Ice Thermal Storage Systems

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Agenda

• Ice storage basics
• Ice storage design considerations
  – Full and partial storage systems
  – Internal and external melt systems
• Ice storage installations and applications
Air Conditioning

68. Ice Bunker Air Conditioning System, 1934.
Ice Build on Ice Coil Tube
Ice Build on Ice Coil
What is Ice Storage?

Ice Storage is the process of using a chiller or refrigeration plant to build ice during off-peak hours to serve part or all of the on-peak cooling requirement.
Ice Thermal Storage

How does it work?
Typical Cooling Load Profile

Cooling Load

Time of Day

0 2 4 6 8 10 12 14 16 18 20 22
Conventional System

Chiller

Cooling Load
Ice Storage System

- Ice Storage Tank
- Chiller
- Cooling Load
Ice Storage Cycle

- Cooling Load
- Time of Day

Ice Storage Cycle

- Ice Storage Cycle
- Ice Storage Cycle
Advantages of Thermal Energy Storage

- Reduced equipment costs
- Reduced energy and operating costs
- Increased flexibility to adapt to changing utility structures and requirements
- Reduces need for new power plants
Typical Daily Utility Load Curve

- **Total Utility Capacity**
- **Demand Charges**
- **High Time of Day Rates**

**Axes:**
- **Power (Megawatts)**
- **Time of Day** (0 to 22)

The graph illustrates the typical daily utility load curve, showing the variation in power demand throughout the day with a peak during the high time of day rates.
Ice Storage Cycle

- Ice Storage Cycle
- Demand Charges
- High Time of Day Rates
- Ice Storage Cycle

Time of Day

Cooling Load
The United States generates more electricity each year than any other country -- nearly a quarter of the world's total -- with 3.9 billion megawatt hours in 2003. That's more than the next three countries -- China, Japan and Russia -- combined. More than half of the U.S. electricity was generated from coal -- 50.8 percent -- with nuclear accounting for about a fifth (19.7 percent).

The map shows the chief source of electricity production for each state -- coal, natural gas, petroleum, nuclear or hydroelectric -- although most states rely on a mix of some or all of those sources. Click on each state for more details.

Note: Energy source figures for each state do not include pumped storage or categories that comprised less than one-tenth of 1 percent of the state total.
Electric Generation Fuel Sources

The Storage Shift

- Hydro-electric 0.2¢/kWh
- Nuclear 0.4¢/kWh
- Coal-fired steam 2.5¢/kWh
- Combined cycle 3.0¢/kWh
- Oil-fired steam 3.5¢/kWh
- Diesel 6.5¢/kWh
- Comb. turbine 7.0¢/kWh

Time of Day

% Generation
Thermal Storage System
Environmental Advantages

- Require less kWh than conventional systems
- Utilize efficient power and produce fewer carbon dioxide emissions
- Energy line losses at night are 4% to 5% lower than during the daytime

Advantages of Ice Thermal Storage

- Reduced equipment costs
- Reduced energy and operating costs
- Colder supply water temperature
Advantages of Ice Thermal Storage

- Reduced equipment costs
  - Only ~60% of chillers and heat rejection equipment required
  - Requires only 1/4 to 1/6 of the space required for chilled water storage (~3Ft^3/Ton-Hour)
  - Requires less chiller plant plan area than instantaneous chiller system
30,000 RT Output
16,000 RT Heat Rejection
Advantages of Ice Thermal Storage

• Reduced equipment costs
• Reduced energy and operating costs
• Colder supply water temperature
Ice Thermal Storage Uses Less Energy

• During daytime, chillers operate at higher supply temperatures and greater efficiency when piped upstream of the ice storage.
• At night, chillers operate when ambient temperatures are lower.
• Pump and fan energy can be less when colder system supply temperatures are used.
EER of Water Cooled Chillers*

*excludes heat rejection
Ice Thermal Storage Reduces Operating Costs

- Reduces air conditioning kW demand by approximately 40%
- Reduces air conditioning kWh by up to approximately 15%
- Reduces electric utility costs
  - Large percentage of energy usage is at night
  - Daytime energy costs 2 to 5 times more than night time energy
LEED Criteria

- Sustainable sites (14 possible points)
- Water efficiency (5 possible points)
- Materials and resources (13 possible points)
- Energy and atmosphere (17 possible points)
  - Ozone depletion
  - Optimize energy performance
    - Cost based analysis vs. ASHRAE 90.1
- Indoor air quality (15 possible points)
- Innovation & design process (5 possible points)
Advantages of Ice Thermal Storage

- Reduced equipment costs
- Reduced energy and operating costs
- Colder supply water temperature
Advantages of Cold Supply Water Temperature

