low-cost off-peak electric rates, properly designed ice thermal storage system can also result in lower first cost, lower operating cost, and more energy efficient compared to non-storage system. This paper examines several recently installed ice thermal storage projects in China, and demonstrates that an ice thermal storage system, when fully integrated with the total building design, will reduce first cost, operating cost, and energy consumption.

Introduction

While China has one of the largest electric power generating capacities in the world, its rapid economic growth has far exceeded the pace of electricity production. Electricity shortages are prevalent throughout China, especially during the peak summer months when electric demand for air-conditioning is the highest. To help alleviate the problem, local electric power bureaus in many parts of China have implemented attractive economic incentives to encourage the application of Ice Thermal Storage technology to shift commercial air conditioning systems peak electric demand to off-peak hours.

Although originally developed to shift electric demand to off-peak periods (from an electric utility's perspective) and to take advantage of low-cost off-peak electric rates (from an end-user's perspective), ice thermal storage applications can also result in lower first costs and higher system efficiency compared with non-storage systems. This paper examines the State Power Management Building in Beijing, along with several other ice thermal storage project in China, and demonstrates that an ice thermal storage system, when fully integrated with the total building design, can reduce first cost, operating cost, and energy consumption. Other benefits of ice thermal storage and cold air distribution include better indoor air quality and greater comfort for building occupants.

Design Engineers:
H.C. Yu and Associates Consulting Engineers.
China Eastern Design Institute.

Air conditioned area:
75,000 square meters

Peak Air Conditioning load:
2200 Tons

Ice Thermal Storage equipment: (8) BAC TSU-890MS, 7120 ton-hours

State Power Management Building

Located at West Chang An Avenue and Xi Dan street in Central Beijing, the $180 million State Power Management Building is the headquarters office for the State Power Company, the nation's largest corporation. By utilizing Ice Thermal Storage technology, the building owner and occupants realize significant benefits including lower first cost, lower energy cost, better energy efficiency, and better indoor air quality and comfort.

Lower First Cost

H.C. Yu and Associates Consulting Engineers (Richmond, VA) conducted a detailed study comparing the first cost of an Ice Thermal Storage System with that of a conventional HVAC system. The results (Table I) show that Ice Thermal Storage System with Cold Air Distribution is lower in first cost compared with that of a conventional HVAC system.

Table 1. First Cost Comparison

Cost Item	Conventional	Ice Storage System
Chillers	939,000	605,655
Cooling Towers	159,000	102,555
Ice Storage		612,500
Glycol/HGR		140,000
Pumps	104,240	80,000
Piping & Insulation	488,750	379,190
Air-handling Units	1,254,500	977,957
Ductwork & Insulation	1,612,500	1,206,855
VAV and Diffusers	328,060	337,500
Controls	275,000	362,500
Misc	455,799	433,001
Total	5,616,849	5,237,713

By utilizing ice thermal storage technology, significant cost savings can be achieved through reduced pumping, piping, and air distribution system.

As shown in Figure 2, the Ice Thermal Storage System employs (8) BAC TSU-890MS Ice Thermal Storage Units to produce 2^{o}C ethylene glycol solution. The low discharge temperature available from the ice storage system allows increased water and air temperature ranges (delta T). The large delta T equates to reduced glycol/chilled water flow rates and air volume resulting in reduced equipment costs including pumps, piping, air handling units (AHU), and ductwork.

The larger water temperature range allows proportional reduction in the primary and secondary chilled water flow rates and reduction in pump and piping sizes. Conventional air-conditioning systems typically are designed with a 5^{o}C delta T (7-12^{o}C). With 2^{o}C discharge temperature available from the ice storage system, delta T can be increased to 9^{o}C (3-12^{o}C). As shown in equation (1), the flow rate of the ice storage system is 55% that of the flow rate of the conventional system. This represents significantly reduced pump and piping costs.

$$\text{\% Flow Rate} = \text{Delta T Conventional/Delta T Ice Storage} \quad (1)$$
$$= (12^{O}C-7^{o}C)/(12^{o}C-3^{o}C) = 5/9 = 0.55$$

