Agenda and Objectives

Trane Engineers Newsletter Live Series

Ice Storage Design and Application

The electrical supply chain of the future will incorporate a higher percentage of renewable energy (i.e. wind and PV solar). While clean and unlimited, these forms of energy are intermittent in nature and will require some form of energy storage to meet their potential. Thermal storage is not only an easy way to store energy but it is reemerging as a valuable energy and energy cost saving technology for building owners.

We'll cover a bit of theory and application, then demonstrate the design steps for a small ice storage system from layout to operation and control. We'll discuss how to make it affordable, expose hidden costs in energy tariffs which raise ROI, and identify and address the most common stumbling blocks.

By attending this ENL you will be able to:

1. Provide a clear understanding of how an ice storage system operates
2. Provide an economic rationale for ice storage
3. Dispel common myths about ice storage
4. Understand how to avoid the most common stumbling blocks

Agenda

1) Opening (welcome, agenda, introductions)

2) Why ice storage

  a) Electrical infrastructure

  b) Economics

  c) Environmental stewardship

  d) Myths about ice storage

3) Typical applications

4) Electricity rate introduction

5) Design overview

  a) Partial versus full

  b) Influences driving partial storage

  c) Influences driving full storage

  d) Considerations

6) Controls

4) Economic summary

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Presenters

Ingersoll Rand

Trane Engineers Newsletter Live Series

Ice Storage Design and Application

(2009)

Susanna Hanson | applications engineer | Trane

Susanna is an applications engineer at Trane with over eleven years of experience with chilled-water systems and HVAC building load and energy analysis. Her primary responsibility is to aid system design engineers and Trane personnel in the proper design and application of HVAC systems. Her main areas of expertise include chilled-water systems and ASHRAE Standard 90.1. She is also a Certified Energy Manager.

She has authored several articles on chilled water plant design, and is a member of ASHRAE SSPC 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings. Susanna earned a bachelor's degree in industrial and systems engineering from the University of Florida, where she focused on building energy management and simulation.

Lee Cline | senior systems engineer | Trane

Lee is an engineer in the Systems Engineering Department with over 28 years experience at Trane. His career at Trane started as a factory service engineer for heavy refrigeration, helping to introduce the CVHE centrifugal chiller with electronic controls to the industry. Following that Lee was a member of the team that kicked off the microelectronic building automation and Integrated Comfort Systems controls – ICS - offering at Trane. He continues to push new unit and system control and optimization concepts into the industry. As a Systems Engineer Lee also has the opportunity to discuss HVAC system application and control with owners, engineers and contractors on a daily basis.

Lee has a Bachelors degree in Mechanical Engineering from Michigan Technological University. He is a Registered Professional Engineer in the State of Wisconsin.

Paul Valenta | Vice-President Sales and Marketing | CALMAC Mfg. Corp.

Paul is a vice-president at CALMAC Manufacturing Corporation with over 20 years experience in the ice energy field. CALMAC celebrated its 60th birthday in 2008 and has a long history of providing valuable energy saving products. Paul's career at CALMAC started as a regional sales manager responsible for sales and distribution of ice storage systems in the Midwest. Without utility incentives and off peak rates, Paul specialized in developing partial ice energy storage applications in schools and offices and demonstrating their viability with life cycle costs. He has been involved in several hundred ice storage projects all over the world. Currently Paul is Marketing and Sales Manager for CALMAC. He has authored several articles on ice energy storage and rightsizing cooling plants with energy storage, is a member or ASHRAE and is a LEED Accredited Professional. Paul has a degree in Electrical Engineering from the University of Nebraska.

Ice Storage Design and Application

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Ice Storage Design and Application

Today's Topics

- Overview—why ice now?
- Typical applications
- Qualifying a job
- Design process
- Minimizing first cost, maximizing ROI
- Project level considerations
- Controls
- Economics

Today's Presenters

Paul Valenta
Calmac National Sales Manager

Susanna Hanson
Applications Engineer

Lee Cline
Systems Engineer

Ice Storage Design and Application

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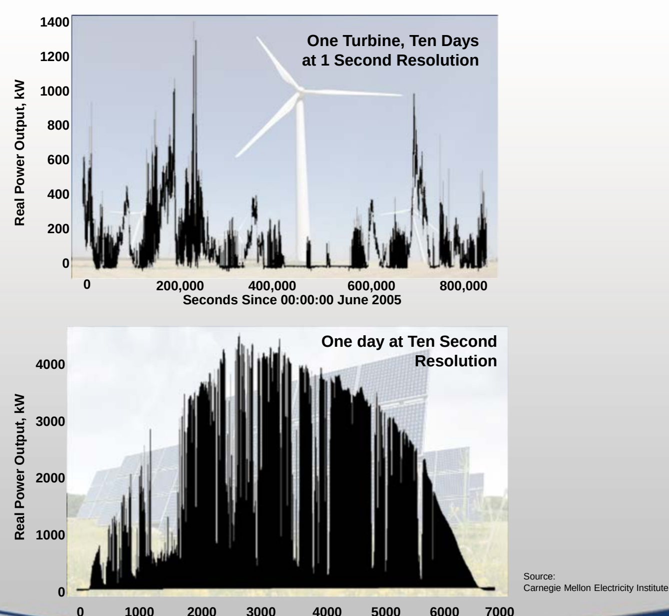
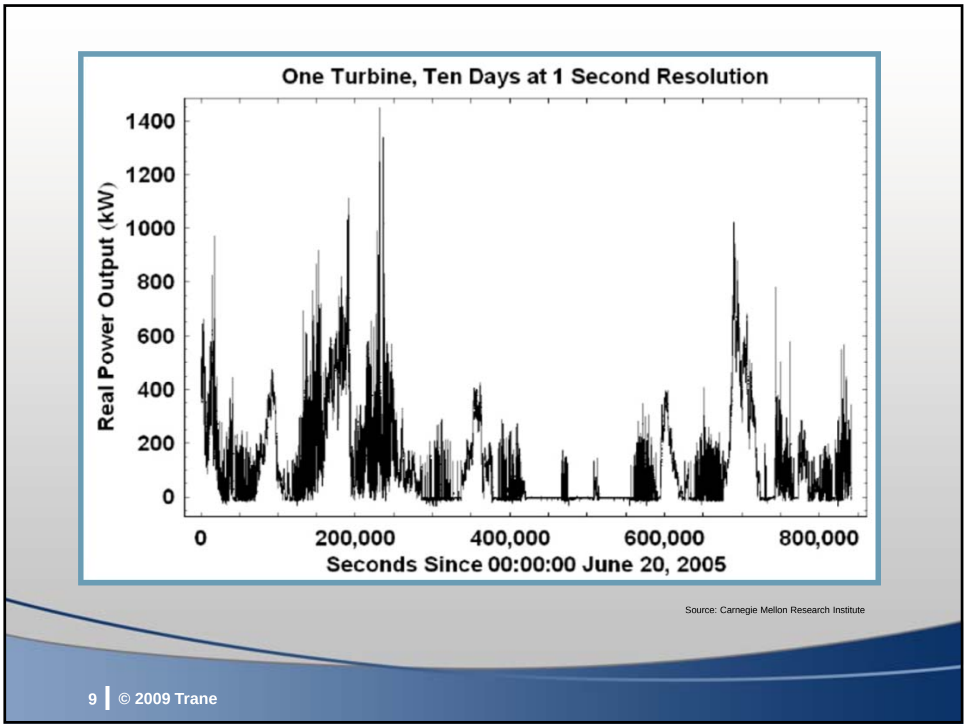
Why Ice Storage and Why Now?

Ingersoll Rand

Why Thermal Energy Storage?

1. **“Green” power needs it**
2. It reduces CO_2 emissions
3. It saves money and has a good ROI





One Turbine, Ten Days at 1 Second Resolution
Real Power Output (kW)
1400
1200
1000
800
600
400
200
0
0
200,000
400,000
600,000
800,000
Seconds Since 00:00:00 June 20, 2005
Source: Carnegie Mellon Research Institute
9
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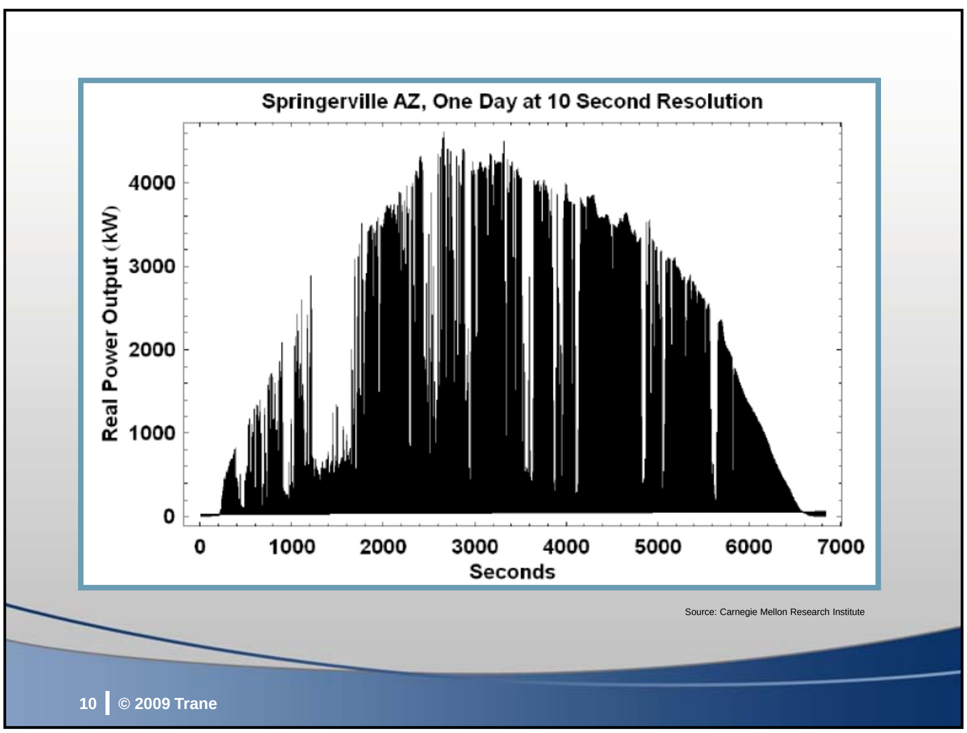


Springerville AZ, One Day at 10 Second Resolution
Real Power Output (kW)
4000
3000
2000
1000
0
0
1000
2000
3000
4000
5000
6000
7000
Seconds
Source: Carnegie Mellon Research Institute
10
© 2009 Trane

Why Thermal Energy Storage?

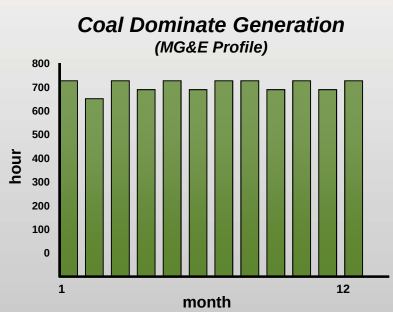
1. "Green" power needs it
2. **It reduces CO_2 emissions**
3. It saves money and has a good ROI

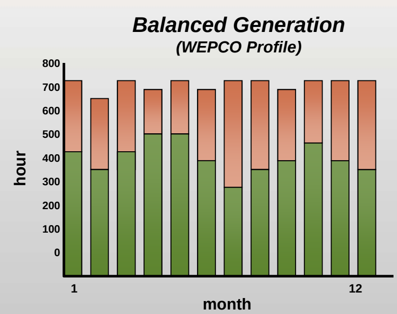
Simulation of Source Energy Utilization and Emissions for HVAC Systems

A report ASHRAE TC 6.9 in response to the 991-TRP work statement

ASHRAE TC 6.9 Research Project

Monthly Power Plant Fuel Source





ASHRAE TC 6.9 Research Project

Ice Storage Site, Source, & CO_2 Savings

System	Coal Dominant Utility Generation Profile			Coal/Natural Gas Utility Generation Profile		
	Site Electricity (% of base)	Source Energy (% of base)	CO_2 Emission (% of base)	Site Electricity (% of base)	Source Energy (% of base)	CO_2 Emission (% of base)
Electric Chiller (base)	100%	100%	100%	100%	100%	100%
Office Ice Storage	86%	86%	86%	86%	86%	86%
School W/C—Ice	88%	88%	87%	88%	88%	88%
School A/C—Ice	87%	87%	86%	87%	87%	88%

Simulation of Source Energy Utilization and Emissions for HVAC Systems

Conclusions

"Thermal energy storage systems should be promoted as an environmentally beneficial technology. These systems have been historically touted as beneficial in terms of operation cost. This study suggests that the economic benefits can be accompanied by environmental ones…"

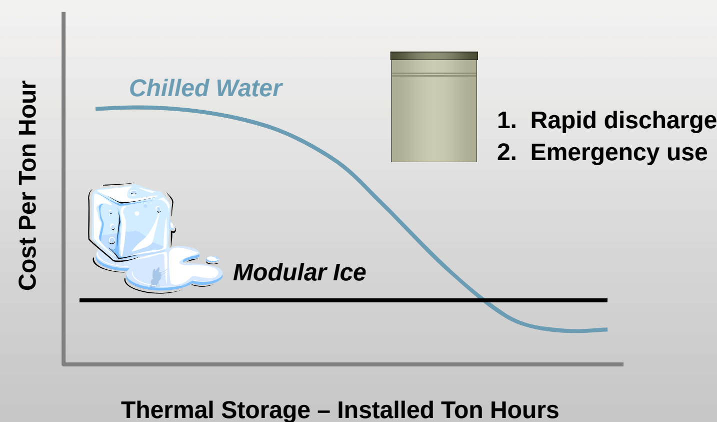
"…Source energy reductions were generally on the order of 10%. Global warming impact reductions were also on the order of 10%..."