- Smaller distribution pumps and piping
- Reduced pumping power
- Allows for economical building isolation (indirect interface) with smaller heat exchangers
- Provides better dehumidification and indoor air quality (IAQ)
  - 78°F (25.5°C) at 40% RH is more comfortable than 76°F (24.4°C) at 50% RH
- Cold air distribution
Burj Dubai Tower

• Will become world’s tallest building at over 180 floors
• Currently at 156 floors
• 41,600 ton-hours
Taipei 101

- Currently the world’s tallest building at 101 floors
- 36,400 ton-hours
Taipei 101

- 74th floor
  - 41.0°F (5°C)

- 42nd floor
  - 39.2°F (4°C)

- 7th & 8th floors
  - 37.8°F (3°C)
Factors Favorable for Ice Storage Systems

- Loads are of short duration
  - Schools
- Loads occur infrequently
  - Churches
  - Sports venues
- Loads are cyclical in nature
  - Process or batch cooling
Factors Favorable for Ice Storage Systems

- Loads are not well matched to availability of the energy source
- Energy costs are time-dependent
  - Time-of-use energy rates
- Energy supply is limited
  - Demand charges for peak energy use
- Utility rebates, tax credits, or other economic incentives are provided for the use of load-shifting equipment
Potential Ice Storage Projects

• Commercial A/C and industrial
  – Schools
  – Hospitals
  – Office buildings
  – Internet data centers
  – Hotels
  – Airports
  – Sports venues
  – Manufacturing plants
Potential Ice Storage Projects

- Commercial A/C and industrial
- District cooling
  - Colleges and universities
  - Corporate campuses
  - Hospitals
  - Convention centers
  - Sports arenas
  - Utilities
Ice Thermal Storage Systems

Design Considerations
Full Storage vs. Partial Storage
Batch Cooling or Process Load Profile

Cooling Load (Tons)

Time of Day

0 2 4 6 8 10 12 14 16 18 20 22
Full Ice Storage
Batch Cooling or Process Application

Cooling Load (Tons)

Time of Day

Ice Charge

Ice Discharge
Air Conditioning Load Profile

Cooling Load (Tons)

Time of Day

0 2 4 6 8 10 12 14 16 18 20 22
Full Ice Storage
Air Conditioning Application

Cooling Load (Tons)

Time of Day

- Ice Charge
- Ice Discharge
Ice Thermal Storage System Design
Full Ice Storage

Advantages
• Best suited for short, peak demand periods and/or high, peak loads
• Shifts largest electrical demand that provides the lowest operating cost
• Provides system standby capability and operating flexibility

Disadvantages
• Largest storage volume required
• Larger chiller required
• Most expensive thermal storage design
Partial Ice Storage
Air Conditioning Application

![Diagram showing the relationship between time of day and cooling load for ice charge, chiller, and ice discharge.]
Partial Ice Storage
Air Conditioning Application

Time of Day
Cooling Load (Tons)

Ice Charge
Chiller
Ice Discharge
Partial Ice Storage
Air Conditioning Application

Cooling Load (Tons)

Time of Day

Ice Charge
Chiller
Ice Discharge
Ice Thermal Storage System Design
Partial Ice Storage

Advantages
• Best suited for long cooling periods
• Lower first cost due to reduced storage volume and smaller chiller
• Provides system operating flexibility

Disadvantages
• Less standby capability
• Less electrical demand shifted to off-peak
Internal Melt vs. External Melt

Indirect vs. Direct Contact Cooling
Ice Storage System Types

Direct Contact Cooling

Indirect Contact Cooling
Ice Thermal Storage
Ice-on-Coil Technology
Ice Thermal Storage System Design

Ice on Coil - Internal Melt

Indirect

- Cold glycol solution is circulated through the coil to the A/C system
- Warm glycol solution, circulating through the coil, is cooled indirectly by the melting ice
Ice Storage Design
Internal Melt (Indirect Contact)
Ice Storage Design
Internal Melt Performance*

*10 hour, constant load w/o air agitation
Ice Storage Design
Internal Melt (Indirect Contact)

Advantages

• **Simple to design and operate**
  – simple controls for various operating modes
  – closed, pressurized loop

• **Stable, cold discharge temperatures**
  – 36°F to 38°F (2.2°C to 3.3°C) typical

• **Durable steel construction**
  – 150 to 300 psi (10.3 to 20.7 bar) design pressure rating
  – tested at 190 to 375 psi (13.1 to 25.8 bar)

• **Flexible layout (modular tanks or vault design)**
System Schematic
Ice Storage Design
Internal Melt (Indirect Contact)

Disadvantages

• Heat exchanger required for chilled water in building loop
• Not able to discharge as quickly as direct contact cooling
  – ice melt limited by flow through coil
Ice Thermal Storage System Design

