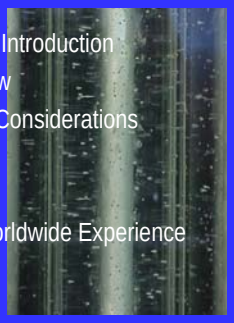
Baltimore Aircoil Company

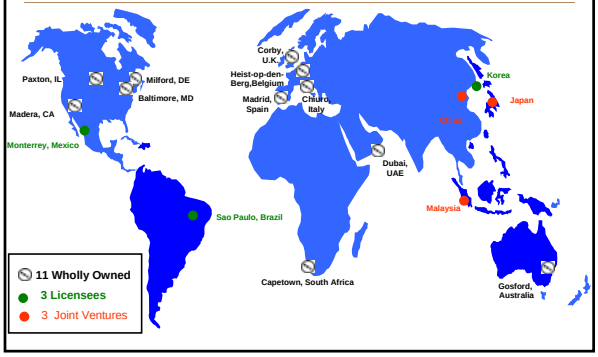
Ice Thermal Storage Applications

Ice Thermal Storage Seminar

- BAC Company and Products Introduction
- Ice Thermal Storage Overview
- Ice Thermal Storage Design Considerations
- Cold Air Distribution
- Case Study
- BAC Ice Thermal Storage Worldwide Experience



Global Facilities and Partners

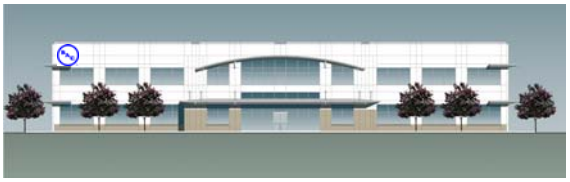


Commitment to Research and Development

25,000 Ft² R&D Labs

Thermal Test Capability

Baltimore Aircoil Company New World Headquarters



Completion by December 2004

Baltimore Aircoil Company

Cooling Towers, Fluid Coolers, & Condensers

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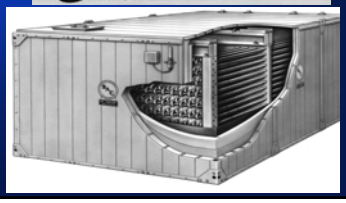
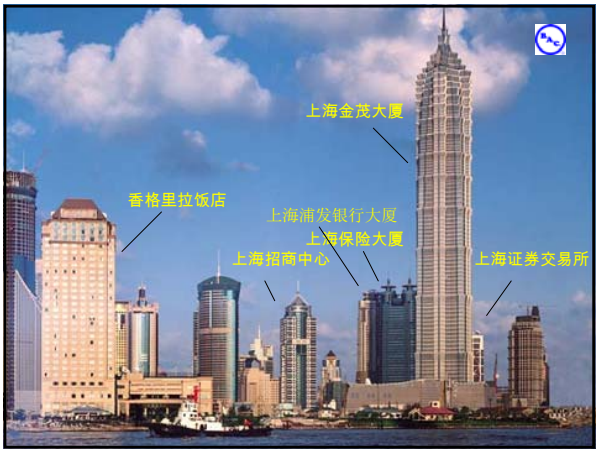
Baltimore Aircoil Company

Ice Coils, Units, and Heat Exchangers



大型建筑用空调设备



Key Semiconductor Customers

TSMC - Taiwan Semiconductor Manufacturing Co.
UMC - United Microelectronics Corp.
Acer Inc
Ritek Display
AU Optronics
Micronix International Inc.
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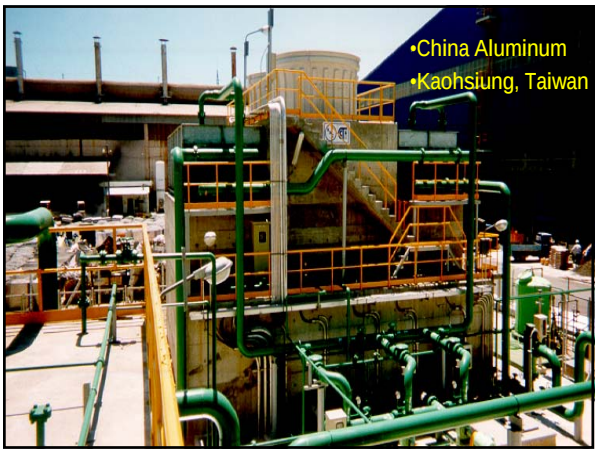
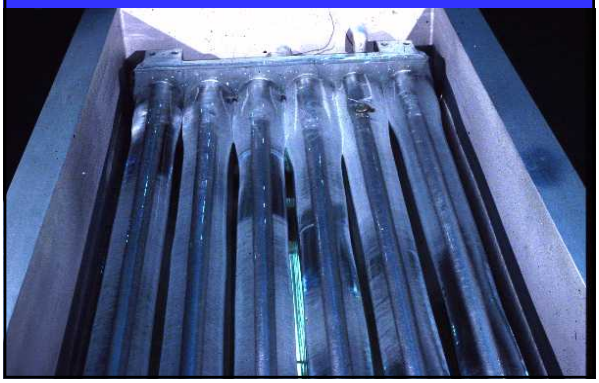


Ice Thermal Storage

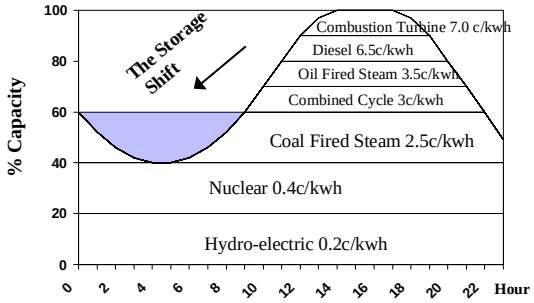


Ice Thermal Storage...

