Today’s Topics

- Technologies
- Design and control methods
- Minimizing first cost, maximizing ROI
- Simplifying the process
Thermal Storage

TECHNOLOGIES
Ice or Chilled Water?

Thermal Storage Incremental Cost

- **Chilled Water**
  - 1. Rapid discharge
  - 2. Emergency use

- **Modular Ice**
  - 1. Factory quality
  - 2. Known performance

Cost Per Ton Hour

Thermal Storage – Installed Ton Hours
Ice Storage Methods

- Ice harvesters
- Ice on pipe—external melt
- Encapsulated ice storage
- Modular ice on pipe—internal melt
Six Modes of Energy Storage Systems

1. Charging
2. Charging and cooling a night time load
3. Chiller cooling
4. Energy storage cooling
5. Chiller and energy storage cooling
6. Off
Ice on Pipe—Internal Melt

Strengths
- Six modes of operation
- Efficient, modular, reliable
- Cataloged data
- Fast installation

Weaknesses
- Secondary heat transfer fluid
- Not easily direct buried
Retrofits

- Chillers/systems being replaced anyway
  - Ice chillers of equal capacity cost the same
  - Cost less if downsize the chillers
- Energy prices are high
- Energy shortages are common
- Rebates or incentives are available
  - States (California, New York)
  - Utilities (Duke Power, FPL)
Internal Melt Ice Storage

DESIGN AND CONTROL
Design Day Load Profile

![Design Day Load Profile Graph](image-url)
How Much Chiller Capacity?

Conventional System
(3)—240 ton chillers

- Idle Chiller Capacity
- Design Day Cooling Load profile

Time

Tons

0 100 200 300 400 500 600 700 800 900

12 2 6 8 10 12 2 4 6 8 10 12
Comparable Ice Storage Design

Storage System (2)—240 ton chillers 2,130 ton-hrs. storage

- Storage System Excess Capacity
- Design Day Load

Time

Tons
Comparable Ice Storage Design

- Conventional System (3) 240 ton chillers
- Storage System Excess Capacity
- Design Day Load

Storage System (2)—240 ton chillers 2,130 ton-hrs. storage
Design Day With Chiller Outage

- Storage Chiller
- Stored Cooling
- Storage System Shortfall

Conventional 2 (2)—240 ton chillers
Design Day With Chiller Outage

- Storage Chiller
- Stored Cooling
- Storage System Shortfall

Storage System
1 (2) 240 ton chillers
2,130 ton-hr storage
Design Overview

Full Storage
- Short on-peak windows or
- Good rebates available

Partial Storage
- Reduces peak demand
- Shifts load to more efficient time
Air-cooled or Water-cooled?

- Not that much design difference
- Air-cooled
  - Reduces initial investment for efficient system
  - Fewer components to select
- Water-cooled
  - Large chiller capacities (>500 tons)
  - May require multiple stages of compression
  - Expanded economizer cycle
Expand “Free” Cooling Cycle

- Ice extends the hours for water economizer free cooling cycle
- Reduces tower energy by charging tanks at night with fans unloaded
Condenser Relief

Typical August Day in Memphis

DB design

WB design

Temperature (°F)

Ice Making

Dry Bulb

Wet Bulb

Ice Making

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

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Simple Air-Cooled Chilled Water System

- Chiller
- Downstream ice tanks
- Blending valve
- Diverting valve
- Controls
- Heat transfer fluid
Ice Tanks in Series

*Downstream of Screw/Scroll Chiller*

![Diagram of Ice Tanks in Series downstream of Screw/Scroll Chiller](image_url)
Ice Tanks in Series
*Upstream* of Centrifugal Chiller

![Diagram of Ice Tanks in Series Upstream of Centrifugal Chiller](image)
Ice and Chillers in Series  

- Chiller in upstream position:
  - Increases chiller efficiency (screws more than CTVs)
  - Increases chiller capacity (screws more than CTVs)
  - Decreases ice capacity
  - Simplifies system layout
  - Tank capacity loss doesn’t exceed chiller efficiency and capacity benefits
    - Smaller system, screw or scroll—tanks downstream
- Chiller in downstream position:
  - Decreases chiller efficiency
  - Decreases chiller capacity
  - Increases ice capacity (reduced number of tanks?)
  - Tank capacity benefit is substantial
    - Larger system, centrifugals—tanks upstream
How Do I?