Similar to water flow, lower water temperature allows supply air to be generated at 7^{o}C, compared to the typical conventional 13^{o}C supply air. With colder supply air, air volume can be reduced, and fans, ducts can be downsized, resulting in substantial reductions in air distribution system costs. As shown in equation (2), the colder supply air reduced the system air volume by 33% and reduced the number of air handling units from 40 to 22 units.

$$\text{\% Air Volume} = \text{Delta T Air Conventional/Delta T Cold Air} \quad (2)$$
$$= (25^{o}C-13^{o}C)/(25^{o}C-7^{o}C)=12/18=0.67$$

The following summarizes the savings associated with cold air distribution technology.

Original Supply Air (13 C)	643,900 CFM
Super-cool Air (7 C)	431,600 CFM
Reduced Air	212,300 CFM
% Reduction of Supply Air	33%

In addition to equipment cost savings, costly connection charges can also be reduced. The current Beijing electrical connection charge is USD$145 per KW. Since ice thermal storage reduced the peak electric power by 700 KW, the owner saved approximately $101,500 in first cost as shown in equation 3.

Electric connection charge savings = $145/KW x 700 KW = $101,500 (3)

Lower Energy Cost

While chillers operating at ice-build mode consume more energy than in water-chilling mode, this increased energy consumption is more than offset by reduction in pumping and fan power associated with ice thermal storage system. If properly designed, ice thermal storage system can reduce annual energy consumption when compared with conventional system design.

Figure 1. State Power Building Energy Cost Comparison

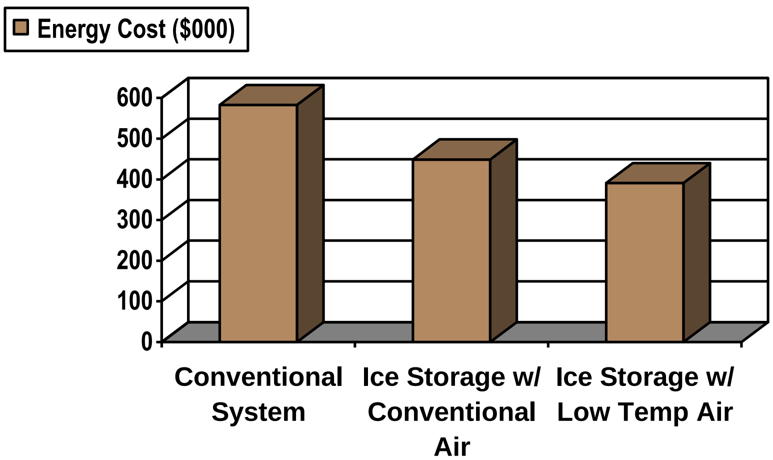


Figure 1 shows operating cost comparisons of a conventional HVAC system, an ice thermal storage system with conventional air distribution (13^{o}C), and an Ice Storage System with Cold Air (7^{o}C) distribution (Yu 1999). The results show that the operating cost of an ice thermal storage system with cold air distribution system is the lowest cost system. The operating cost savings mainly come from the following:

Electric rate differential. Since 1995, Beijing has established electric rate differentials to encourage the use of ice thermal storage technology. In Beijing, the difference in on-peak and off-peak electrical rate is approximately 3.5 to 1, The current Beijing utility rate structure is as follows:

Peak – $0.115/Kwh, 8–11 a.m., 6-11 p.m.
Mid Peak - $0.073/Kwh, 7-8 a.m., 11–5 p.m
Off Peak - $0.033/Kwh, 11-7 a.m.

Lower pumping energy

In addition to operating cost savings derived from operating chillers at night when the electricity cost is the lowest, significant energy savings can be achieved from reducing pumping energy. For this project, the larger fluid temperature range associated with the ice thermal storage system equates to a 45% reduction in flow rate which represents a 45% reduction in pump energy consumption.