- **Benefits for the Government**
  - Shifts electric demand to off-peak hours
  - Reduces need for new power plants
- **Benefits for Building Owners**
  - Reduces first cost
  - Reduces operating cost
  - Can be designed to supply cooling during power shut down

Electric Generation

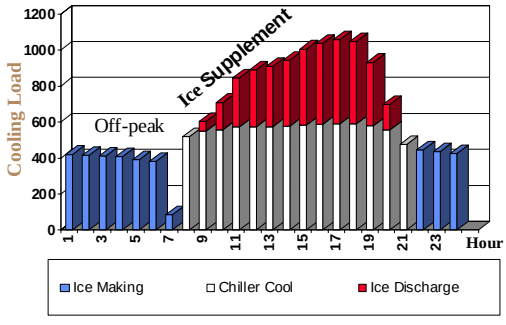
USRT



Ice Storage...

- Reduces Peak Chiller Demand
- Reduces Operating Cost

USRT



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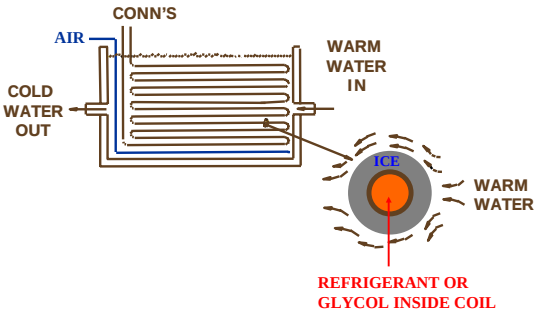
BAC Ice Storage Systems Available

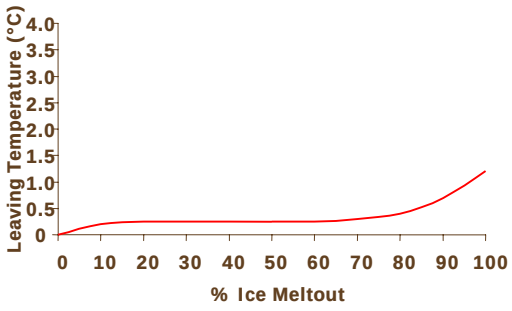
BAC Ice Storage System Offering
EXTERNAL MELT SYSTEM

SYSTEM CIRCULATING WATER IS IN DIRECT CONTACT WITH THE ICE

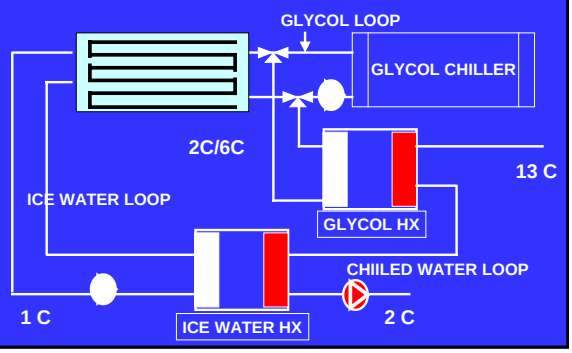
BAC Ice Storage System Offering
EXTERNAL MELT SYSTEM



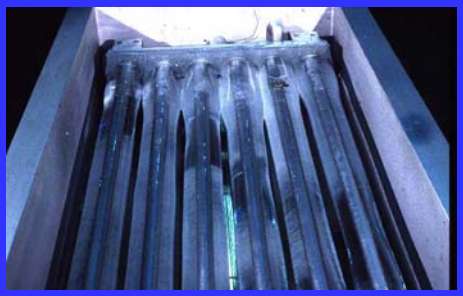
BAC Ice Storage System Offering
EXTERNAL MELT SYSTEM PERFORMANCE



External Melt - Dual Set Point Chiller



ICE STORAGE SYSTEM
- DIRECT CONTACT Ice On Coil



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ICE STORAGE SYSTEM
- DIRECT CONTACTIce On Coil

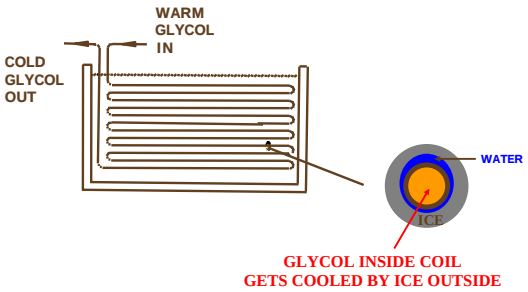
BAC Ice Storage System Offering
EXTERNAL MELT SYSTEM

- Advantages
  - Lowest chilled water supply temperatures
  - Quickest discharge capability
  - Eliminates glycol from chilled water loop
- Disadvantages
  - Chiller with lower temperature capability generally required
  - Control sequences are usually more complicated; glycol control valves required on larger systems
  - Hydraulic issues with non-pressurized tank
  - More difficult to monitor amount of ice in inventory; requires more frequent monitoring

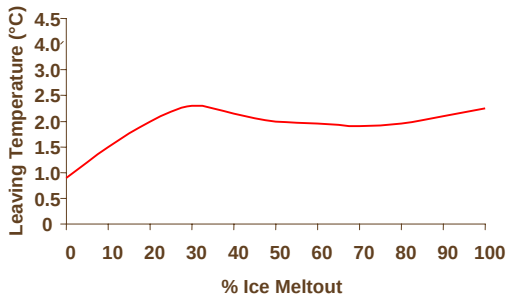
BAC Ice Storage System Offering
INTERNAL MELT SYSTEM

The warm return glycol circulating through the coil is cooled indirectly by the ice on the coil

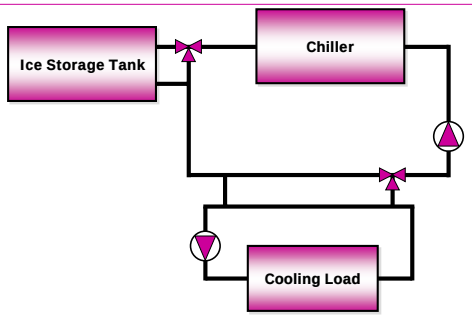
BAC Ice Storage System Offering
INTERNAL MELT SYSTEM