MINIMIZE FIRST COST, MAXIMIZE ROI
Minimize First Cost, Maximize ROI

Project Specifics

- Chilled water
- Building usage and future plans
  - Emergency cooling
  - Enhanced redundancy
  - Expansion
  - Green energy
  - Teaching tool
Minimize First Cost, Maximize ROI

Project Specifics

- Chilled water
- Building usage and future plans
- Space for tank farm
  - Outside
  - Inside
  - Stacked
  - Partial or complete burial
Minimize First Cost, Maximize ROI

Project Specifics

- Chilled water
- Building usage and future plans
- Space for tank farm
- System distribution design
  - Glycol throughout system
  - Wide delta T/low flow / low temp
  - Constant/variable flow
  - Dedicated ice/cooling chillers
University

- 21 chillers
  33,000 tons
- 156 ice tanks
  23,400 ton-hours
- Ice storage
  saves $423,000/year
- Self-generates at
  4–5 cents/kWh
- Purchases at 7.5-8.5
cents/kWh

Ice flattens load profile for utility rate negotiation
High School

- 260,000 ft$^2$ conditioned space
- Grades 10–12
- 1,800 students
  - Rule of thumb
    - 400 sq. ft./ton
- Peak load—250 Tons
  - 1,040 sq. ft./ton
- Actual chiller—130 tons,
  1,280 ton hrs ice storage
  - 2,000 sq. ft./ton
Ice Energy Storage Design

Acquire Data

- Cooling load
- Utility rates
  - kW charge—Ratcheted?
  - On-Peak/Off-Peak—kW and/or KWh
  - Real time pricing
  - Up front or on-going incentives
Electric Rates and Types

- Demand rate—most common
  - Ratchet
  - Time of day
Ton-hr Cost on a Standard Demand Rate

$11.00/kW and $.08/kWh*

<table>
<thead>
<tr>
<th></th>
<th>Energy Cost $/kWh</th>
<th>Demand Cost $/kWh</th>
<th>Ton-hr cost $/Tn. Hr.</th>
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<tbody>
<tr>
<td>Nighttime Costs</td>
<td>$.00</td>
<td>$.108</td>
<td>$.016</td>
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<tr>
<td>Daytime Costs</td>
<td>$.08</td>
<td>$.08</td>
<td>$.1884</td>
</tr>
</tbody>
</table>

* Assumes building with daytime peak
Proper Use of Glycol

- EG v PG
  - EG more efficient
  - PG less toxic

- Affect on coils
  - New
  - Existing

- Affect on chillers
  - Reduced heat transfer
  - Reduced flow rates, wider delta T
Proper Use of Glycol

- Do you *want* glycol through the whole building?
  - Smaller systems—yes
    - Freeze protection in coils (no need for coil pumping)
    - Not a lot of glycol, avoid HX cost
  - Larger systems—maybe not
    - First cost of glycol
    - Pumping cost
    - Glycol compatible control valves
    - Heat exchangers are a one time cost
    - Head pressure requirements for larger systems
Dedicated Ice Chillers with HX

- Ice chiller on tank loop shields building from glycol
- Tanks shielded from building pressure
- Ice chiller can be used as a backup
Proper Use of Glycol—Chillers

- Tank surface area affects tank charging temperature
  - Ice tank types and tank manufacturers vary
    - May need another tank if the charging temp is too low
  - Make sure chiller can handle the charging temperature
    - Chiller types and chiller manufacturers vary

- Chillers are selected for lower leaving water temperatures—why not take advantage of it?
  - Wider system ΔT—lower flows
  - Lower supply water temperatures
Design—Project Level Considerations

- How should it be piped
  - Constant volume—3-way valves on AHU coils
  - Constant primary/variable secondary
  - Variable primary flow

- Direction of flow during charge and discharge
  - Same direction for best operation
Chilled Water Distribution Design Constant Volume

- 3-way valves on coils
- Wider delta Ts reduce pumping horsepower
  - Larger CV system justified
- Better for small systems
Chilled Water Distribution Design Constant Volume