**Ice on Coil - External Melt**

- Ice water is circulated through the ice storage tank to the A/C system.
- Warm return water, circulating through the tank, is cooled via direct contact with the ice.
Ice Storage Design
External Melt (Direct Contact)
Ice Storage Design
External Melt Performance*

*10 hour, constant load
External Melt Supply Temperatures

Leaving Water Temp. (°F)

% Ice Remaining

Hours

0 10 20 30 40 50 60 70 80 90 100

32
33
34
35
36
37
38
39
40
External Melt System Schematic
Ice Storage Design
External Melt (Direct Contact)

Advantages

- Lowest chilled water supply temperatures
- Quickest discharge capability
- Eliminates glycol from chilled water loop
Ice Storage Design
External Melt (Direct Contact)

Disadvantages

• Chiller with lower temperature capability generally required
• Glycol control valves required on larger systems
• Heat exchanger may require to manage static head of open system
• More difficult to monitor amount of ice in inventory
Ice Thermal Storage Systems
External Melt vs. Internal Melt

External Melt
- Project requires a constant, cold supply water temperature of 34°F (1°C) or quick discharge periods
- Trained operating staff available
- Large savings in distribution piping system
- Highest energy efficiency

Internal Melt
- Project does not require coldest possible supply temperature
- Simpler design and operation
- Individual buildings
- Energy efficiency is less critical (extra heat transfer step required)
Ice Thermal Storage Systems
External Melt vs. Internal Melt

• Most air conditioning applications use internal melt
• Most process and district cooling systems use external melt
Maryknoll Grade School
Honolulu, Hawaii

Below-Grade Concrete Tank
2,000 Ton-Hours Ice Storage
District Cooling Retrofit
Maryland Stadium Authority
Oriole Park at Camden Yards
Ravens Stadium at Camden Yards
Baltimore, Maryland

Buried Concrete Tank
13,000 Ton-Hours Ice Storage
LET'S HAVE ONE MORE
AND THEN WE'LL GO!!
Comfort Link District Cooling
Baltimore, Maryland USA

- 32,000 TR peak system capacity
- 21,650 TR chiller capacity
- 75,000 TH ice storage
- 10 miles+ of distribution system piping
- Chilled water distributed at 37°F (2.8°C)
- 50+ customers
  - commercial and government office, hospital, data center, hotel, residential, convention center, entertainment and retail space
Comfort Link Plant #2
Saratoga and Eutaw Streets
Baltimore, Maryland

Above-Grade Steel Tanks
27,000 Ton-Hours Ice Storage
Comfort Link Market Center Chilling Station – Construction (1999)
Comfort Link Market Center Chilling Station – Construction (1999)
Comfort Link Market Center Chilling Station – Construction (1999)
Comfort Link Market Center Chilling Station – Construction (1999)
Comfort Link Market Center Chilling Station – Completion (1999)
Comfort Link District Cooling
Baltimore, Maryland USA

- Operations began in 1996 with traditional electric tariff
  - 10:00 AM to 8:00 PM peak window
  - Fixed peak demand charge
  - Time of day energy rates
- Began purchase of electricity through independent suppliers in June, 2002
- System flexibility allows daily changes to operating schedules to minimize spot market consumption and capacity charges
Electric Cost Components - Typical User
SRC Current Market Estimate - PJM Mid-Atlantic

- Market - Energy Cost: 72%
- Market - Capacity Cost: 5%
- Market - Other Costs: 4%
- Local Delivery / Utility: 19%

Current Market Supply Estimate, 1 Year: $85-$88/MWh
Electric Cost Components

• Energy
  – Based on prevailing market prices
  – Daytime energy costs average twice nighttime energy costs

• Capacity
  – UCAP (generation capacity charge)
    • Highest system load hour on each of 5 highest load days (not customer)
  – Transmission
  – More than $60/kW/year
Demand Limiting Operating Strategy

Chart courtesy of Comfort Link

June 27, 2007
High of 100°F (37.8°C)
Low of 80°F (26.7°C)

12 mW Demand Shift
August 8, 2007
High of 108°F (42.2°C)
Low of 86°F (30.0°C)

(1) 1750 TR chiller out of service

Chart courtesy of Comfort Link
August 8, 2007
High of 108°F (42.2°C)
Low of 86°F (30.0°C)

Load Leveling Operating Strategy

(1) 1750 TR chiller out of service

6 mW Demand Shift

Chart courtesy of Comfort Link
Demand Limiting Operating Strategy

Predicted performance with all chillers in service

August 8, 2007
High of 108°F (42.2°C)
Low of 86°F (30.0°C)

Chart courtesy of Comfort Link
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