Ice Thermal Storage Design
BAC Internal Melt Performance

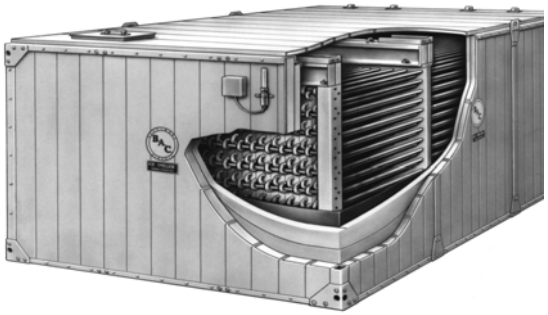


Typical Ice Storage Piping Schematic – Internal Melt



ICE STORAGE SYSTEM
- INDIRECT CONTACT Ice On Coil (BAC)

BAC Modular Ice Chiller



BAC Ice Storage System Offering
INTERNAL MELT SYSTEM

Advantages
- Closed loop
- Easy to design
- Simple to control
- Easy to maintain

Disadvantages
- Higher leaving temperatures than external melt
- Can not handle quick melt outs
- Requires glycol in the chilled water system or a heat exchanger

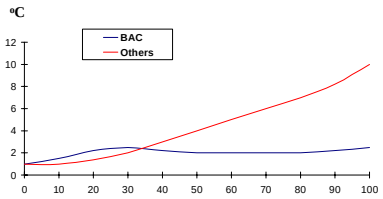
BAC Ice Storage System Offering

- Most air conditioning applications use internal melt
- Most process and district cooling systems use external melt

System Sizing Guideline

The key to a successful thermal storage design is the use of low temperature fluids and
Larger Temperature Ranges
to minimize the size of the system components!

Lower Discharge Temperature Enables ...



- 100% Utilization of Ice Storage Capacity
- Chillers to be Placed Upstream Operating at Higher Temperatures
- Reduced, Pumping, Piping, HGR, AHU, Ductwork, VAV
- Savings in Pump and Fan Power Consumption

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First and Operating Costs - Driving Force

Larger Temperature Range Reduces First Cost ...

First Cost Comparison - 4000 Ton Convention Center

Cost Item	Non-storage,$	Ice Storage, $
Chillers	1,048,800	540,000
Cooling towers	139,500	70,000
Glycol	-	50,000
Ice Storage	-	900,000
Pumps	170,200	114,000
Piping	1,577,200	1,367,700
Air-handling units	1,036,500	782,000
Ductwork	5,209,200	4,682,900
Electrical	-	80,000
Cold air diffusers	-	24,000
Controls	-	20,000
Utility incentive		-317,550
Total	9,181,400	8,313,050
Cost Savings		$868,350

Non storage: 4000 RT, supply air temp = 12.8 C
Storage: 2000 RT, 15,000 TH ice storage, supply air temp = 7.2 C
Source: Design Guide for Cool Thermal Storage - ASHRAE

Larger Temperature Range Reduces Energy Consumption...

- Reduce chilled water flow by 50% resulting in 50% pump energy consumption
  12C-7C/12C-2C = 5/10 = 0.5
- Reduce air volume by 33% resulting in 70% fan energy savings
  25C-13C/25C-7C=12/18=0.66

System Comparison - Kraft General Foods, Inc

Kraft Glenview

- 525,000 ft^2 Office Bldg.
- Peak Cooling Load : 1,350 Ton
- System Water Temp : 44 ºF (6.7 ºC)
- Airhandler Temp : 55 ºF (12.8 ºC)

System Comparison - Kraft General Foods, Inc

Kraft Northfield

- 500,000 ft2 Office Bldg.
- Total 11,840 Ton-Hr
- Peak Cooling Load : 1,350 Ton
- System Water Temp : 36 ºF (2.2 ºC)
- Airhandler Temp : 45 ºF (7.2 ºC)

System Comparison - Kraft General Foods, Inc

One Month Operating Cost Result

- Kraft Glenview - Conventional System
  - Operating Period : one month (30 days of service)
  - $154,430
- Kraft Northfield - BAC Ice Storage System
  - Operating Period : one month (32 days of service)
  - $80,939

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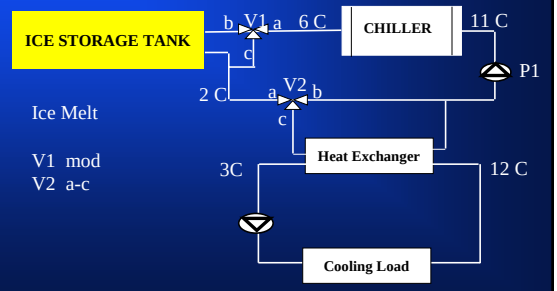
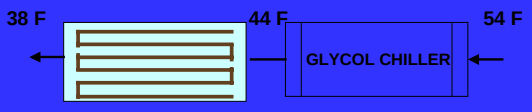
Ice Storage System Diagram

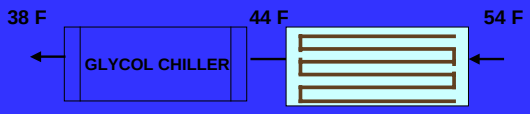


Chiller Upstream of Ice Storage



- Chiller cools 54 F glycol to 44 F - 500 Ton.

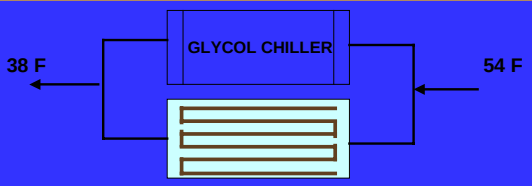
Chiller Downstream of Ice Storage



- Chiller cools 44 F glycol to 38 F

500 Ton @ 44 F = 450 Ton @ 38 F
10% reduction in chiller capacity

Chiller In Parallel with Ice Storage



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500 Ton @ 44 F = 450 Ton @ 38 F
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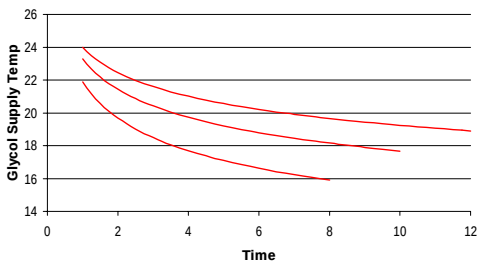
Custom Ice Coil Configurations
Glycol Temperature vs. Build Time