Diagram showing a chilled water distribution system with an ICE unit, P1, V1, back pressure regulating valve, and air handlers.
Ice-enhanced Air-cooled Chiller Plant Layout

- Watt meter in chiller
- Glycol management system
- Chiller bypass valve VAL-4
- Minimum flow bypass Valve VAL-3
- Ice inventory Meter
- Building load by pass valve VAL-2
- Flow meter

VFDs
Series, Decoupled, Chiller Downstream

- Simple bypass
- Recirculation to temper hx supply

Diagram details:
- V1, V2 valves
- P1, P2, P3 points
- Glycol and water flow paths
Thermal Storage
Control of an ICE System

- Define and document the modes
- Define the goal
- Coordinate with the utility rate structure
- Operator interface
Thermal Storage Control

System Operating Modes

1. Cool building with chiller only
2. Cool building with ice only
3. Cool building with chiller & ice
4. Make ice
5. Make ice & cool building
6. Off
Mode Chart

- Describes behavior of system in different modes
- Active mode highlighted
- Printer friendly

<table>
<thead>
<tr>
<th>Mode</th>
<th>System Pumps</th>
<th>Chiller</th>
<th>Ice Valve</th>
<th>Bypass Valve</th>
<th>Diverting Valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiller Only</td>
<td>Modulate on remote DP setpoint</td>
<td>Enabled</td>
<td>Modulate on system supply temp setpoint</td>
<td>Modulate on chiller flow to maintain minimum pressure DP setpoint</td>
<td>Fully open to building load</td>
</tr>
<tr>
<td>Tank Discharge Only</td>
<td>Modulate on remote DP setpoint</td>
<td>Off</td>
<td>Modulate on system supply temp setpoint</td>
<td>Closed</td>
<td>Fully open to building load</td>
</tr>
<tr>
<td>Chiller and Tank Discharge At The Same Time</td>
<td>Modulate on remote DP setpoint</td>
<td>Enabled to temperature setpoint or demand limit or operator intervention</td>
<td>Modulate on system supply temp setpoint</td>
<td>Modulate on chiller DP to maintain minimum DP setpoint</td>
<td>Fully open to building load</td>
</tr>
<tr>
<td>Make Ice</td>
<td>Modulate to ice making flow using DPT-1</td>
<td>Ice making mode enabled</td>
<td>Modulate on system supply temp setpoint (100% to ice)</td>
<td>Closed</td>
<td>Fully open to bypass</td>
</tr>
<tr>
<td>Make Ice and Cool</td>
<td>Modulate to ice making flow using DPT-1</td>
<td>Ice making mode enabled</td>
<td>Modulate on system supply temp setpoint (100% to ice)</td>
<td>Closed</td>
<td>Modulate to building DPT-2 starting at minimum reset DP setpoint</td>
</tr>
<tr>
<td>Off (Tanks Secured)</td>
<td>Off</td>
<td>Off</td>
<td>100% Ice bypass</td>
<td>Closed</td>
<td>Fully open to building load</td>
</tr>
</tbody>
</table>
Make Ice

<table>
<thead>
<tr>
<th>Mode</th>
<th>Mode Scheduled Hours</th>
<th>System Pump(s)</th>
<th>Chiller(s) CH-1, CH-2</th>
<th>Ice Valve VAL-1</th>
<th>Bypass Valve VAL-3</th>
<th>Diverting Valve VAL-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make Ice</td>
<td>11pm to 7am or until termination setpoint is reached.</td>
<td>P-1, P-2, P-3</td>
<td>Ice Making Mode enabled</td>
<td>Modulate on system supply temp of 15°F (100% to ice)</td>
<td>Closed</td>
<td>Fully open to bypass</td>
</tr>
</tbody>
</table>

56 Deg

31 Deg

25 Deg

32 Deg

22 Deg

31 Deg

59 gpm

DPT1

DPT2

VAL1

VAL3

VAL4

VAL2

On

32 Deg

25 Deg

56 Deg

Make Ice
Ice Storage

Freeze Mode Termination

<table>
<thead>
<tr>
<th>Fluid Temperature Leaving Storage Tank</th>
<th>Charge Time, Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>32°F (0°C)</td>
<td></td>
</tr>
<tr>
<td>30°F (-1.1°C)</td>
<td></td>
</tr>
<tr>
<td>28°F (-2.2°C)</td>
<td></td>
</tr>
<tr>
<td>26°F (-3.3°C)</td>
<td></td>
</tr>
</tbody>
</table>