Why Thermal Energy Storage?

1. "Green" power needs it
2. It reduces CO_2 emissions
3. **It saves money and has a good ROI**

Why Concentrate on Ice?

Thermal Storage Incremental Cost



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Ice Storage Design and Application

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Ice Storage Overview

Paul Valenta

Ingersoll Rand

Energy Storage Background

- 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

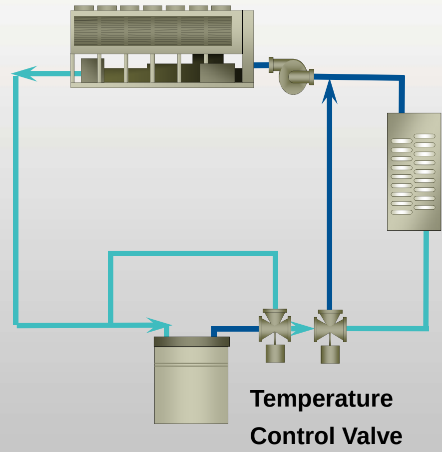
Ice on Pipe—Internal Melt

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

Weaknesses
- Secondary heat transfer fluid
- Not easily direct buried

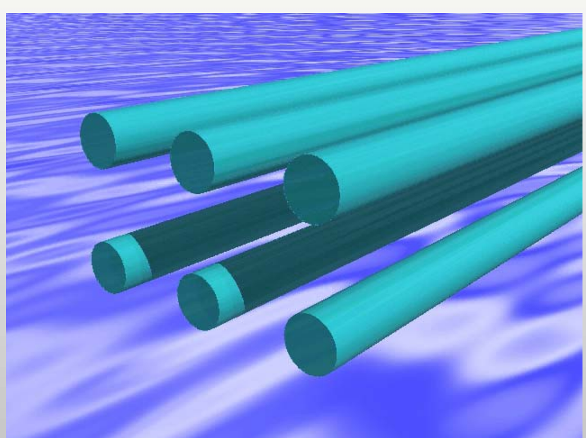
Ice on Coil—Internal Melt

- Easily adapts to chilled-water system
- Added:
  - Blending valve
  - Diverting valve
  - Ice tank(s)
  - Controls
  - Heat transfer fluid



Ice Building and Melting Cycle

Ice on Pipe—Internal Melt



Rules of Thumb for Partial Ice Storage Designs

- Most projects are partial storage unless utilities support full storage with rebates
- Chiller loses 1/3 of capacity during ice build
- Ice making time is usually 8 to 10 hours
- Typical systems store about 1/4 to 1/3 of the total design day ton-hours
- Chiller reduction
  - To 50% in schools, 35%–40% office buildings
- Design for high delta T, 15°F to 18°F

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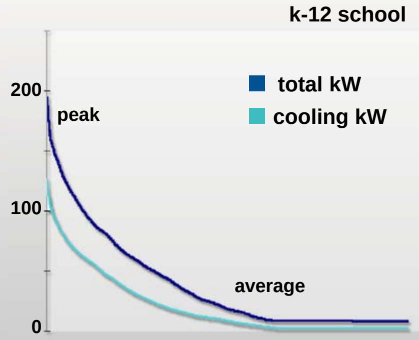
Design Overview

Susanna Hanson

Ingersoll Rand

Visualize the Potential Impact

- Building kW load duration curve
- Diversity factor
  - Average load/peak load
  - Total kW
  - HVAC kW
  - Chiller tons

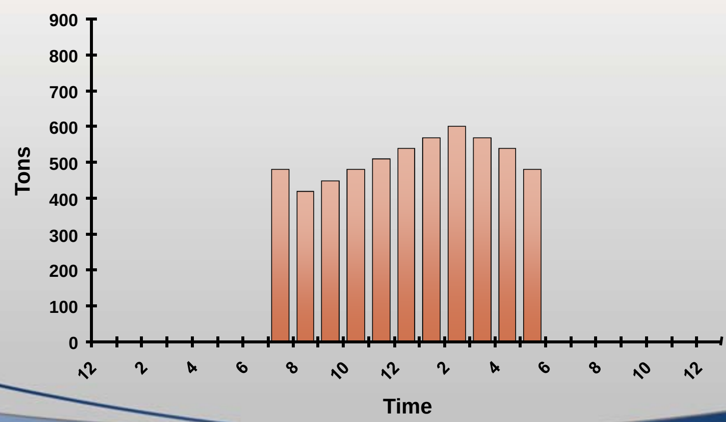


University of Arizona

Ice flattens load profile for utility rate negotiation

- 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

Design Day Load Profile



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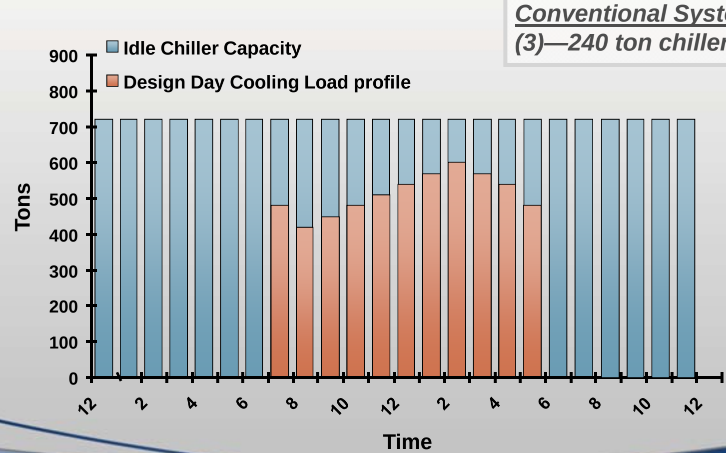
How Much Chiller Capacity?

Conventional System
(3)—240 ton chillers



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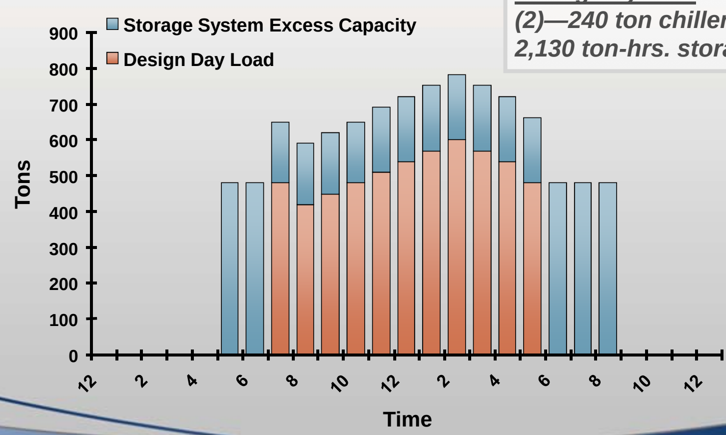
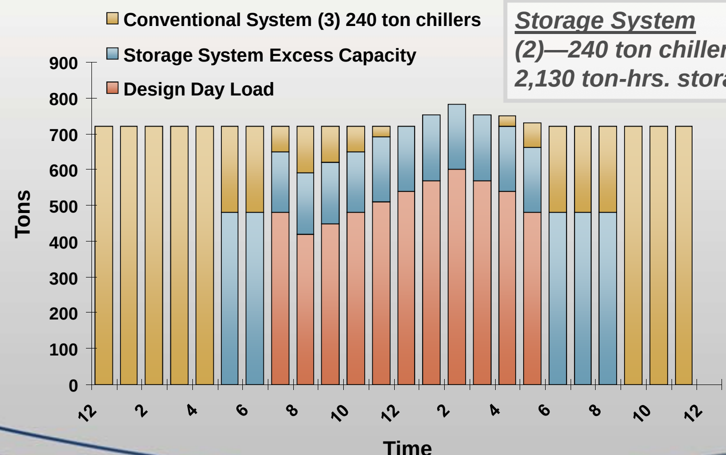
Comparable Ice Storage Design



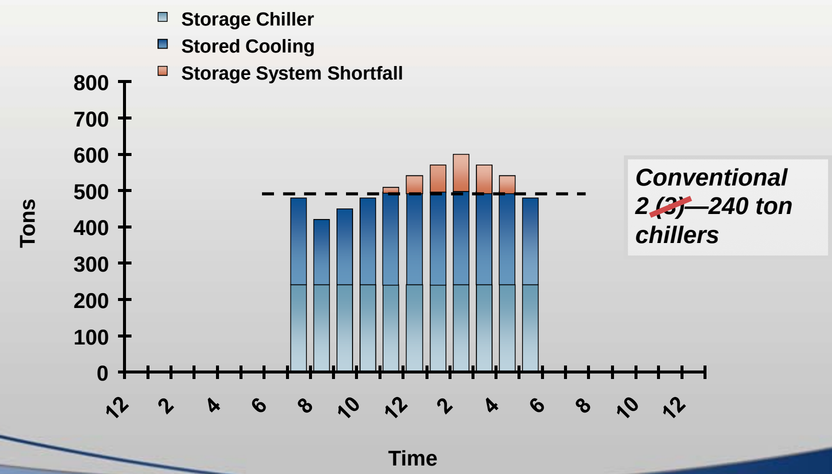
Storage System
(2)—240 ton chillers
2,130 ton-hrs. storage

Comparable Ice Storage Design



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

Design Day With Chiller Outage



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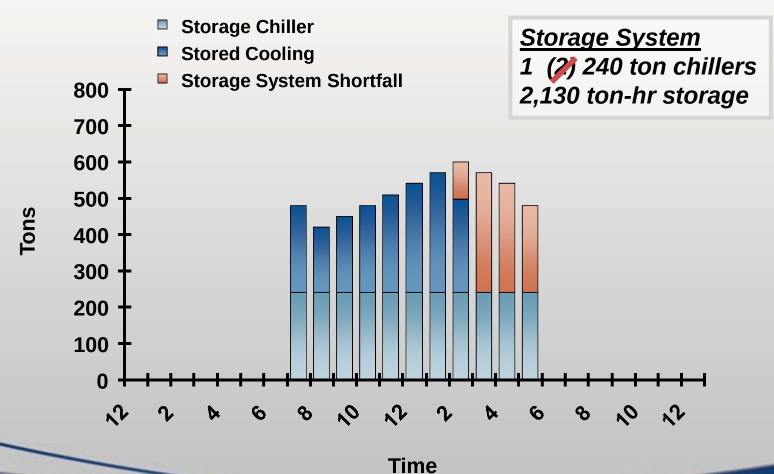
Design Day With Chiller Outage



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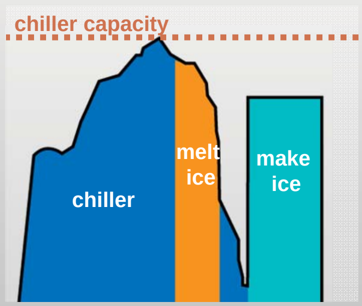
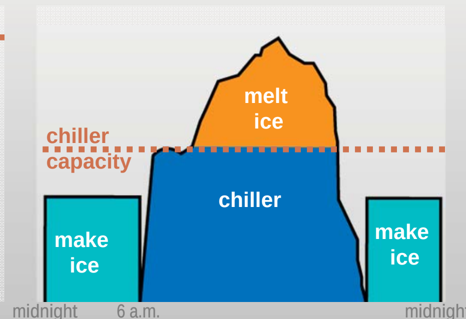
Design Overview

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

Partial Storage
- Reduces peak demand
- Shifts load to more efficient time



downsized chiller



downsized chiller

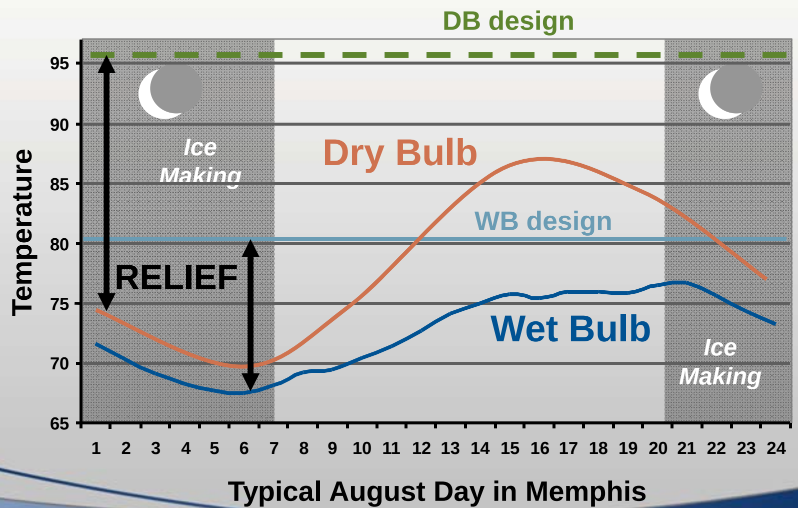
Air-cooled or Water-cooled?