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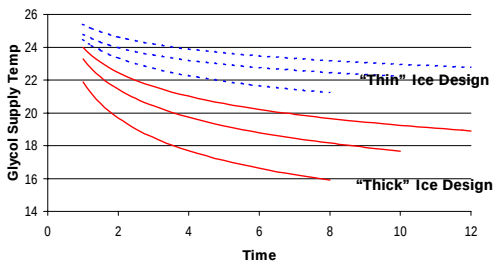

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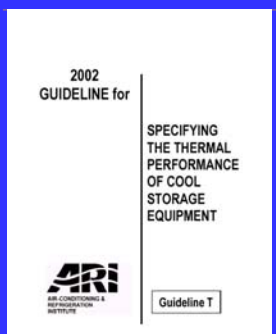
ARI Guideline T



The guide line is based on the system, not just for the thermal storage product

- Appendix C
  - User-specified data
- Appendix E
  - Supplier specified data

Designer Specified Data

Ice Thermal Storage Systems Information Required for Design

- 24-hour load profile (use ARI Guideline T)
- Build and melt times ("on peak" window)
- System design temperatures
- Site limitations
  - Maximum length, width and height for storage tanks
  - Maximum plan area for heat rejection equipment
  - Other site-specific requirements

BAC Ice Thermal Storage Selection Demo

Background Information

- Definition:
  - Cold air distribution is the art & engineering of designing & operating cooling systems with system supply air at temperatures at or below 51 °F (11 °C). Nominal cold air distribution supply air temperature is considered to be 44 °F (7 °C.)

Background Information

- Why the traditional 55 °F (13 °C)?
  - Chilled water supply limit of 44 °F (7 °C);
  - Reasonable coil ΔT design limit of 9 to 11 °F (5 to 6 °C);
  - Maintaining space RH below 60% @ 75 °F (24 °C);
  - Above conditions are economical based on first cost basis for DX packaged units.

- History:
  - Has been used since 1950s with 51 °F (11 °C.)
  - Used in VAV systems in 1970s with 48 °F (9 °C.)

Benefits of Cold Air Distribution

- Economics
- Comfort & Indoor Air Quality

Benefits of Cold Air Distribution

- Economics
  - Construction Benefits
    - Building
    - Mechanical
  - Operational Benefits

Benefits of Cold Air Distribution

- Economics
  - Construction Benefits
    - Building
      - Building Envelope (1 to 4%)
      - Structural Framework (minimum of 3%)
      - Prefabricated Walls (approximately 3%)
      - Drop Ceilings & Light Fixtures ($0.10 to $0.25/ft² = $1.10 to $2.70/m²)
      - Mechanical Equipment Rooms (above ceiling, 1 per 2 floors, reduced size)
      - Elevators & Stairs (shorter shaft height)
      - Reduced Electrical Wiring (reduced wiring & transformers)

Source: EPRI

Benefits of Cold Air Distribution:

55° F (13 °C) System

move 33% less air

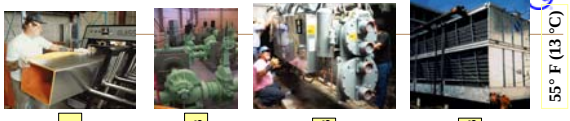
- Economics
  - Construction Benefits
    - Mechanical

move 50% less water

44° F (7 °C) System

Source: EPRI

Benefits of Cold Air Distribution:



55° F (13 °C)

36% less ductwork

50% smaller pumps

40% smaller chillers

40% smaller towers

44 °F (7 °C)

Source: EPRI

Benefits of Cold Air Distribution

- Economics
  - Construction Benefits

Mechanical
- Ductwork & Insulation (36% smaller duct area)
- Piping & Insulation (25 to 50% less)
- AHUs & Cooling Coils (20-30% smaller - 61% less air volume)
- Pumps (smaller chilled water + condenser pumps)
- Chillers & Refrigerant (50 to 60% with TES)
- Heat Rejection Equipment(50 to 60% with TES)
- Thermal Storage Tanks (indoor or outdoor, above ground or under ground for lowest costs)

Source: EPRI

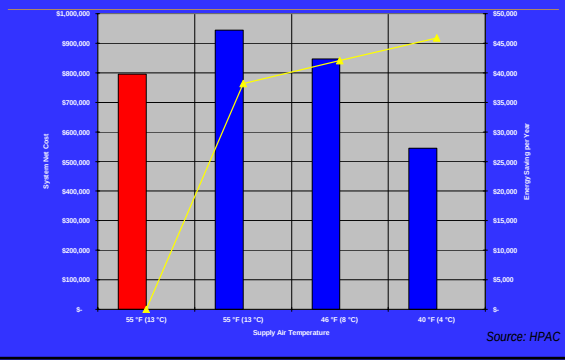
Benefits of Cold Air Distribution

Operational Benefits

- Reduced Operational Costs
  - Lower Off-peak electric rates
  - Lower system energy consumption
- Reduced Maintenance & Replacement Costs
  - Smaller motors and other components

Source: EPRI

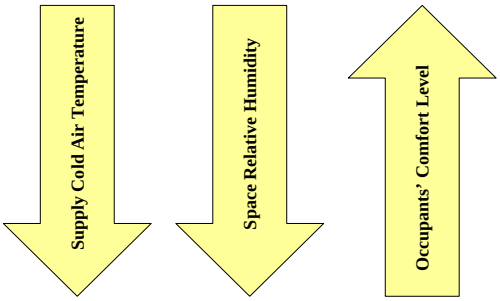
Designing Cold Air Systems



Source: HPAC

Benefits of Cold Air Distribution [3/14]

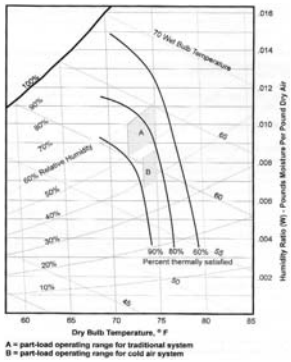
- Comfort & Indoor Air Quality: Humidity



Benefits of Cold Air Distribution [4/14]