Lower fan power consumption

As shown in equation (2), the percentage decrease in the volume of air from the 7°C system compared to the 13°C system is proportional to the ratio of the temperature difference between the supply air and the room air for the two systems. For this project, the colder supply air equates to a 33% air volume reduction. Since the relationship of air volume to fan power is the power of 3, fan energy consumption can be reduced by as much as 70%.

Improved Comfort

In addition, the lower humidity resulting from lower supply air temperatures results in improved air quality and freshness, as well as increased comfort.

The condensation on air handling unit coil fins is much greater than standard conditions. With the coils wetted a greater percentage of time, impurities in the air such as dust or dirt are removed by the high quantity of condensate removed at the coil, providing superior indoor air quality (Dorgan 1995).

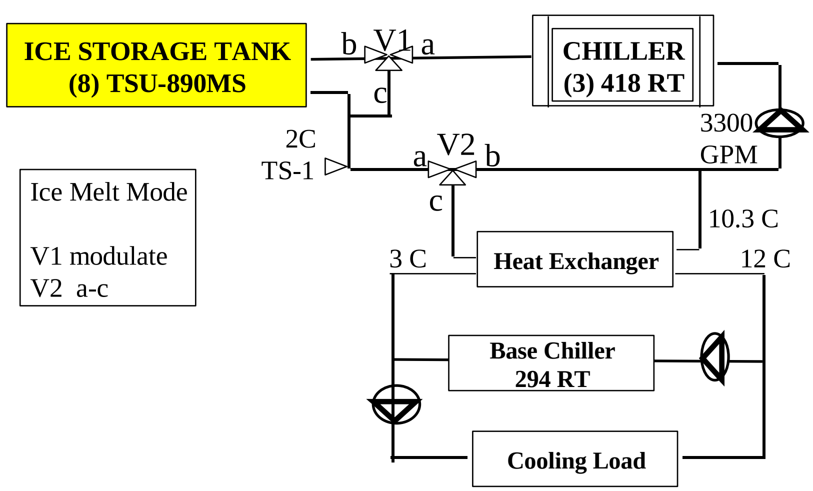
The natural result of lowering the supply air temperature is further dehumidification of the air stream. Typically in a cold air system with 7°C supply air, the space relative humidity will be approximately 10% lower than in a similar 13°C system (Dorgan 1995). Studies have shown (Berglung 1994) that if the space humidity is lowered while the space dry bulb temperature is held constant, occupants feel more comfortable. The owner and occupants of the State Power Management Building have observed this to be true. A more comfortable working environment can also means increased employee productivity.

Ice Thermal Storage System Description

As shown in Figure 2, The ice thermal storage system consists of (8) BAC TSU-890MS Ice Thermal Storage Units, three (3) 418 ton screw chillers, glycol pumps, two sets of motorized valves, and a heat exchanger.

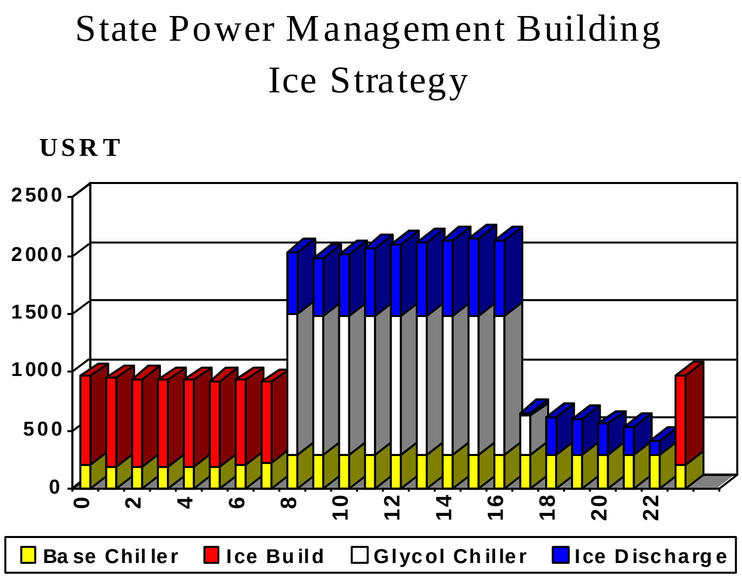
Ice is built during off-peak hours from 23:00 to 8:00 am. When making ice, both sets of motorized valves are open a-b permitting glycol

Figure 2. State Power Management Building System Diagram



flow only in the primary glycol loop and not through the heat exchanger. Screw chillers are used to produce cold glycol solution at approximately -5.5 C which is circulated through the coil building ice on the outside surface of the coil. Approximately 7120 ton-hours of ice is generated during this period.