- 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

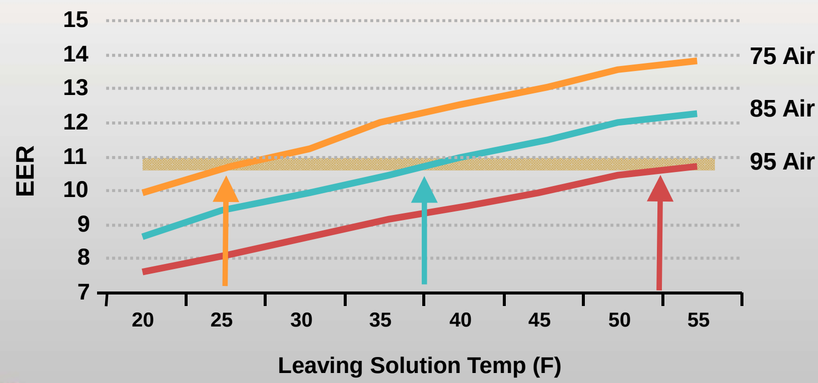
Expand "Free" Cooling Cycle

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

Condenser Relief



EER
Leaving Solution Temp and Ambient Relief



Fossil Ridge High School

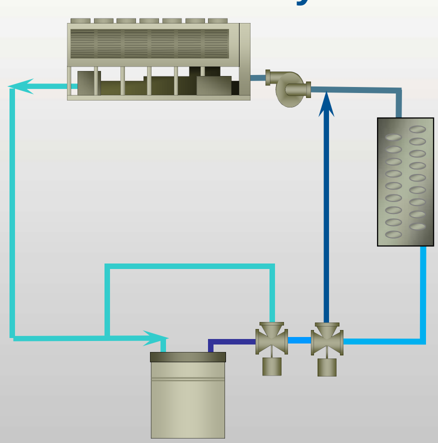
- 260,000 ft² conditioned space
- Grades 10–12
- 1,800 students
  - Rule of thumb
  - ***400 sq. ft./ton***
- Peak load—250 Tons
  - ***1,040 sq. ft./ton***
- Actual chiller—130 tons, 1,280 ton hrs ice storage
  - ***2,000 sq. ft./ton***

Retrofits

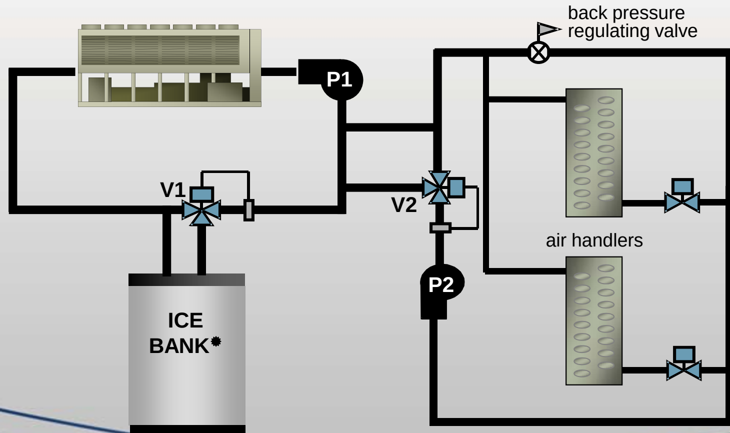
- Chillers/systems being replaced anyway
  - Ice chillers of equal capacity cost the same
  - Cost less if downsize the chillers
- Energy prices are high
- Energy shortages are common
- Rebates or incentives are available
  - States (California, New York)
  - Utilities (Duke Power, FPL)

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



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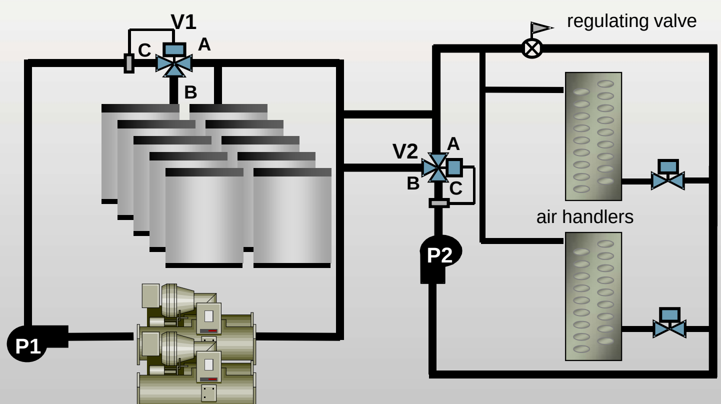
Ice Tanks in Series
Upstream of Centrifugal Chiller



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Ice and Chillers in Series S.I.C.

- 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

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Qualifying

Lee Cline

Ingersoll Rand

Ice Storage Design Process

Qualify Job

Target Prospective Job	Acquire Data	Initial System Sizing	Initial Financial Analysis	Initial Financial Proposal

• Chilled water
• Doing something
• Utility cost conscious
• Day loading
• Tank siting
• Code compliance
	• New/existing
	• Preliminary load profile
	  • Peak
	  • Daily curve
	•Utility rate
	•Future use
		• Ice Pick	• System Analyzer
			• First Pass
				•Proforma
				•ROI
				•Schedule

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Ice Energy Storage Design
Project Specifics

- Chilled water
- Building usage and future plans
  - Emergency cooling
  - Enhanced redundancy
  - Expansion
  - Green energy
  - Teaching tool

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Ice Energy Storage Design
Project Specifics

- Chilled water
- Building usage and future plans
- Space for tank farm
  - Outside
  - Inside
  - Stacked
  - Partial or complete burial

Ice Energy Storage Design
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

Ice Storage Design Process

Qualify Job

Target Prospective Job	Acquire Data	Initial System Sizing	Initial Financial Analysis	Initial Financial Proposal

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	  • Daily curve
	•Utility rate
	•Future use
		• Ice Pick	• System Analyzer
			• First Pass
				•Proforma
				•ROI
				•Schedule

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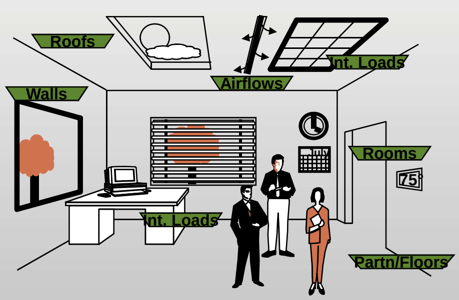
Ice Energy Storage Design
Acquire Data

- Cooling load
  - Design day hourly profile
    - Tall peak?
    - Low and flat?
    - Off peak usage?
- Acquire from…
  - Load program
  - Chiller logs
  - BAS logs



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Ice Storage Design and Application

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Qualifying Preliminary Analysis

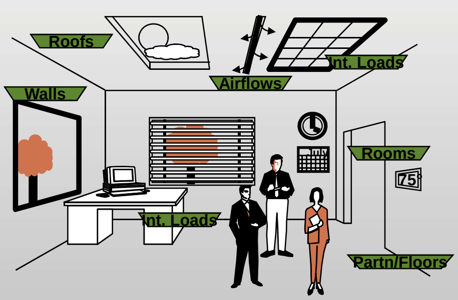
Paul Valenta

Ingersoll Rand

Ice Energy Storage Design

Cooling Load

- 24 hour design day load profile from
  - Load program
  - Chiller logs
  - BAS logs
- Night loads
  - > 20% of peak loads
  - If > 20% consider night chiller



Internal-Melt Tank Dynamics

- Performance dependencies
  - Flow rate
  - Temperatures
  - Ice capacity remaining
- Performance requirements
  - Peak discharge rate
  - Hourly discharge rate
  - Total storage capacity

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Equipment Selection Criteria

- Heat transfer fluid type and concentration
- Ice tank model
- Chiller daytime contribution as a % of nominal
- Chiller charging capacity as a % of nominal
- Supply and Return delta T
- 24 hour load profile
  - Full or partial storage

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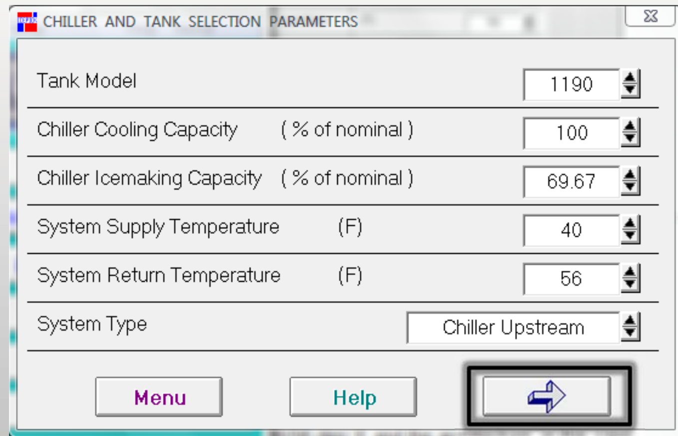
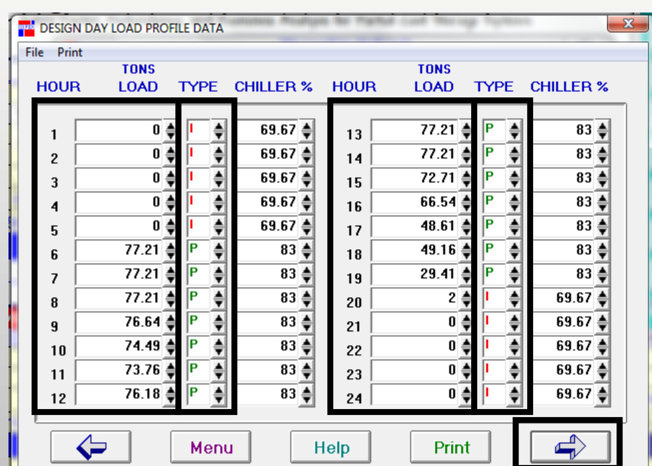
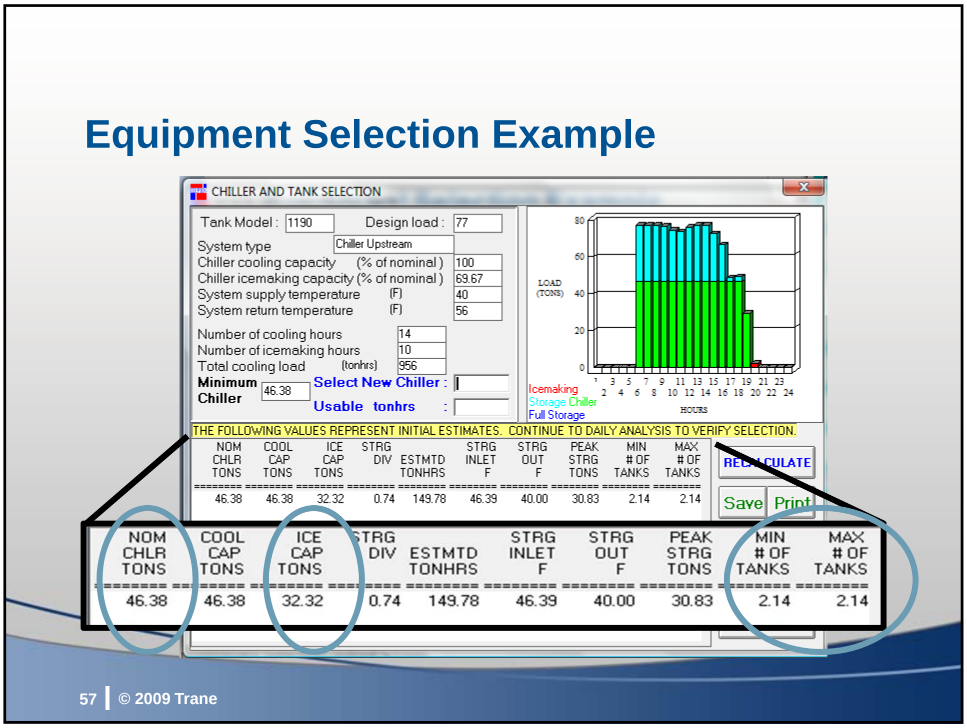
IcePick—Input Screens