- Comfort & Indoor Air Quality: Temperature

Satisfaction levels over the seasonal operations are higher for cold air systems

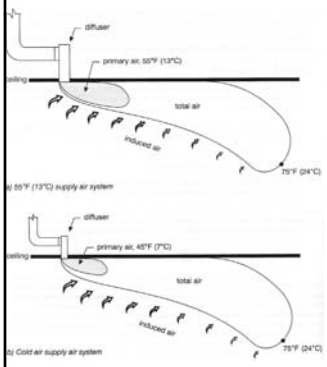


Source: ASHRAE / EPRI

Lower Relative Humidity

- A cold air system with 44 F (7C) supply air will be approximately 10% lower Relative Humidity than in a 55 F (13C) system.
  - Conventional air 55F (13C) - 50% RH
  - Cold air - 40% RH
- 10% decrease in space humidity enables the space temperature to be increased 1F (.5C)

Benefits of Cold Air Distribution [5/14]



- Comfort & Indoor Air Quality: Air Distribution

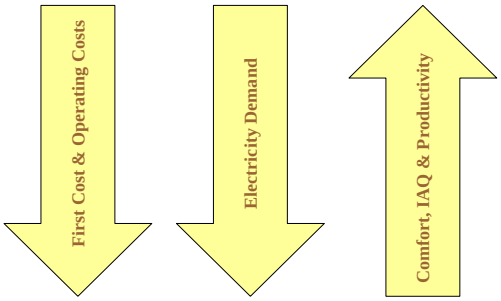
Cold air distribution has higher induction ratio

Source: ASHRAE / EPRI

Improved Indoor Air Quality

- Lower space humidity
- Better filtration
- Better air purification
- Increased Productivity

Benefits of Cold Air Distribution



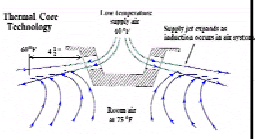
Benefits of Cold Air Distribution

Retrofit Opportunities

Low Cost alternative for Increase Capacity in Existing Building Ductwork

Low Temp Air Distribution

- Low Temperature Air Diffusers
  - Direct Induction of 7 C cold air through
  - cold air diffusers



- Fan Powered VAV boxes
  - Mix 75 F return air with 45 F supply air to achieve 55 F air distribution, same as conventional air temperature

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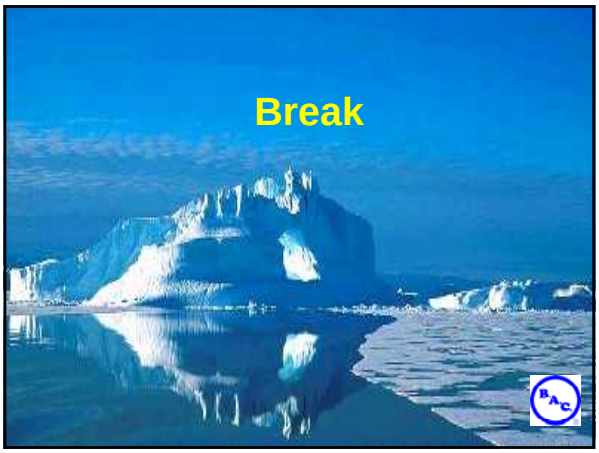
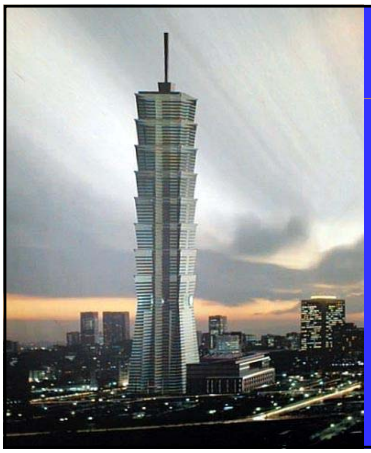


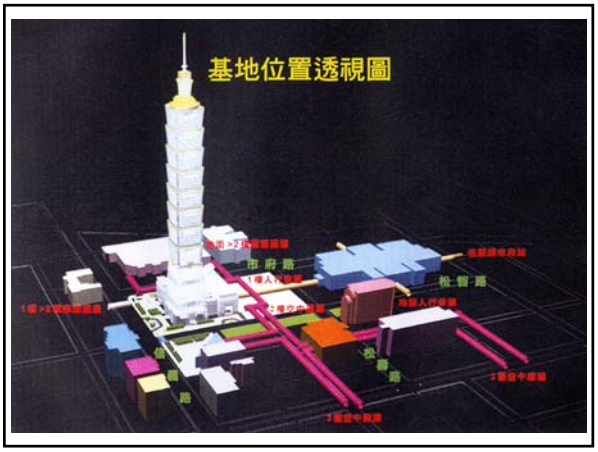


Taipei Financial Center

BAC Equipment

(51) BAC Ice Thermal Storage Tanks
- (30) TSU-L592M
  17,760 TH Podium Portion
- (21) TSU-890MSK
  18,690 TH Tower Portion

(23) BAC Cooling Towers
- (12) VT1-1335
- (1) VT1-680-P
- (3) VT0-75-K
- (7) 15201 Cooling Towers



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Ice Thermal Storage Tank Installation – Tower

Taipei Financial Center

Ice Thermal Storage Tank Installation - Podium Basement

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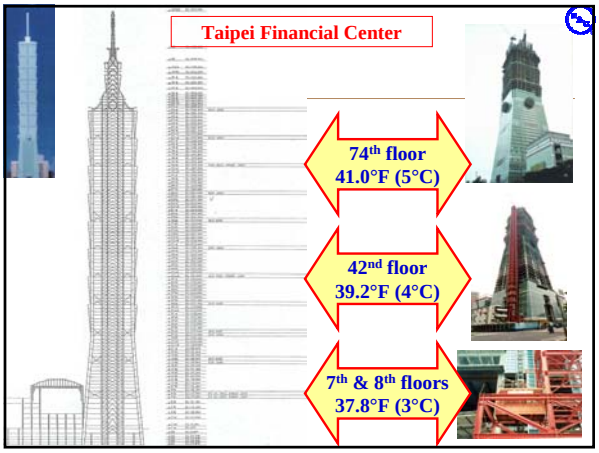
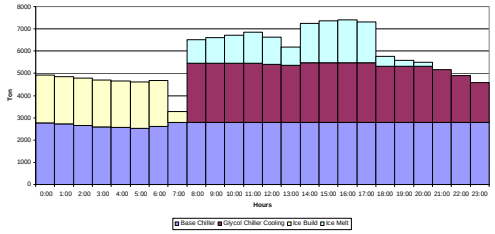
Taipei Financial Center