The 3°C chilled water is circulated to 22 Air Handling Units throughout the building. The Air Handling Units supply 7°C cold air to VAV terminal control boxes with direct supply of primary air to zones.



Ceiling mounted cold air diffusers are used to supply 7°C air into room space. The diffusers supply air through small openings to produce horizontal air jets that significantly increase induction and mixing compared to typical ceiling diffusers. To prevent condensation from forming on the diffusers under all possible operating conditions, all parts of the diffuser are constructed of a self-insulating material. Glycol and chilled water piping are insulated with Armflex material. Ductwork is insulated with 1.57 inches of fiberglass insulation material. To this date, building owner and occupants have not observed evidence of condensation on the air distribution system.

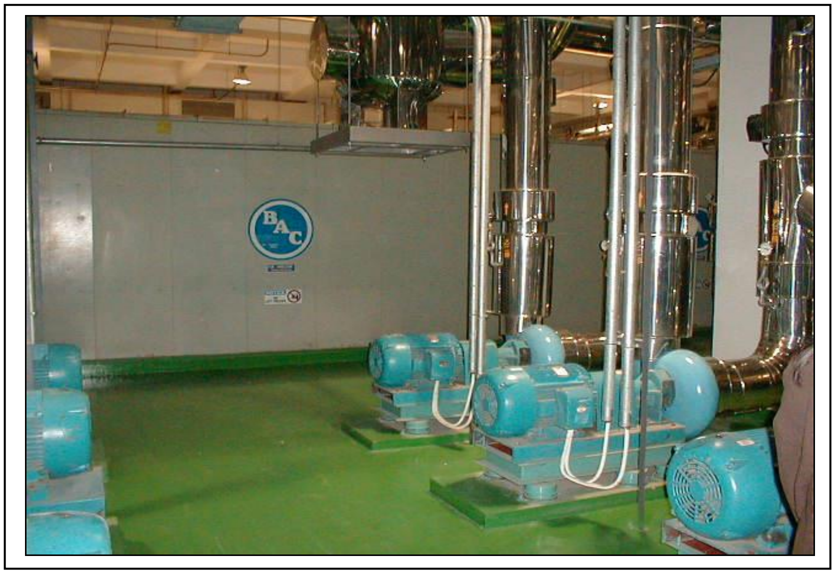
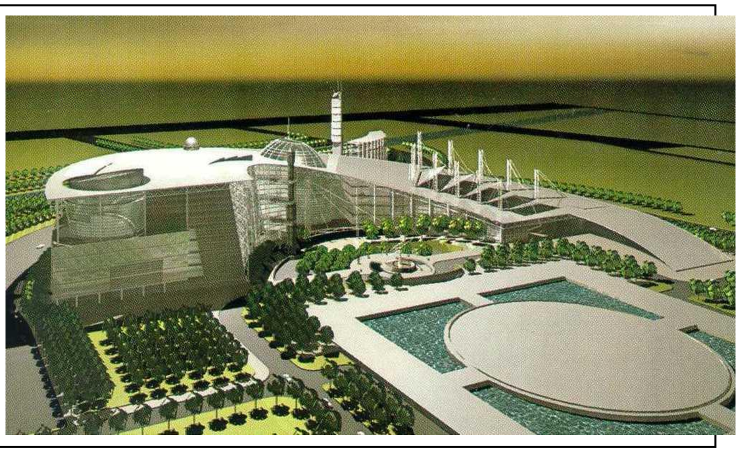


Figure 4. Ice Thermal Storage units installed in the basement

Other Ice Thermal Storage/Cold Air Distribution Projects in China

Ice Thermal Storage and Cold Air Distribution technology has been successfully applied on several projects in China. The following are a few examples.