Design Day Load Profile



HOUR	TONS LOAD	TYPE	CHILLER %	HOUR	TONS LOAD	TYPE	CHILLER %
1	0	I	69.67	13	77.21	P	83
2	0	I	69.67	14	77.21	P	83
3	0	I	69.67	15	72.71	P	83
4	0	I	69.67	16	66.54	P	83
5	0	I	69.67	17	48.61	P	83
6	77.21	P	83	18	49.16	P	83
7	77.21	P	83	19	29.41	P	83
8	77.21	P	83	20	2	I	69.67
9	76.64	P	83	21	0	I	69.67
10	74.49	P	83	22	0	I	69.67
11	73.76	P	83	23	0	I	69.67
12	76.18	P	83	24	0	I	69.67



Equipment Selection Example
CHILLER AND TANK SELECTION
Tank Model : 1190
Design load : 77
System type Chiller Upstream
Chiller cooling capacity (% of nominal) 100
Chiller icemaking capacity (% of nominal) 69.67
System supply temperature (F) 40
System return temperature (F) 56
Number of cooling hours 14
Number of icemaking hours 10
Total cooling load (tonhrs) 956
Minimum Chiller 46.38
Select New Chiller :
Usable tonhrs :
LOAD (TONS)
HOURS
Icemaking
Storage Chiller
Full Storage
THE FOLLOWING VALUES REPRESENT INITIAL ESTIMATES. CONTINUE TO DAILY ANALYSIS TO VERIFY SELECTION.
RECALCULATE
Save
Print
NOM CHLR TONS | COOL CAP TONS | ICE CAP TONS | STRG DIV | ESTMTD TONHRS | STRG INLET F | STRG OUT F | PEAK STRG TONS | MIN # OF TANKS | MAX # OF TANKS
46.38 | 46.38 | 32.32 | 0.74 | 149.78 | 46.39 | 40.00 | 30.83 | 2.14 | 2.14
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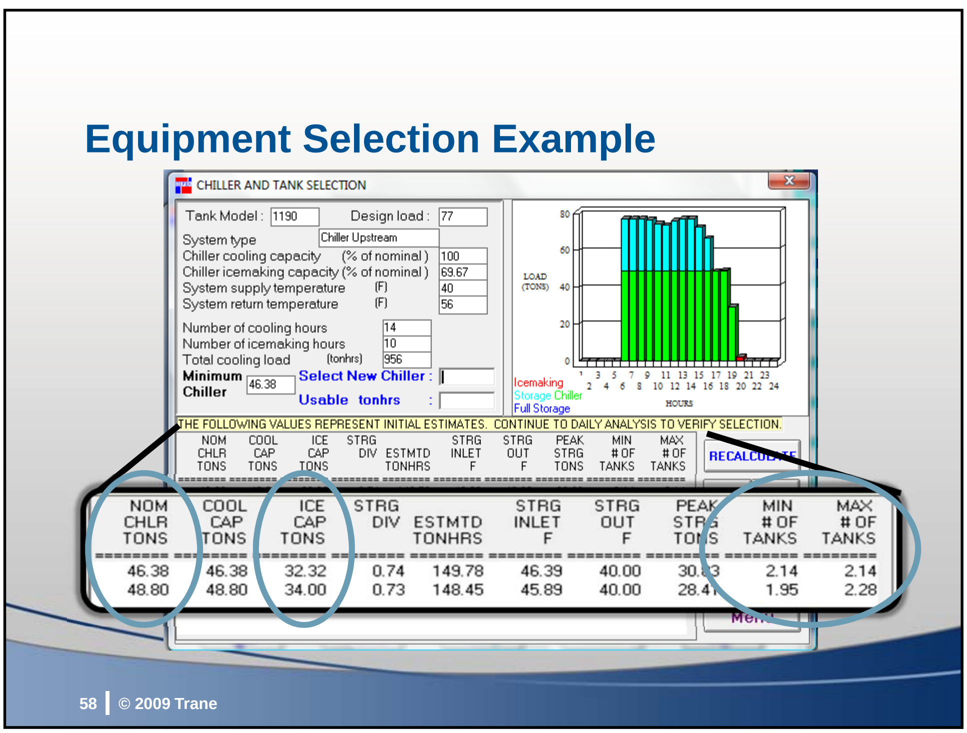

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Minimum Chiller 46.38
Select New Chiller :
Usable tonhrs :
LOAD (TONS)
HOURS
Icemaking
Storage Chiller
Full Storage
THE FOLLOWING VALUES REPRESENT INITIAL ESTIMATES. CONTINUE TO DAILY ANALYSIS TO VERIFY SELECTION.
RECALCULATE
NOM CHLR TONS | COOL CAP TONS | ICE CAP TONS | STRG DIV | ESTMTD TONHRS | STRG INLET F | STRG OUT F | PEAK STRG TONS | MIN # OF TANKS | MAX # OF TANKS
46.38 | 46.38 | 32.32 | 0.74 | 149.78 | 46.39 | 40.00 | 30.83 | 2.14 | 2.14
48.80 | 48.80 | 34.00 | 0.73 | 148.45 | 45.89 | 40.00 | 28.41 | 1.95 | 2.28
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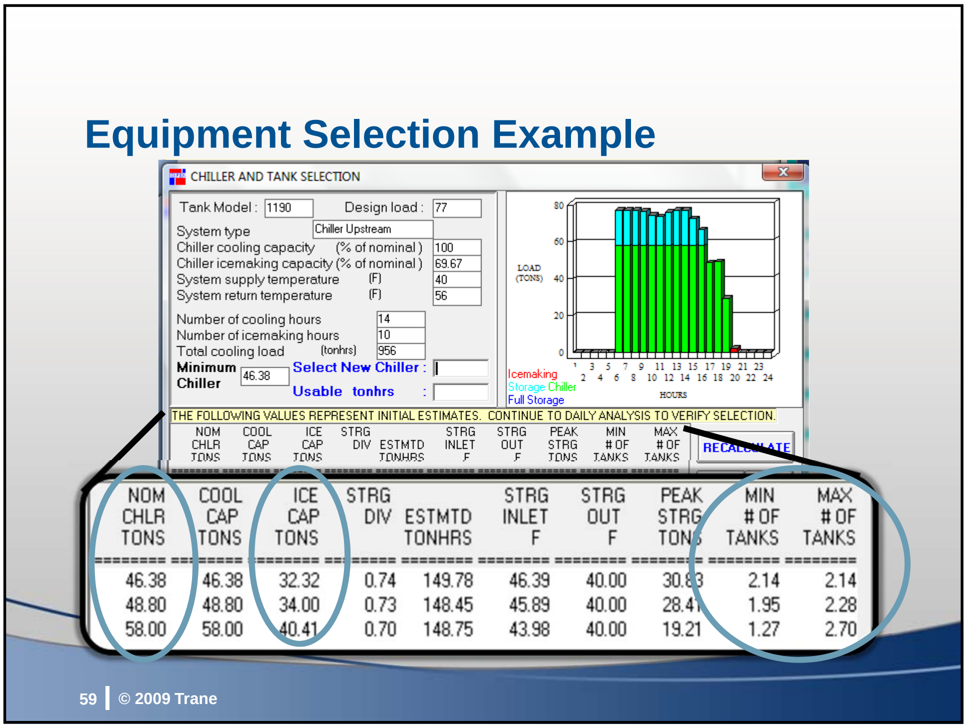

Equipment Selection Example
CHILLER AND TANK SELECTION
Tank Model : 1190
Design load : 77
System type: Chiller Upstream
Chiller cooling capacity (% of nominal) 100
Chiller icemaking capacity (% of nominal) 69.67
System supply temperature (F) 40
System return temperature (F) 56
Number of cooling hours 14
Number of icemaking hours 10
Total cooling load (tonhrs) 956
Minimum Chiller 46.38
Select New Chiller :
Usable tonhrs :
Icemaking
Storage Chiller
Full Storage
LOAD (TONS)
HOURS
THE FOLLOWING VALUES REPRESENT INITIAL ESTIMATES. CONTINUE TO DAILY ANALYSIS TO VERIFY SELECTION.
RECALCULATE
NOM CHLR TONS | COOL CAP TONS | ICE CAP TONS | STRG DIV | ESTMTD TONHRS | STRG INLET F | STRG OUT F | PEAK STRG TONS | MIN # OF TANKS | MAX # OF TANKS
46.38 46.38 32.32 0.74 149.78 46.39 40.00 30.83 2.14 2.14
48.80 48.80 34.00 0.73 148.45 45.89 40.00 28.41 1.95 2.28
58.00 58.00 40.41 0.70 148.75 43.98 40.00 19.21 1.27 2.70
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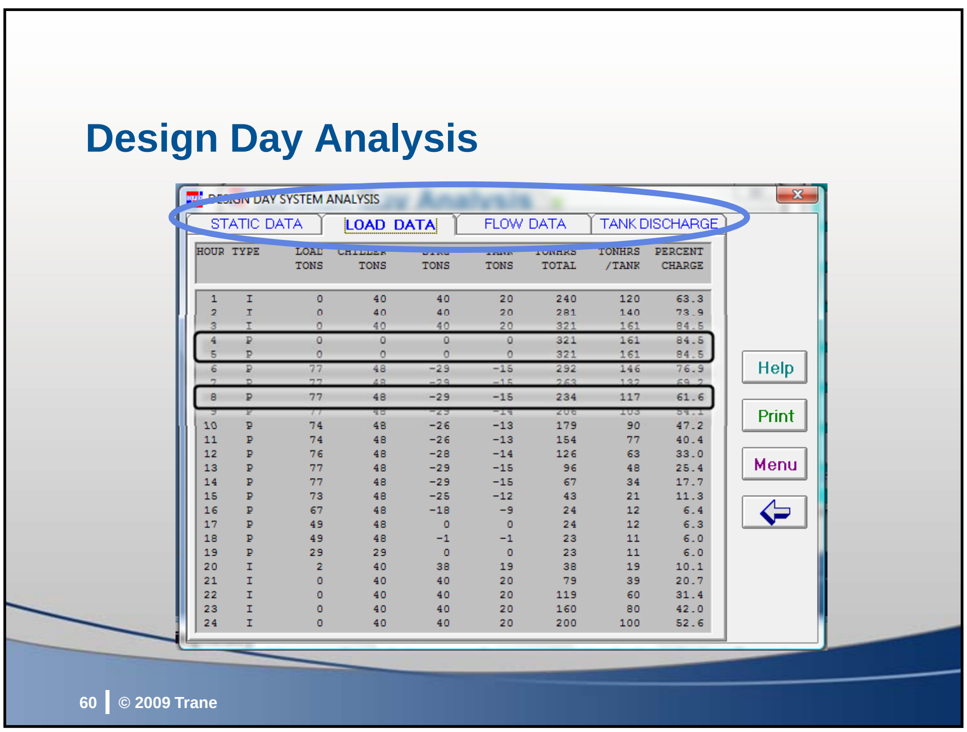

Design Day Analysis
DESIGN DAY SYSTEM ANALYSIS
STATIC DATA
LOAD DATA
FLOW DATA
TANK DISCHARGE
Help
Print
Menu
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Ice Storage Selection Options

- 46 ton nominal chiller/3 ice tanks

or

- 58 ton nominal chiller/2 ice tanks
  - Less charging time
  - Demand limit chiller on peak day

or

- 70 ton nominal chiller/3 ice tanks
  - Higher first cost
  - Will it pay back?