(12) VT1-1335 BAC Cooling Towers

Taipei Financial Center

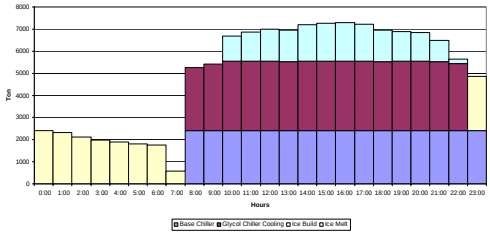


TIFB - 90, Tower Portion



Load Profile

TFC, Podium Portion



ICE CHILLER THERMAL STORAGE UNIT

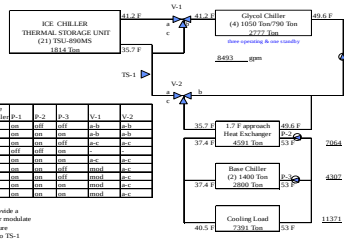
INTERNAL MELT

SYSTEM SCHEMATIC IM-3a

Single Loop with Heat Exchanger, Chiller Upstream

Base Water Chiller in Parallel

Project: TFC, Tower Portion
Customer: Kailay Engineering
BAC Rep: BAC - Taipei
Date: 03/31/2000
Mode: Melt
Time: 16:00



Control Logic

Control Logic	Glycol Chiller	Base Chiller	P-1	P-2	P-3	V-1	V-2
Build	on	off	on	off	off	a-b	a-b
Build and Base	on	on	on	on	on	a-b	a-b
Chiller Only	on	off	on	on	off	a-c	a-c
Base Only	off	on	off	off	on	a-c	a-c
2 Chillers	on	on	on	on	on	a-c	a-c
Ice Chile	off	off	on	on	off	mod	a-c
Ice and Chiller	on	off	on	on	off	mod	a-c
Ice and Base	off	on	on	on	on	mod	a-c
Ice and 2 Chiller	on	on	on	on	on	mod	a-c

Notes:
1) V2 can be positioned to provide a constant flowrate to the load or modulate in response to return temperature
2) V1 modulates in response to TS-1

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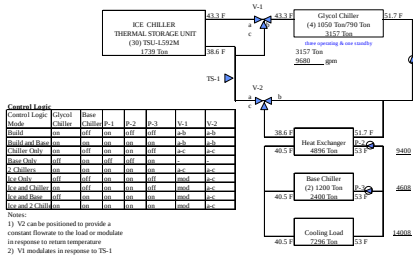
ICE CHILLER THERMAL STORAGE UNIT

INTERNAL MELT
SYSTEM SCHEMATIC IM-3a
Single Loop with Heat Exchanger, Chiller Upstream
Base Water Chiller in Parallel

Project: TFC 101, Podium
Customer: Kaller Engineering
BAC Rep: BAC - Taipei
Date: 01/11/2000
Mode: Melt
Time: 16:00



Control Logic

Control Logic Mode	Glycol Chiller	Base Chiller	P-1	P-2	P-3	V-1	V-2
Build	on	off	on	off	off	a-b	a-b
Build and Base	on	on	on	on	on	a-b	a-b
Chiller Only	on	off	on	on	off	a-c	a-c
Base Only	off	on	off	off	on	-	-
2 Chillers	on	on	on	on	on	a-c	a-c
Ice Only	off	off	on	on	off	mod	a-c
Ice and Chiller	on	off	on	on	off	mod	a-c
Ice and Base	off	on	on	on	on	mod	a-c
Ice and 2 Chill	on	on	on	on	on	mod	a-c

Notes:
1) V2 can be positioned to provide a constant flowrate to the load or modulate in response to return temperature
2) V1 modulates in response to TS-1

Case Study: State Power Management Building Beijing, China

80,000 Square Meter, Peak A.C. load ; 2400 Tons
BAC Ice Storage: (8) TSU-890MS, 7120 ton-hours

Ice Thermal Storage Technology Provided the Building Owner and Occupants Significant Benefits Including

- Lower first cost
- Lower energy cost
- Better energy efficiency
- Better indoor air quality and comfort

State Power Management Building Ice Strategy

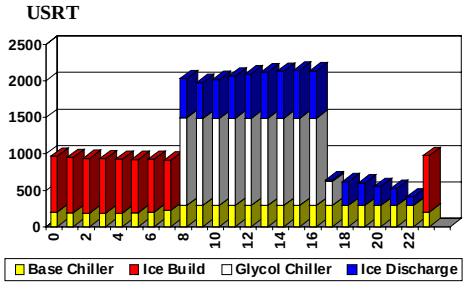
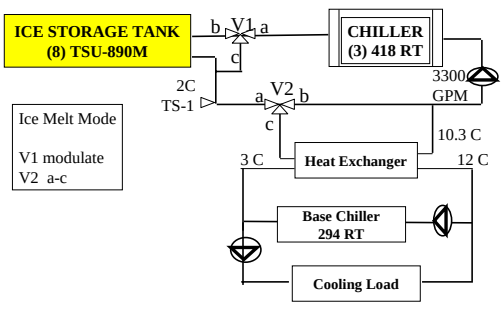


Figure 3.

State Power Management Building Ice Storage System Diagram



State Power Building Ice Thermal Storage Units

Lower First Cost

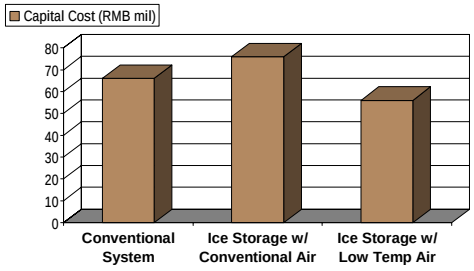
By utilizing ice thermal storage technology, significant cost savings can be achieved through reduced pumping, piping, and air distribution system.