Terminate freeze mode
Simultaneous Chiller and Tank Discharge

<table>
<thead>
<tr>
<th>Mode Scheduled Hours</th>
<th>Pumps</th>
<th>Chillers</th>
<th>Ice Valve - 1</th>
<th>Bypass Valve-3</th>
<th>Diverting VAL2</th>
</tr>
</thead>
<tbody>
<tr>
<td>11am-6pm April to October</td>
<td>Modulate on remote (out in the system) DP</td>
<td>Modulate to chiller setpoint or %RLA operator intervention</td>
<td>Modulate to System supply temperature</td>
<td>Modulate on DPT-1 to maintain chiller minimum flow</td>
<td>Fully open to building load</td>
</tr>
</tbody>
</table>
Ice Energy Storage

Energy Saving Goal

- Peak shaving—kW reduction
- Load shifting—kWh deferral
- Real-Time pricing response
Energy Saving Goal
Peak Shaving—kW Reduction

kW avoidance

Do not run out of ice!
Thermal Storage
Control of an ICE System

- Define the modes
  - Support all six
- Define the goal
  - Peak shaving—kW reduction
  - Load shifting—kWh deferral
  - Real-time pricing response
- Coordinate with the utility rate structure
  - Direct measurement of building demand
  - Time of day based mode selection
  - Demand response signal from utility
  - Monitoring of real-time pricing
- Operator interface
Making the Economics Work

- Use actual utility rate for life cycle costs if possible
- Use storage for the safety factor
- Use actual load profile for equipment selection
- Take credit for smaller electrical and mechanical ancillary equipment
- Take advantage of any utility rebates that might be available
- Use low flow high delta T energy distribution
- Use low temperature air distribution
Office

Energy Charges:
- $0.0700/kWh On-Peak
- $0.0477/kWh Off Peak

Demand Charge:
- $8.33/kW/month

10% less energy/sq ft. than average Florida state building
# Fort Myers Regional Service Center

<table>
<thead>
<tr>
<th></th>
<th>Conventional A/C System</th>
<th>Energy Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chillers</td>
<td>$717,000</td>
<td>$447,000</td>
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<tr>
<td>Ice Storage</td>
<td>$0</td>
<td>$357,000</td>
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<tr>
<td>Pipe &amp; Pumps</td>
<td>$395,000</td>
<td>$264,000</td>
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<tr>
<td>Air Distribution</td>
<td>$988,000</td>
<td>$976,000</td>
</tr>
<tr>
<td><strong>TOTAL COST</strong></td>
<td><strong>$2,100,000</strong></td>
<td><strong>$2,044,000</strong></td>
</tr>
<tr>
<td>FPL Rebate</td>
<td>$0</td>
<td>$187,500</td>
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<tr>
<td><strong>NET Cost to Customer</strong></td>
<td><strong>$2,100,000</strong></td>
<td><strong>$1,856,500</strong></td>
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<tr>
<td>Net Cost/Ton</td>
<td>$2,800</td>
<td>$2,475</td>
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<tr>
<td><strong>Net First Cost Savings</strong></td>
<td></td>
<td><strong>$243,500</strong></td>
</tr>
<tr>
<td><strong>Annual Savings over past 3 years</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity (Demand &amp; Energy)</td>
<td></td>
<td>$119,500</td>
</tr>
<tr>
<td>Maintenance &amp; Water (no cooling towers)</td>
<td></td>
<td>$25,000</td>
</tr>
<tr>
<td><strong>Total Annual Operating Savings</strong></td>
<td></td>
<td><strong>$144,500</strong></td>
</tr>
</tbody>
</table>
Economic Assumptions

- **Electricity**: $0.09198 per kWh, first 15,000
  $0.04347 thereafter
- **Demand**: $0.00 first 50 kW
  $12.91 thereafter
- **Base**: (2) 50-ton air-cooled chillers, no ice
- **Alt 1**: 60-ton air-cooled chiller, 320 ton-hours of ice
- **Alt 2**: 70-ton air-cooled chiller, 464 ton-hours of ice
Load Profile