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Ice Storage Design and Application

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Qualifying Design —Utility Rates

Lee Cline

Ingersoll Rand

Ice Storage Design Process

Qualify Job

Target Prospective Job	Acquire Data	Initial System Sizing	Initial Financial Analysis	Initial Financial Proposal

• Chilled water
• Doing something
• Utility cost conscious
• Day loading
• Tank siting
• Code compliance
	• New/existing
	• Preliminary load profile
	  • Peak
	  • Daily curve
	•Utility rate
	•Future use
		• Ice Pick	• System Analyzer
			• First Pass
				•Proforma
				•ROI
				•Schedule

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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

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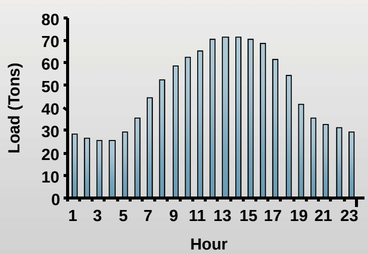
Ice Energy Storage Design
Monthly Load Factor

$$\frac{\text{Month's kWh Usage}}{\text{Peak Demand (kW) x 730 hours per month}}$$

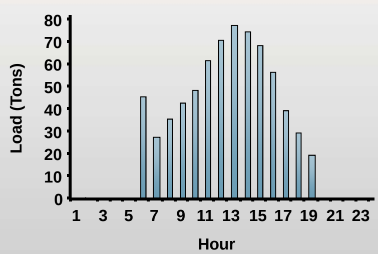
Ice Energy Storage Design
Monthly Load Factor

High Load Factor



Load Factor = 63

Low Load Factor



Load Factor = 37

Ice Storage and Application

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Ice Storage Design and Application

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Qualifying Rates

Paul Valenta

Ingersoll Rand

Electric Rates and Types

- Demand rate—most common
  - Ratchet
  - Time of day

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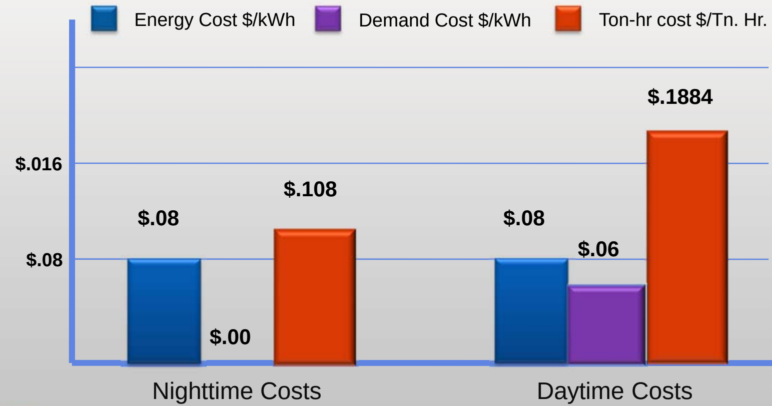
Ton-hr Cost on a Standard Demand Rate

$ 11.00/kW and $.08/kWh*



* Assumes building with daytime peak

Electric Rates and Types

- Demand rate—most common
  - Ratchet
  - Time of day
- Stepped rate

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Georgia Power Electric Rates PLM-4

All consumption (kWh) not greater than

200 hours times the billing demand:

First 3,000 kWh ....@..................... 9.317¢ per kWh
Next 7,000 kWh ....@.....................8.540¢ per kWh
Next 190,000 kWh ....@.....................7.350¢ per kWh
Over 200,000 kWh..@.....................5.696¢ per kWh

All consumption (kWh) in excess of 200 hours and not greater than 400 hours times the billing demand.. @......................... 0.949¢ per kWh

All consumption (kWh) in excess of 400 hours and not greater than 600 hours times the billing demand.. @......................... 0.715¢ per kWh

All consumption (kWh) in excess of 600 hours times the billing demand.............................. @......................... 0.623¢ per kWh

Minimum Monthly Bill:

A. $15.00 base charge plus $6.83 per kW of billing demand with a ratchet of 95% of peak
B. Summer demand

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Electric Rates and Types

- Demand rate—most common
  - Ratchet
  - Time of day
- Stepped rate
- Flat rate
- Real-time pricing

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Ice Storage Design and Application
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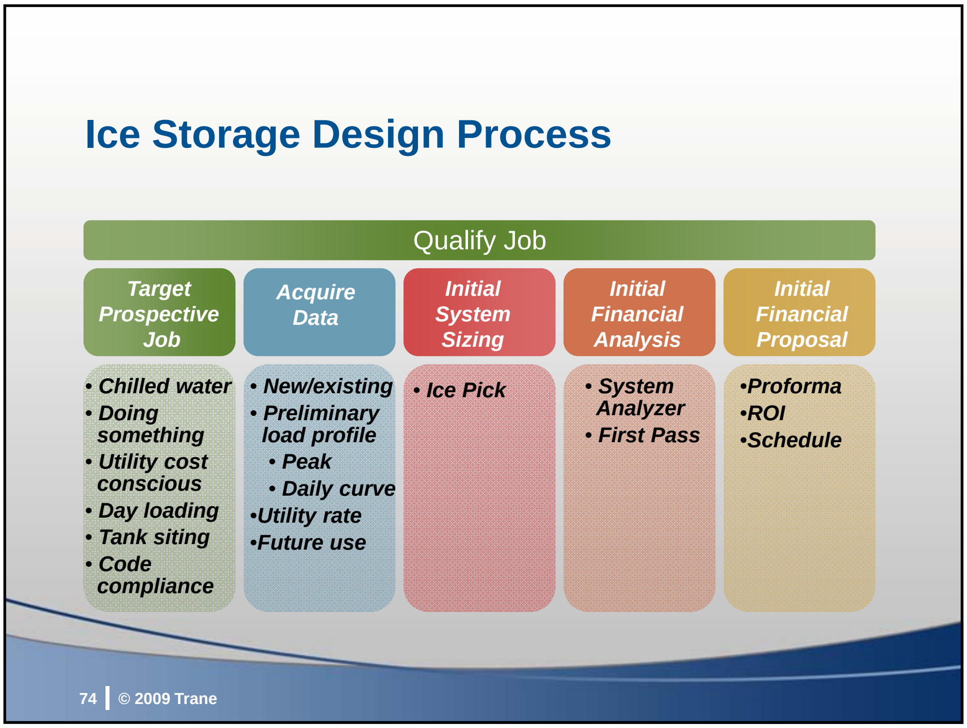
Qualifying ROI
Lee Cline
Ingersoll Rand


Ice Storage Design Process
Qualify Job
Target Prospective Job
Acquire Data
Initial System Sizing
Initial Financial Analysis
Initial Financial Proposal
• Chilled water
• Doing something
• Utility cost conscious
• Day loading
• Tank siting
• Code compliance
• New/existing
• Preliminary load profile
• Peak
• Daily curve
•Utility rate
•Future use
• Ice Pick
• System Analyzer
• First Pass
•Proforma
•ROI
•Schedule
74
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Ice Storage Design Process
Qualify Job
Target Prospective Job
Acquire Data
Initial Financial Proposal
CUSTOMER APPROVED
• Utility cost conscious
• Code compliance
• Preliminary load profile
• Ice Pick
• Schedule
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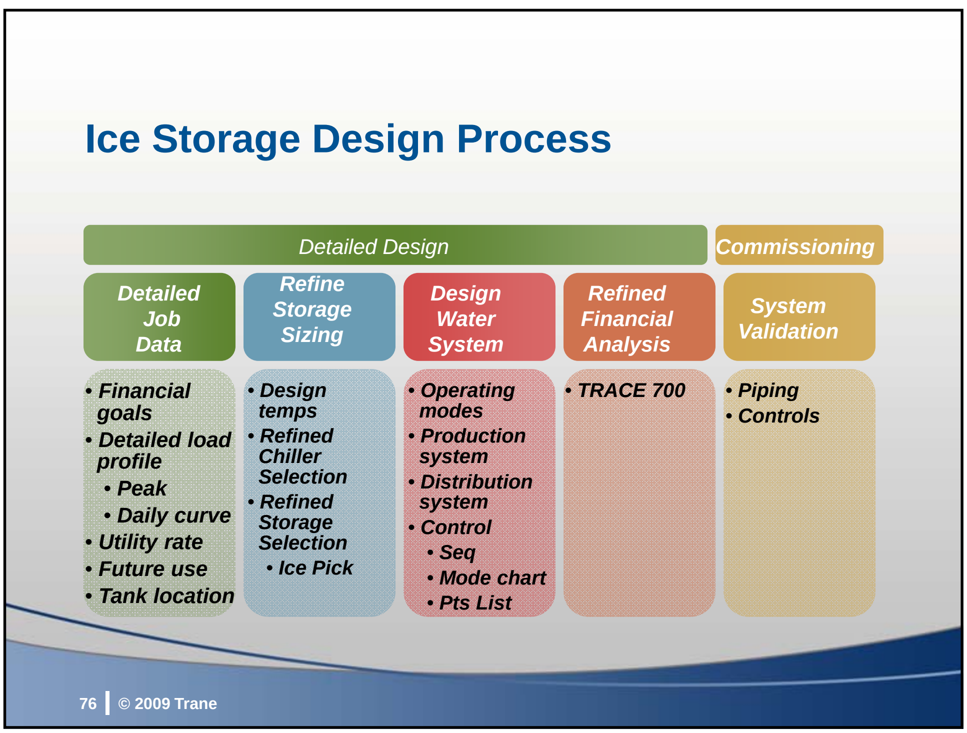

Ice Storage Design Process
Detailed Design
Commissioning
Detailed Job Data
Refine Storage Sizing
Design Water System
Refined Financial Analysis
System Validation
• Financial goals
• Detailed load profile
• Peak
• Daily curve
• Utility rate
• Future use
• Tank location
• Design temps
• Refined Chiller Selection
• Refined Storage Selection
• Ice Pick
• Operating modes
• Production system
• Distribution system
• Control
• Seq
• Mode chart
• Pts List
• TRACE 700
• Piping
• Controls
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Ice Storage Design and Application

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Design

Susanna Hanson

Ingersoll Rand

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

solution	freeze point	specific heat	viscosity
water	32°F	1.0 Btu/lb-°F	1.5 cp
ethylene glycol (25%)	11.4°F	0.90 Btu/lb-°F	3.2 cp
propylene glycol (30%)	9.3°F	0.92 Btu/lb-°F	5.2 cp

fluid temperature = 40°F

79 |

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

80 |

Proper Use of Glycol—Coils

solution	entering fluid °F	coil rows	total capacity MBh	pressure drop (air) in. H_2O	fluid flow rate gpm	pressure drop (fluid) ft. H_2O
water	45	6	455	0.64	75.5	6.89
25% EG	45	6	395	0.62	86.4	7.83

Proper Use of Glycol—Coils

solution	entering fluid °F	coil rows	total capacity MBh	pressure drop (air) in. H_2O	fluid flow rate gpm	pressure drop (fluid) ft. H_2O
water	45	6	455	0.64	75.5	6.89
25% EG	45	6	395	0.62	86.4	7.83
25% EG	45	8	455	0.83	86.4	9.81

Proper Use of Glycol—Coils

solution	entering fluid °F	coil rows	total capacity MBh	pressure drop (air) in. H_2O	fluid flow rate gpm	pressure drop (fluid) ft. H_2O
water	45	6	455	0.64	75.5	6.89
25% EG	45	6	395	0.62	86.4	7.83
25% EG	45	8	455	0.83	86.4	9.81
25% EG	45	6	455	0.65	120.7	14.3

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Proper Use of Glycol—Coils

solution	entering fluid °F	coil rows	total capacity MBh	pressure drop (air) in. H_2O	fluid flow rate gpm	pressure drop (fluid) ft. H_2O
water	45	6	455	0.64	75.5	6.89
25% EG	45	6	395	0.62	86.4	7.83
25% EG	45	8	455	0.83	86.4	9.81
25% EG	45	6	455	0.65	120.7	14.3
25% EG	40	6	455	0.64	84.1	7.52

We didn’t change the coil, so this works in existing building retrofits too

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Proper Use of Glycol—Coils

solution	entering fluid °F	coil rows	total capacity MBh	pressure drop (air) in. H_2O	fluid flow rate gpm	pressure drop (fluid) ft. H_2O
water	45	6	455	0.64	75.5	6.89
25% EG	45	6	395	0.62	86.4	7.83
25% EG	45	8	455	0.83	86.4	9.81
25% EG	45	6	455	0.65	120.7	14.3
25% EG	40	6	455	0.64	84.1	7.52
25% EG	38	6	455	0.64	76.8	6.41

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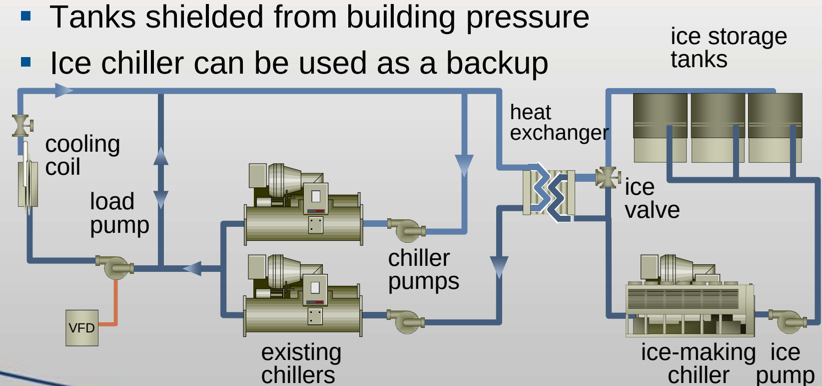
Dedicated Ice Chillers with HX

- Ice chiller on tank loop shields building from glycol
- Tanks shielded from building pressure
- Ice chiller can be used as a backup



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Chiller Impact of Glycol

- Chiller plus ice cooling mode
  - 48–56 for upstream chiller
  - 60-ton nominal chiller
  - 25% glycol
  - Ice making capable
- Ice charging mode
  - 21.6 average leaving chiller (from IcePick)
  - 134 gpm (from IcePick)
  - 60-ton nominal chiller
  - 25% glycol

87 |

Chiller Selections—Dual Modes

CGAM-1, 48-56

Performance

Unit type:	High efficiency	Full load efficiency:	10.7 EER
Unit nominal tonnage:	60 tons	IPLV:	15.8 EER
Capacity:	59.50 tons	NPLV:	16.8 EER