First Cost Comparison

Cost Item (RMB yuan)	Conventional	ce Storage System
Chillers	8,665,200	6,700,000
Cooling Towers	1,080,000	820,000
Ice storage		5,030,000
Glycol		500,000
Pumps	1,000,000	1,210,000
Piping&Insulation	7,220,000	6,920,100
Heat Exchanger		770,000
Air-handling Units	11,797,333	6,320,000
Ductwork &Insulation	17,229,419	13,490,000
VAV and Diffusers	7,958,048	6,676,900
Controls	11,280,000	7,520,000
Total	66,230,000	55,957,000

Non storage: 2400 RT, supply air temp = 12.8 C
Storage: 1600 RT, 7120 TH ice storage, supply air temp = 7 C
Source: Hydin Engineering Technology Ltd./HC Yu and Associates

State Power Management Building First Cost Comparison



Lower Pumping and Piping Costs

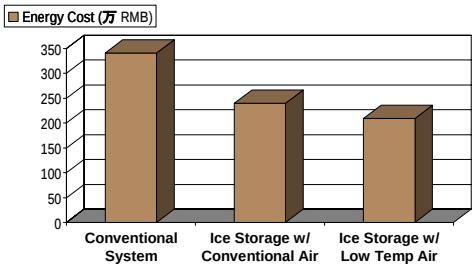
- % Flow Rate = Delta T Conventional/Delta T Ice Storage
  = (12°C-7°C)/(12°C-3°C) = 5/9 = 0.55
- The flow rate of the ice storage system is 55% that of the flow rate of the conventional system representing significantly reduced pump and piping costs.

Lower Airside Equipment Cost

- % Air Volume = Delta T Air Conventional/Delta T Cold Air
  = (25°C-13°C)/(25°C-7°C)=12/18=0.67

Original Supply Air (13 C)	1,094,610 M^3/H
Super-cool Air (7 C)	733,669 M^3/H
Reduced Air	360,941 M^3/H
% Reduction of Supply Air	33%
Original Number of AHU	40
Revised Number of AHU	22

State Power Management Building Energy Cost Comparison



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Lower Energy Costs

- Electric Rate Differential
  - Peak to off-peak rate differential: 3.5 : 1
- Lower Pumping Energy
  - Larger fluid temperature range equates to a 45% reduction in flow rate or 45% reduction in pump energy consumption.
- Lower Fan Power Consumption
  - Colder supply air equates to a 33% reduction in air volume. 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 Occupant Comfort

- 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 resulting in improved occupant comfort.
- As condensation on air handling unit coil fins is much greater than standard conditions, more impurities in the air such as dust or dirt are removed providing superior indoor air quality.
- Better air quality and a more comfortable working environment can also mean increased employee productivity.

BAC Ice Thermal Storage Experience

- Over 2000 Thermal Storage System Installations Worldwide
- Over 50 Years of Experience in the Refrigeration and HVAC Industries
- Constant Low Temperature Fluid Resulting in Lowest First Cost and Operating Cost System

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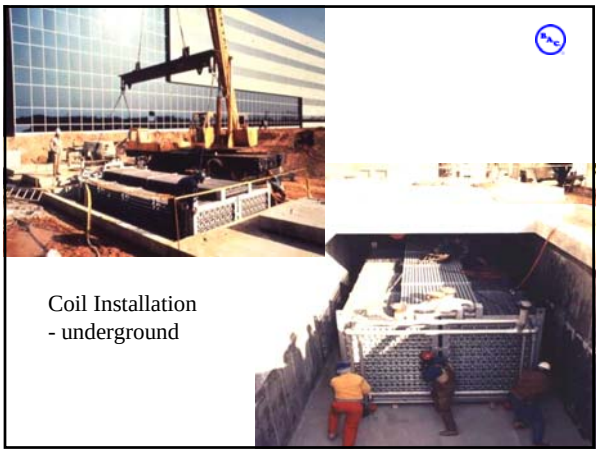
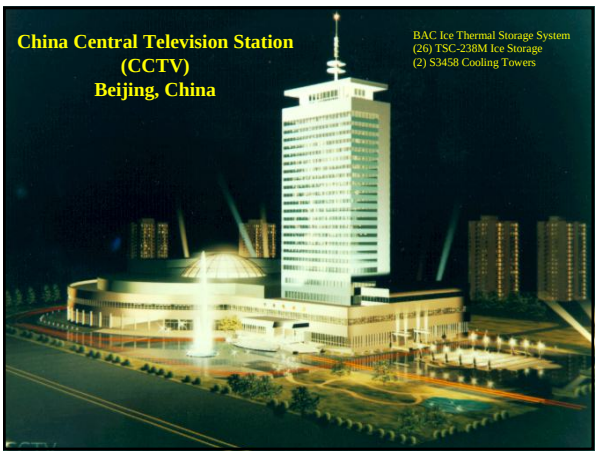


Coil Installation
- underground

Selected BAC Ice Thermal Storage Installations in Taiwan

- Taipei Financial Center - 36,450 TH
- Uni-presidential Group – 8,847 TH
- Software Park Phase I - 22,782 TH
- Software Park Phase II - 22,496 TH
- Taipei World Trade Center- 23,782 TH
- Koo Foundation Hospital - 12,480 TH
- Macronix - 7,086 TH
- Kong Kuo Building - 5,250 TH
- Fubon Commercial Building - 4,144 TH
- Chia Yia Winery - 4,200 TH
- Taiwan Admin. Bldg - 3281 TH
- Minshen Pumping Station - 7610 TH