Shanghai Science and Technology Museum



Design Engineer: Shanghai Institute of Architectural Design and Research

Equipment:
(10) BAC TSU-924MS Ice Thermal Storage Tanks
(4) BAC 33620 & 15250 Cooling Towers

As part of their state-of-the-art approach, Shanghai Science and Technology Museum incorporated BAC Ice Thermal Storage system in the building design to demonstrate the benefits of ice thermal storage technology. Utilizing low temperature fluid available from BAC Ice Storage equipment, the Museum incorporated Cold Air Distribution technology to reduce equipment cost and energy cost while improving occupant comfort. The Shanghai Science and Technology Museum celebrated its grand opening as the meeting site for the Asia-Pacific Economic Cooperation (APEC) Summit in October 2001. Expected to be one of the major tourist attractions of the world, the futuristic Shanghai Science and Technology Museum will serve as an educational institute to promote further advances in science and technology.

Shanghai Children's Hospital

Design Engineers:
H.C. Yu and Associates.
Shanghai Institute of Architectural Design and Research.

The Shanghai Children’s Medical Center is a collaboration between Project Hope and the government of China to develop the country’s first major pediatric referral and teaching hospital. The 40,000 square meter Shanghai Children’s Medical Center serves as a national training center for health professionals and provide state-of -the art clinical care for children with the most serious health problems. Opened at the end of 1998, the hospital cares for more than 250,000 children per year.

The ice thermal storage system consists of (15) BAC TSU-293 ice thermal storage coils with finned coil heat exchangers (installed in 3 separate concrete tanks in the basement), three 400 ton screw chillers (plus one standby), glycol pumps, two sets of motorized valves, and a glycol to water heat exchanger. 2^oC chilled water, produced from ice storage tanks, is circulated to air handling units to generate 7^oC cold air, which is delivered to VAV mixing terminal boxes.

Hangzhou Construction Bank

Engineer: Hangzhou Huayuan Artificial Environment Engineering Co. Ltd.

The Hangzhou Construction Bank building complex includes a banking area, office space, conference rooms and restaurants. The total occupied area is approximately 31,000 square meters with a peak cooling load of 989 RT.

The ice thermal storage system stores 2970 Ton-hours of ice in 5 sets of TSU-594MS.

Ice is built on coils in seven off-peak hours by two screw chillers. During the on-peak period from 8:00 am to 6:00 pm, 4^oC glycol discharge from the ice tank is directly supplied to 2 sets of air handling units to produce 7^oC low temperature air for supply to VAV mixing terminal boxes.

Northwest Electric Power Management Communications Building

Engineer: Northwest Explore Design Institute of National Electric Bureau

Located in Xian, the North-west Electric Power Management Communication Building is an office building with a total air conditioned area of 30,000 square meters and peak cooling load of 864 Tons. 3564 Ton-hours of ice is stored in 6 sets of TSU-594MS during 8 hours ice build time. The discharge temperature from ice thermal storage tank is 3^oC.

Conclusion

Ice thermal storage inherently produces very cold chilled water that can be beneficially used to reduce initial system and energy costs and to improve the air quality in the building. When properly designed and managed, the first cost, energy cost and operating costs are lower with a ice thermal storage/cold air system than with a $13^{o}C$ conventional system. Additionally, cold air systems can reduce the electrical demand and total energy use related to air-conditioning operations. This is a major benefit to utilities and building owners and is a design concern of energy professionals - a true benefit to our future energy needs. Since ice storage systems provide both first and operating cost benefits, ice thermal storage /cold air systems should be evaluated for all new and retrofit construction projects.

Besides the economic benefits for owners, there are other reasons to use ice thermal storage. With increased nighttime usage of electricity, power plants will be running more close to full load (most efficient). Furthermore, power generation and electricity transmission is more efficient at lower nighttime ambient temperatures. With more efficient power generation, we gain the benefits of lower emission of CO_2 and other greenhouse gases. Thus, ice thermal storage is friendly to the environment.

References

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