Evaporator

Evap application:	Ice making w/ interface	Evap fluid freeze point:	11.40 F
Evap leaving temp:	48.00 F	Evap fouling factor:	0.00010 hr-ft?-deg F/Btu
Evap entering temp:	56.00 F	Min evap flow rate:	71.00 gpm
Evap flow rate:	190.70 gpm	Press drop at min evap flow:	5.70 ft H2O
Evap press drop:	35.70 ft H2O	Max evap flow rate:	213.10 gpm
Evap fluid type:	Ethylene glycol	Press drop at max evap flow:	43.90 ft H2O
Evap fluid concentration:	25.00 %	Pressure vessel code:	BPHE - exempt from ASME

88 |

Chiller Selections—Dual Modes

CGAM 21-27 EG

Performance

Unit type:	High efficiency	Full load efficiency:	7.1 EER
Unit nominal tonnage:	60 tons	IPLV:	15.8 EER
Capacity:	39.60 tons	NPLV:	11.6 EER

Evaporator

Evap application:	Ice making w/ interface	Evap fluid freeze point:	11.40 F
Evap leaving temp:	21.60 F	Evap fouling factor:	0.00010 hr-ft?-deg F/Btu
Evap entering temp:	27.60 F	Min evap flow rate:	71.00 gpm
Evap flow rate:	170.40 gpm	Press drop at min evap flow:	5.70 ft H2O
Evap press drop:	29.00 ft H2O	Max evap flow rate:	213.10 gpm
Evap fluid type:	Ethylene glycol	Press drop at max evap flow:	43.90 ft H2O
Evap fluid concentration:	25.00 %	Pressure vessel code:	BPHE - exempt from ASME

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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

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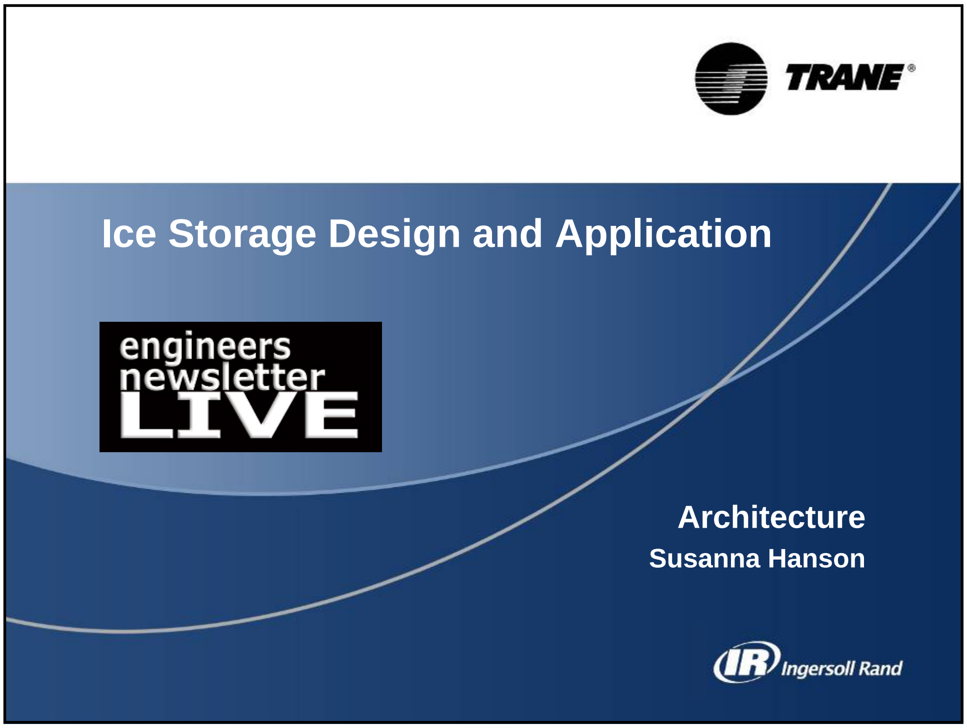

Design—Project Level Considerations

- 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

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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

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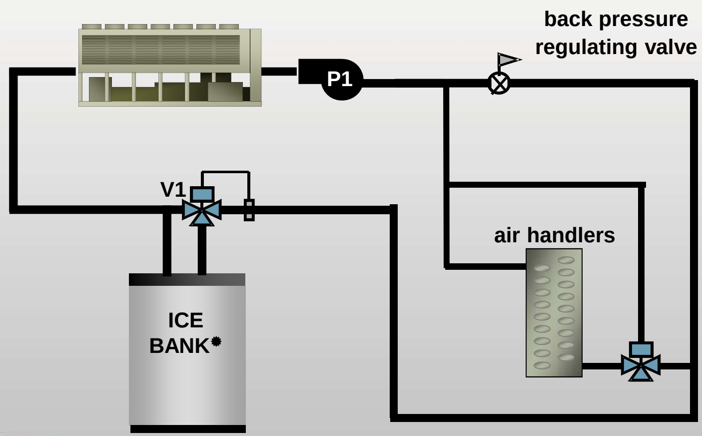
Chilled Water Distribution Design
Constant Volume



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Chilled Water Distribution Design
Variable Primary Flow

- **Preference for high system delta T in systems with ice**
  - Gives the chiller more flow turndown
  - New chiller designs don't need this for good turndown
- **If glycol throughout system**
  - Variable flow and pump pressure optimization save more energy than primary secondary
  - Wide delta T may have eliminated pump penalty already
- **Not as much experience**
  - IcePick does not currently model it
- **Controls more complicated**
  - Cool plus charge mode more difficult

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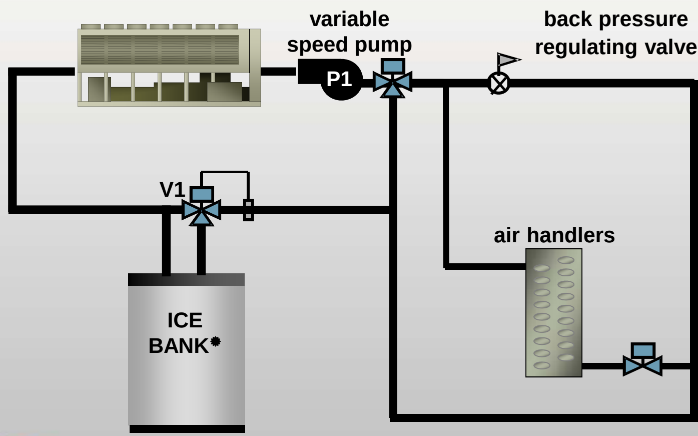
Chilled Water Distribution Design
Variable Primary Flow



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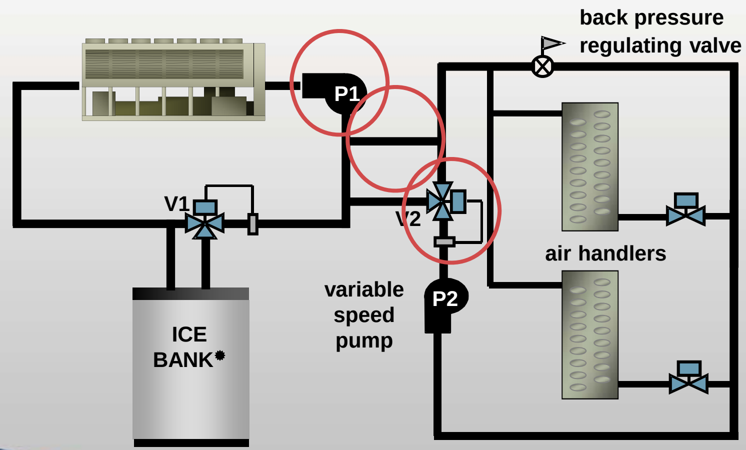
Chilled Water Distribution Design
Constant Primary/Variable Secondary



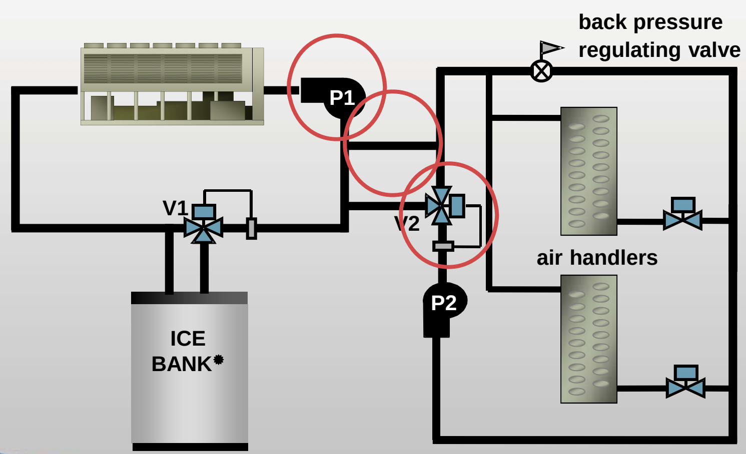
Chilled Water Distribution Design
Constant Primary/Variable Secondary

- Ice chillers and cooling only chillers
  - Simplified pumping and control
- Natural way to blend water temps to control the distribution supply water temp
  - Needed for simultaneous Freeze + Cool mode
- If glycol throughout system
  - Variable flow and pump pressure optimization
  - Increased net-usable ton hours from higher return water temperatures

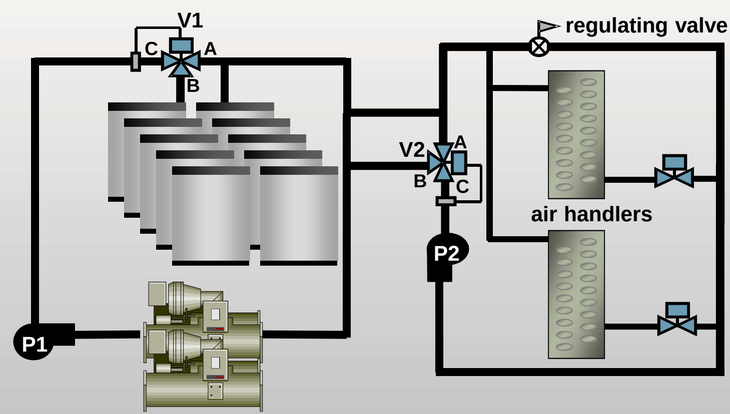
Alternative Designs

- How many pumps? Pump location?
- Bypass location?
- Valves location?

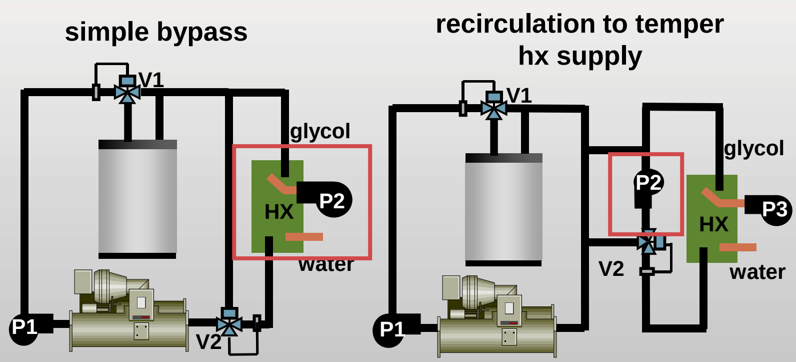
Alternative Designs



Alternative Designs



Series, Decoupled, Chiller Downstream



Ice Storage Design and Application

engineers newsletter LIVE

Controls

Ingersoll Rand

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

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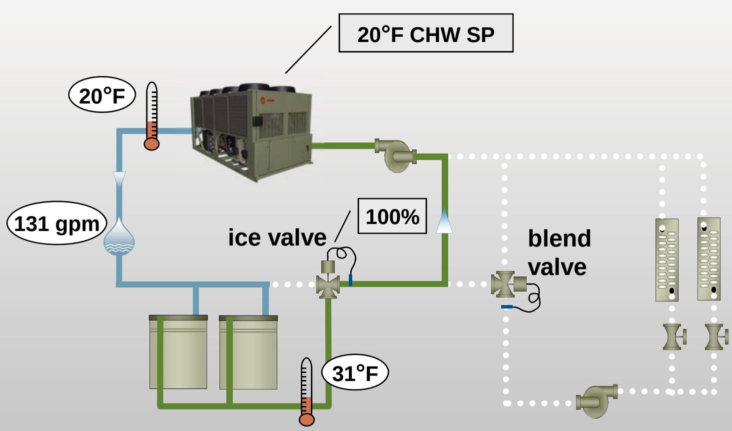
System Mode Diagrams
Ice Making Mode