- Peak design: 77 tons
- 4°F unoccupied setback
- Minimal unoccupied load
- Optimum start
- Base case: (2) 50-ton chillers
  - Peak load x 1.2 /2
Economics

- Alt 1: (2) 50-ton chillers
- Alt 2: (1) 60-ton chiller
  (2) tanks (320 t-h)
- Alt 1: $51,600/yr
- Alt 2: $48,300/yr
- Alt 1: $143,000 first cost
- Alt 2: $158,000 first cost
- 3.7 year payback
- IRR 30%

Economic Summary:

<table>
<thead>
<tr>
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<td>1</td>
<td>143,000.00</td>
<td>51,599.49</td>
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<td>2</td>
<td>158,015.00</td>
<td>48,329.84</td>
<td>48,329.84</td>
<td>1,200.00</td>
<td>1,200.00</td>
<td>579,600.40</td>
</tr>
</tbody>
</table>

Alt. - Alt. | First Cost Difference | Simple Payback | Net Present Value | Life Cycle Payback | Internal Rate of Return |
<table>
<thead>
<tr>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>2 - 1</td>
<td>15,015.00</td>
<td>3.7 yrs</td>
<td>36,389.67</td>
<td>4.8 yrs</td>
<td>29.7 %</td>
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</table>
## Reduced Demand

### Alternative 1

<table>
<thead>
<tr>
<th>Equipment Description</th>
<th>Electrical Demand (kw)</th>
<th>Percent of Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling Equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air-cooled chiller - 002</td>
<td>61.68</td>
<td>27.72</td>
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<tr>
<td>Air-cooled chiller - 001</td>
<td>68.88</td>
<td>30.95</td>
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<tr>
<td><strong>Sub total</strong></td>
<td><strong>130.56</strong></td>
<td>58.67</td>
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### Traditional A/C System 2 cl

Yearly Time of Peak: 14(Hr)  8(Month)

### Alternative 3

<table>
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<tr>
<th>Equipment Description</th>
<th>Electrical Demand (kw)</th>
<th>Percent of Total (%)</th>
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<tbody>
<tr>
<td>Cooling Equipment</td>
<td></td>
<td></td>
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<tr>
<td>Air-cooled chiller - 001</td>
<td>59.54</td>
<td>36.46</td>
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<tr>
<td><strong>Sub total</strong></td>
<td><strong>59.54</strong></td>
<td>36.46</td>
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</tbody>
</table>

### Larger Thermal Storage 1 cl

Yearly Time of Peak: 11(Hr)  8(Month)
Larger Storage System
Larger Storage System

- Lower kW
- About the same kWh
- 11 year payback versus no storage, 10.5% IRR
- Smaller storage system better

### Economic Summary

<table>
<thead>
<tr>
<th></th>
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<td>1,200.00</td>
<td>579,690.40</td>
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### Economic Comparison of the Alternatives

<table>
<thead>
<tr>
<th>Alt. - Alt.</th>
<th>First Cost Difference</th>
<th>Simple Payback</th>
<th>Net Present Value</th>
<th>Life Cycle Payback</th>
<th>Internal Rate of Return</th>
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<tr>
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<td>3.7 yrs</td>
<td>36,389.67</td>
<td>4.8 yrs</td>
<td>29.7 %</td>
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<tr>
<td>3 - 1</td>
<td>50,023.00</td>
<td>11.5 yrs</td>
<td>3,887.36</td>
<td>15.1 yrs</td>
<td>10.9 %</td>
</tr>
<tr>
<td>3 - 2</td>
<td>35,008.00</td>
<td>118.9 yrs</td>
<td>-32,502.31</td>
<td>Does not pay back</td>
<td>Does not pay back</td>
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</tbody>
</table>
Could We Have Done More to Maximize ROI?

- Other benefits
- Focus on incremental cost to the project
- Negotiate with utility for different tariff
Ice Storage Design and Application Summary

- Reduces a building’s utility bill and benefits the environment as well
- Will play a significant role in the utility grid of the future
- Applicable over a wide range of building sizes and types
- Simple and economical
- You don’t need a time-of-day rate, an expensive kilowatt-hour charge, or even a demand ratchet to get an attractive return on investment
Questions?

Thank you for your participation!