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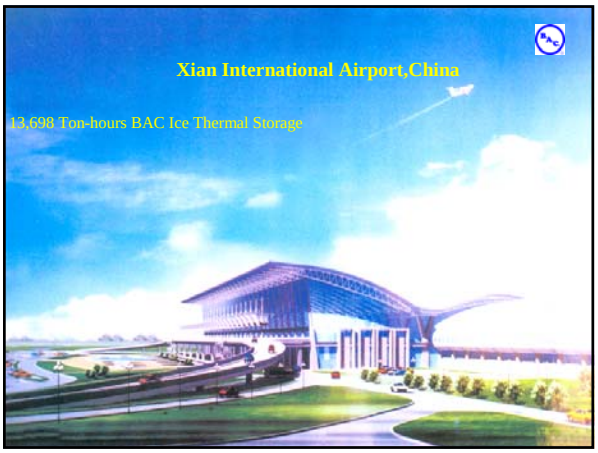
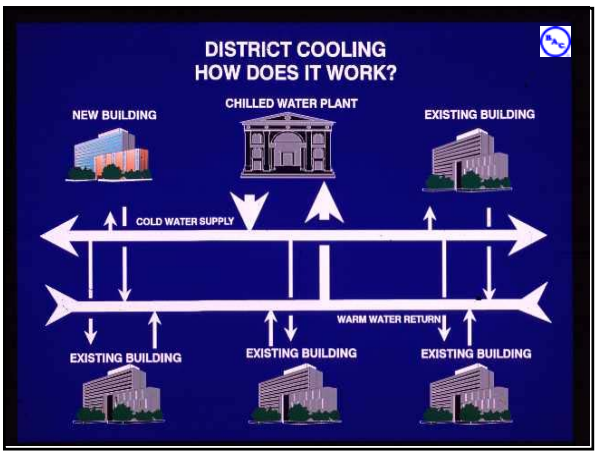
Shanghai Science Museum
Shanghai, China

(10) TSU-924MS Ice Storage Units, (4) 33620 & 15250 Cooling Towers





Chicago Ice Thermal Storage District Cooling Plants

- Merchandise Mart (IL)
  - 26,400 TH
- Unicom at State and Adams (IL)
  - 66,000 TH
- Columbus and Randolph
  - 100,000 TH
- Unicom at Franklin & Van Buren (IL)
  - 125,000 TH

Franklin and Van Buren, Chicago

Ice Storage Coil Installation

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Franklin and Van Buren, Chicago

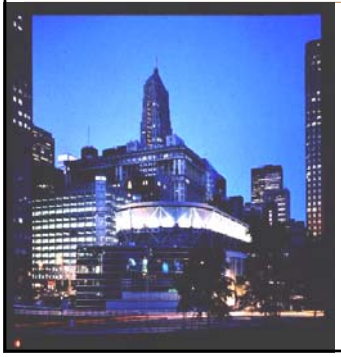
Ice Storage Coil Installation

Franklin and Van Buren, Chicago

Ice Storage Coil Installation

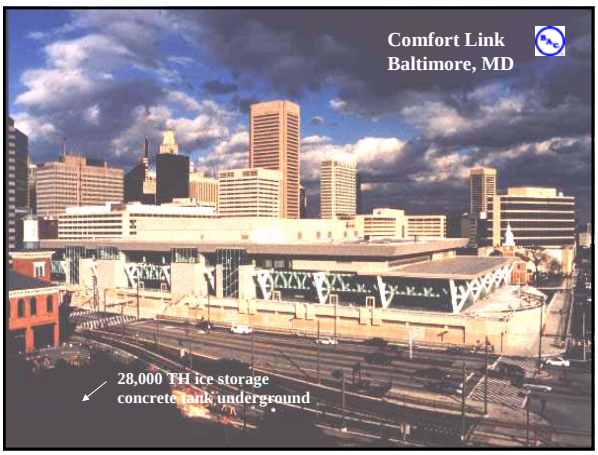
Franklin and Van Buren
Chicago, IL

Franklin and Van Buren
Chicago, IL



World's Largest Thermal Storage Installation

- 125,000 Ton-Hr (438 MWH)
- 434 Total Coils
- 435 Miles (700 km) of Tubing
- 10,400,000 lb. (4,700,000 kg) of Ice Each Night
- 114' L x 91' W x 32' H Tank (35 m x 28 m x 10 m)



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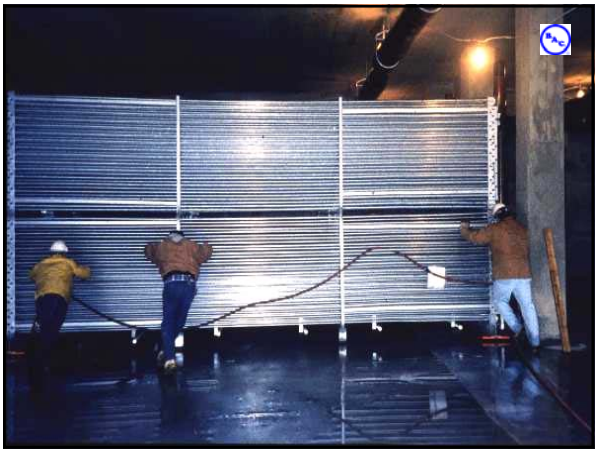
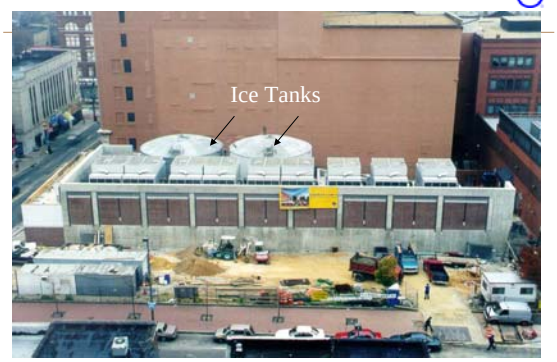


Saratoga and Eutaw Streets



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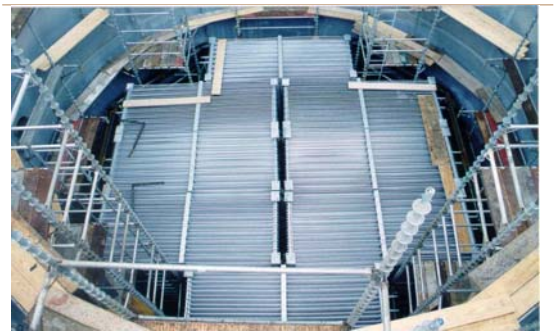
First Ice Coil Being Rigged into the Tank

Ice Coil Pattern Inside Steel Tank



Conclusion

- Ice thermal storage inherently produces very cold chilled water that can be used beneficially in A/C system design.
- When properly designed with larger temperature difference, Ice Thermal Storage Technology provides significant benefits including
  - Lower first cost
  - Lower energy cost
  - Better energy efficiency
  - Better indoor air quality and comfort

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