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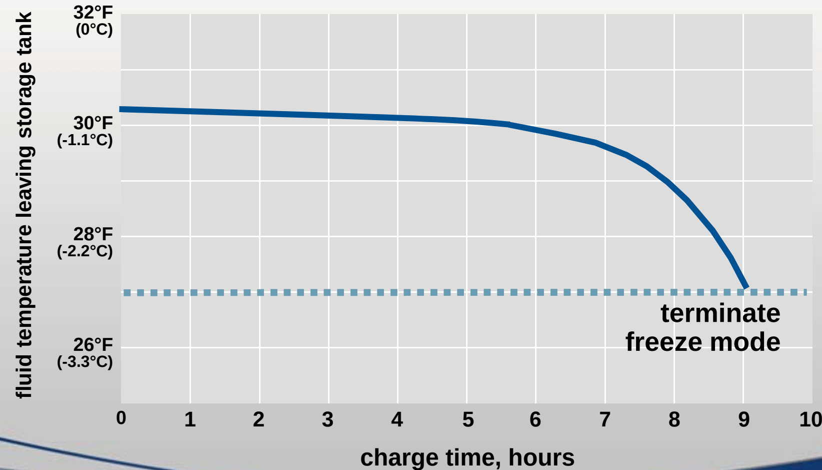
Ice Storage
Freeze Mode Termination



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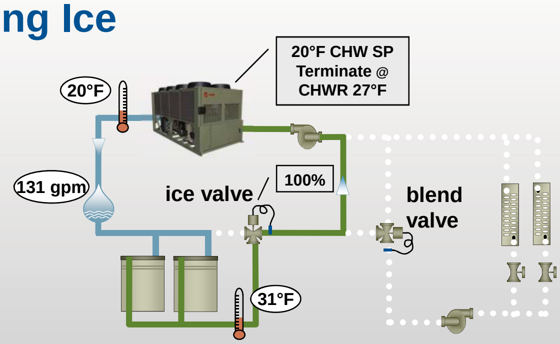
Control Mode Definition
Making Ice



Mode	Chiller Pump	Chiller	Ice Valve	Blend Valve	Distribution Pump
Make Ice	On at design	Enable CHWSP: 20°F Terminate @ CHWR 27°F	15°F (100% thru ice)	--	Off

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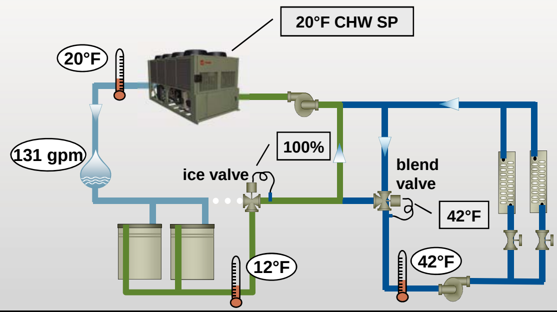
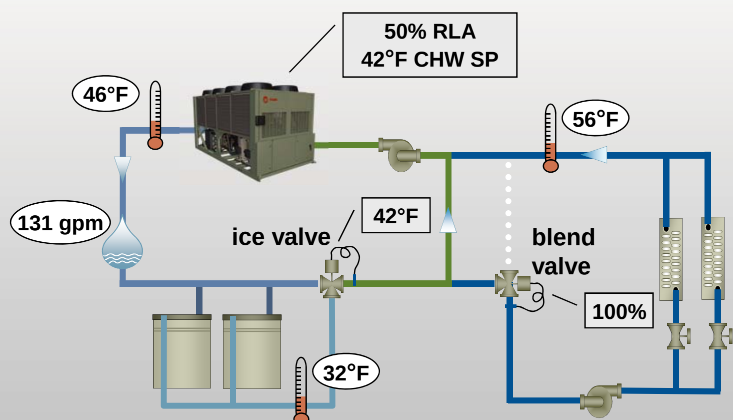
Control Mode Definition
Making Ice and Cool



Mode	Chiller Pump	Chiller	Ice Valve	Blend Valve	Distribution Pump
Make Ice	On at design	Enable CHWSP: 20°F Terminate @ CHWR 27°F	15°F (100% thru ice)	42°F	Modulate on remote ΔP

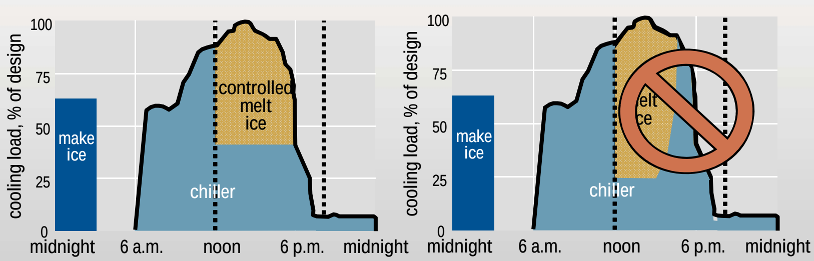
Control Mode Definition
Chiller + Ice Cooling



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

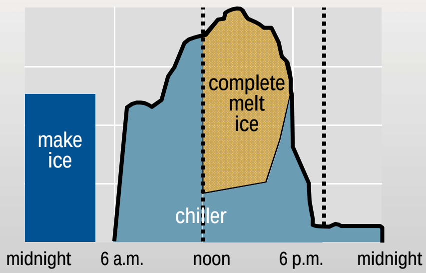


kW avoidance

Do not run out of ice!

Energy Saving Goal

Load Shifting—kWh Deferral

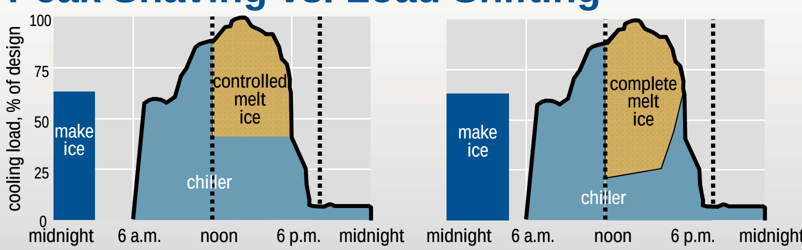


kWh deferral

Melt as much ice as possible!

Control Mode Definition

Peak Shaving vs. Load Shifting



Mode	Chiller Pump	Chiller	Ice Valve	Blend Valve	Distribution Pump
Chiller + Ice Cooling	On at design	Enable RLA Limit: 50% CHWSP: 42°F	42°F	40°F (100% to load)	Modulate on remote ∆P
Chiller + Ice Cooling	On at design	Enable RLA Limit: 30% CHWSP: 42°F	42°F	40°F (100% to load)	Modulate on remote ∆P

Ice Storage
Control Mode Definition

Mode	Chiller Pump	Chiller	Ice Valve	Blend Valve	Distribution Pump
Chiller Only	On	Enable CHWSP 42°F	55°F (0% Ice)	40°F (100% to load)	Modulate on remote ∆P
Ice Only	On	OFF	42°F	40°F (100% to load)	Modulate on remote ∆P
Chiller & Ice	On	Enable CHWSP 42°F RLA Limit 30-50%	42°F	40°F (100% to load)	Modulate on remote ∆P
Make Ice	On	Enable CHWSP 23°F	15°F (100% to ice)	80°F 0% to load)	Off
Make Ice & Cool	On	Enable CHWSP 23°F	15°F (100% to ice)	42°F	Modulate on remote ∆P
Off	Off	Off	-	-	Off

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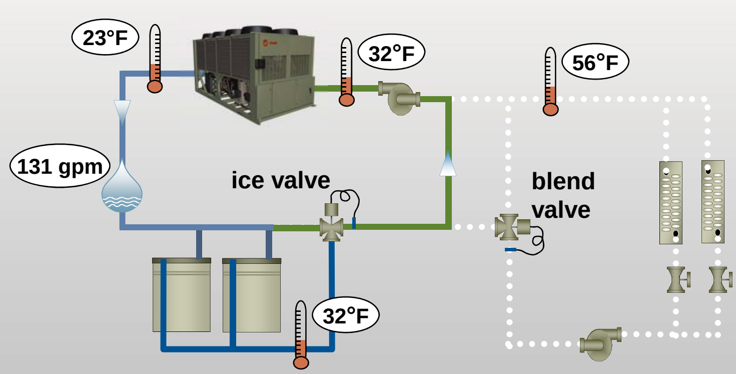
Control Mode Definition
Diagnostics



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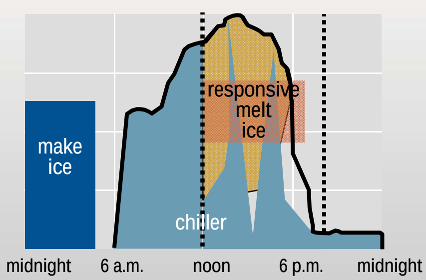
Control of an Ice System

Utility Rate Coordination

- Time of day based mode selection
- Direct measurement of building demand
- Demand response signal from utility
- Monitoring of real-time pricing

Energy Saving Goal

Real Time Pricing Response



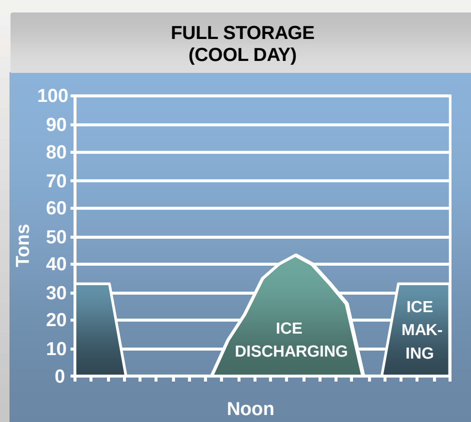
kWh deferral

Melt as much ice as possible!

Control of an Ice System
Informed Operators

- Operator interface
  - Well-documented sequence of operation
  - Mode diagram based graphical interface
- Flexible chiller demand control
  - Three button manual control

Control of an Ice System
Keep It Simple



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

Ice Storage Design and Application

engineers newsletter LIVE

Economics
First Cost
Paul Valenta

Ingersoll Rand

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

Fort Myers Regional Service Center

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

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

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Economic Analysis
TRACE
Susanna Hanson

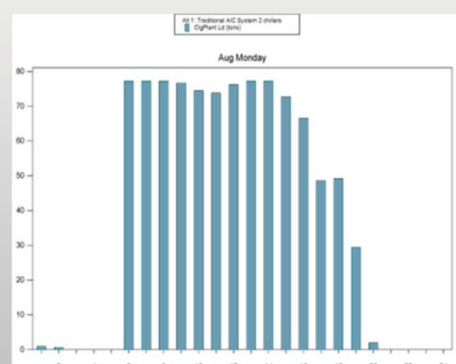
Ingersoll Rand

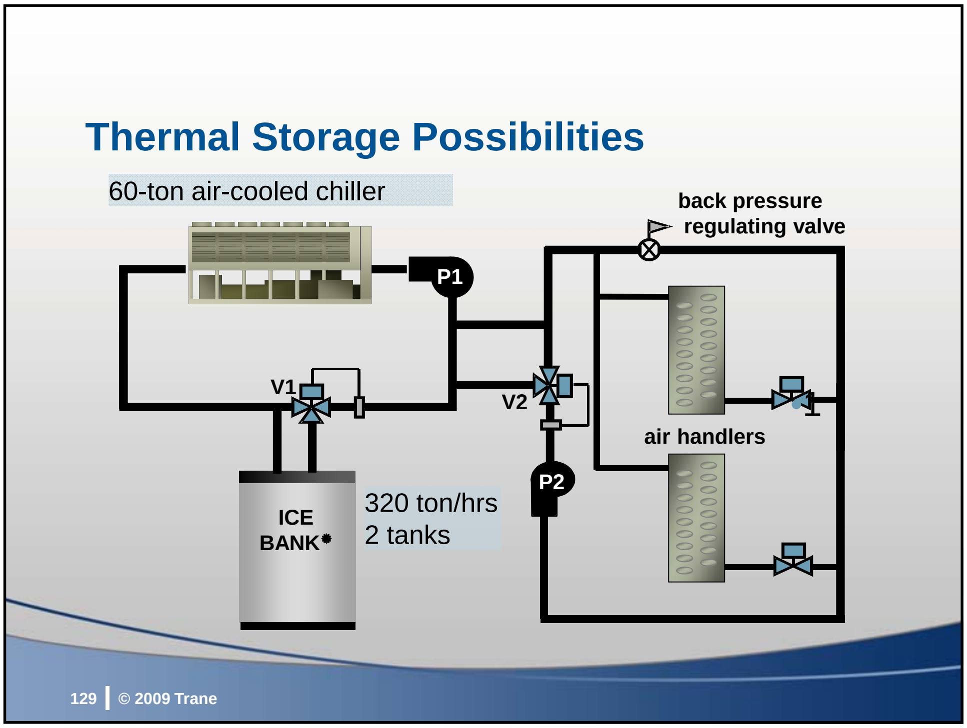
Economic Assumptions

- 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




Thermal Storage Possibilities
60-ton air-cooled chiller
back pressure
regulating valve
P1
V1
V2
air handlers
P2
ICE
BANK
320 ton/hrs
2 tanks
129
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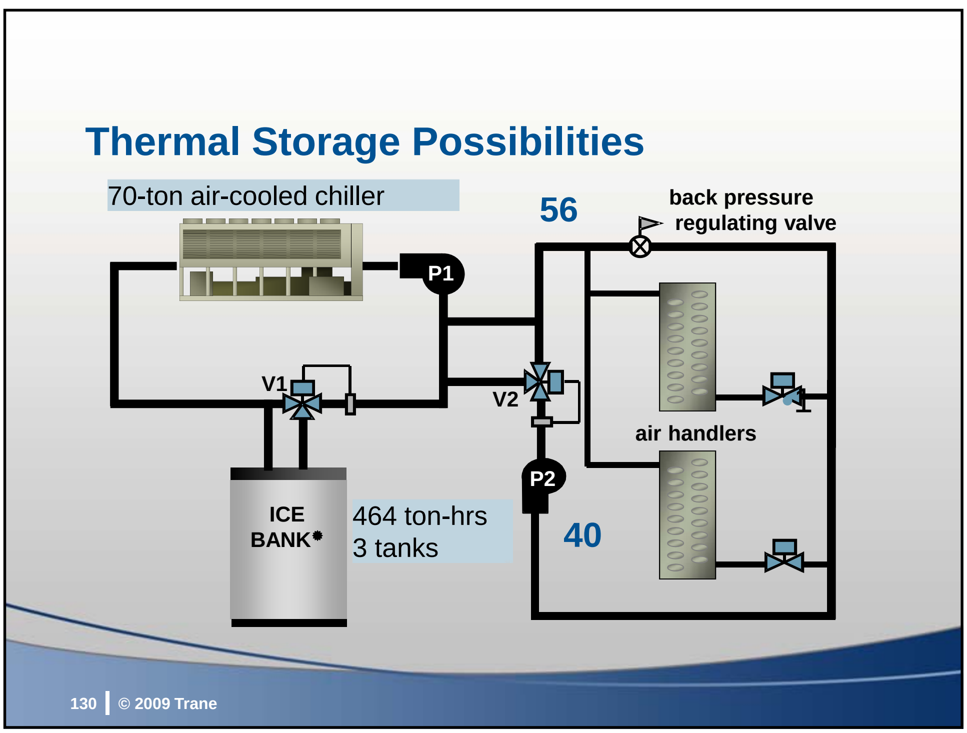
Thermal Storage Possibilities
70-ton air-cooled chiller
56
back pressure
regulating valve
P1
V1
V2
air handlers
P2
ICE
BANK
464 ton-hrs
3 tanks
40
130
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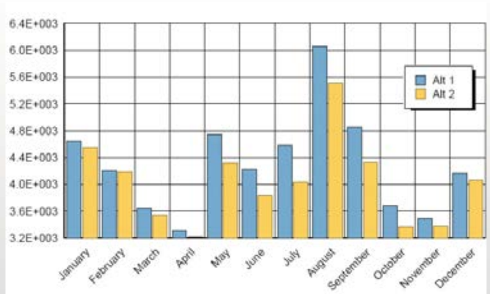
Economics

- 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

Alternative Number	Installed Cost	First Year Util.Cost	Final Year Util. Cost	First Year Maint. Cost	Final Year Maint. Cost	Life Cycle Cost
1	143,000.00	51,599.49	51,599.49	2,000.00	2,000.00	616,080.07
2	158,015.00	48,329.84	48,329.84	1,200.00	1,200.00	579,690.40

Alt. - Alt.	First Cost Difference	Simple Payback	Net Present Value	Life Cycle Payback	Internal Rate of Return
2 - 1	15,015.00	3.7 yrs	36,389.67	4.8 yrs	29.7 %

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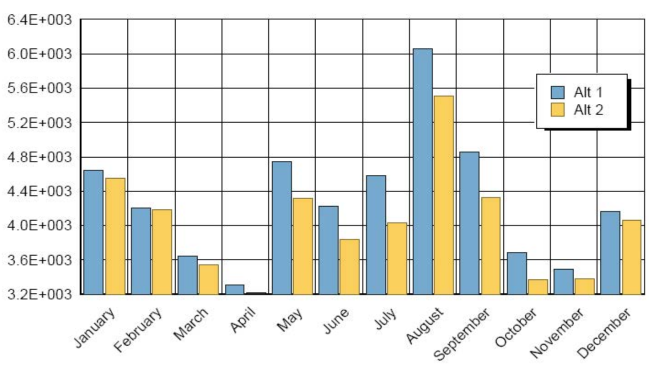
Economic Summary

Alternative Number	Installed Cost	First Year Util.Cost	Final Year Util. Cost	First Year Maint. Cost	Final Year Maint. Cost	Life Cycle Cost
1	143,000.00	51,599.49	51,599.49	2,000.00	2,000.00	616,080.07
2	158,015.00	48,329.84	48,329.84	1,200.00	1,200.00	579,690.40

Economic Comparison of the Alternatives

Alt. - Alt.	First Cost Difference	Simple Payback	Net Present Value	Life Cycle Payback	Internal Rate of Return
2 - 1	15,015.00	3.7 yrs	36,389.67	4.8 yrs	29.7 %



Reduced Demand

Alternative 1 **Traditional A/C System 2 cl**

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

Equipment Description		Electrical Demand (kw)	Percent of Total (%)
Cooling Equipment			
Air-cooled chiller - 002		61.68	27.72
Air-cooled chiller - 001		68.88	30.95
	Sub total	130.56	58.67

Alternative 3 **Larger Thermal Storage 1 c**

Yearly Time of Peak: 11(Hr) 8(Month)

Equipment Description		Electrical Demand (kw)	Percent of Total (%)
Cooling Equipment			
Air-cooled chiller - 001		59.54	36.46
	Sub total	59.54	36.46

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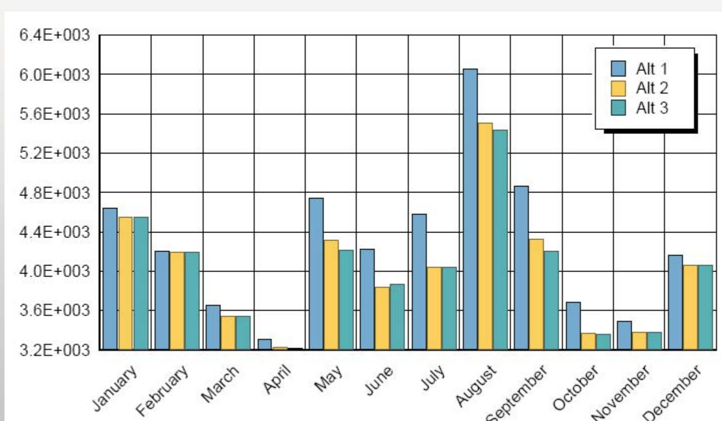
Larger Storage System



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Larger Storage System

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

Economic Summary

Alternative Number	Installed Cost	First Year Util.Cost	Final Year Util. Cost	First Year Maint. Cost	Final Year Maint. Cost	Life Cycle Cost
1	143,000.00	51,599.49	51,599.49	2,000.00	2,000.00	616,080.07
2	158,015.00	48,329.84	48,329.84	1,200.00	1,200.00	579,690.40
3	193,023.00	48,035.53	48,035.53	1,200.00	1,200.00	612,192.71

Economic Comparison of the Alternatives

Alt. - Alt.	First Cost Difference	Simple Payback	Net Present Value	Life Cycle Payback	Internal Rate of Return
2 - 1	15,015.00	3.7 yrs	36,389.67	4.8 yrs	29.7 %
3 - 1	50,023.00	11.5 yrs	3,887.36	15.1 yrs	10.9 %
3 - 2	35,008.00	118.9 yrs	-32,502.31	Does not pay back	Does not pay back

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Alternative 1 — **Traditional A/C System 2 cl**

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

Equipment Description		Electrical Demand (kw)	Percent of Total (%)
Cooling Equipment			
Air-cooled chiller - 002		61.68	27.72
Air-cooled chiller - 001		68.88	30.95
	Sub total	130.56	58.67

Alternative 2 — **Thermal Storage 1 chiller 2**

Yearly Time of Peak: 11(Hr) 8(Month)

Equipment Description		Electrical Demand (kw)	Percent of Total (%)
Cooling Equipment			
Air-cooled chiller - 001		69.86	40.23
	Sub total	69.86	40.23

Alternative 3 — **Larger Thermal Storage 1 c**

Yearly Time of Peak: 11(Hr) 8(Month)

Equipment Description		Electrical Demand (kw)	Percent of Total (%)
Cooling Equipment			
Air-cooled chiller - 001		59.54	36.46
	Sub total	59.54	36.46

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What If We Got a Rebate?

Economic Summary

Alternative Number	Installed Cost	First Year Util.Cost	Final Year Util. Cost	First Year Maint. Cost	Final Year Maint. Cost	Life Cycle Cost
1	143,000.00	51,599.49	51,599.49	2,000.00	2,000.00	616,080.07
2	146,015.00	48,329.84	48,329.84	1,200.00	1,200.00	567,690.40
3	179,023.00	48,035.53	48,035.53	1,200.00	1,200.00	598,192.71

Economic Comparison of the Alternatives

Alt. - Alt.	First Cost Difference	Simple Payback	Net Present Value	Life Cycle Payback	Internal Rate of Return
2 - 1	3,015.00	0.7 yrs	48,389.67	0.8 yrs	135.0 %
3 - 1	36,023.00	8.3 yrs	17,887.36	14.2 yrs	15.0 %
3 - 2	33,008.00	112.2 yrs	-30,502.31	Does not pay back	Does not pay back

Economic Comparison of the Alternatives

Alt. - Alt.	First Cost Difference	Simple Payback	Net Present Value	Life Cycle Payback	Internal Rate of Return
2 - 1	3,015.00	0.4 yrs	75,417.46	0.5 yrs	240.3 %
3 - 1	36,023.00	4.2 yrs	53,111.56	5.8 yrs	25.0 %
3 - 2	33,008.00	26.3 yrs	-22,305.90	Does not pay back	Does not pay back

Could We Have Done More to Maximize ROI?

- Other benefits
- Focus on incremental cost to the project
- Negotiate with utility for different tariff

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Ice Storage Design and Application

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Conclusion

Ingersoll Rand

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

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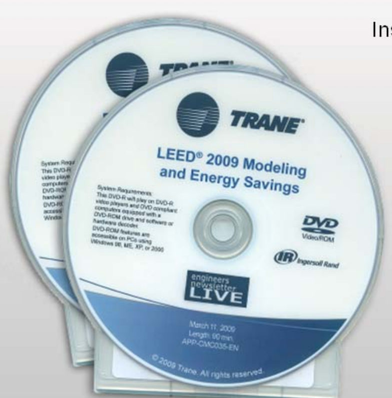

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- Air distribution
- Refrigerant-to-air systems
- Control strategies
- Industry standards and LEED
- Energy and the environment
- Acoustics
- Ventilation
- Dehumidification

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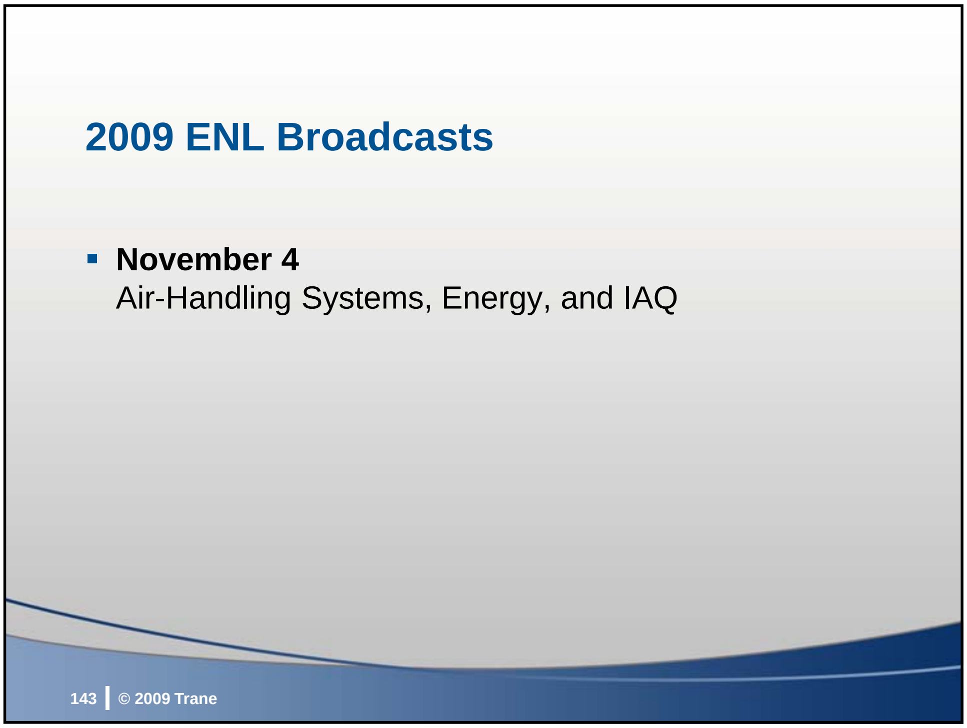
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