# The Pennsylvania State University
# Architectural Engineering

## GEORGE W. HAYS PK-8
## CINCINNATI, OH

### Ice Storage System Implementation

Rodrick A. Crousey
April 18, 2007

Mechanical Focus
Senior Thesis

Rendering Courtesy Moody·Nolan, Inc.

# Presentation Topics

- Building Overview
- Ice Storage System Design and Analysis
- Location of Ice Storage Tanks
- Electrical Equipment Downsizing
- Cost Payback Analysis
- Conclusion



# Criteria for Evaluation

- Cost
  - Higher First Cost vs. Annual Energy Savings
- Effect on Building Function
- Effect on Surrounding Community
  - On-Peak Energy Usage
  - Energy Consumption
- Educational



# Presentation Topics

- **Building Overview**
  - Ice Storage System Design and Analysis
  - Location of Ice Storage Tanks
  - Electrical Equipment Downsizing
  - Cost Payback Analysis
  - Conclusion



# Project Team

Moody-Nolan, Inc. – Architect & Civil Engineer

ThermalTech Engineering, Inc. – MEP Engineer

GOP Limited – Structural Engineer

Turner/DAG/TYS – Construction Manager

# Building Overview

- Pre-Kindergarten Through 8th Grade
  - Classrooms, Offices, Cafeteria, and Gym
- 500 Students
- 66,000 $ft^2$
- Owned by Cincinnati Public Schools

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# Building Overview

- $11,149,342 Construction Costs
- Construction 2006 - 2007
- Concrete Slabs on Metal Decking
- Brick Veneer, CMU Back Up
- EPDM Membrane Roof System

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# Building Overview

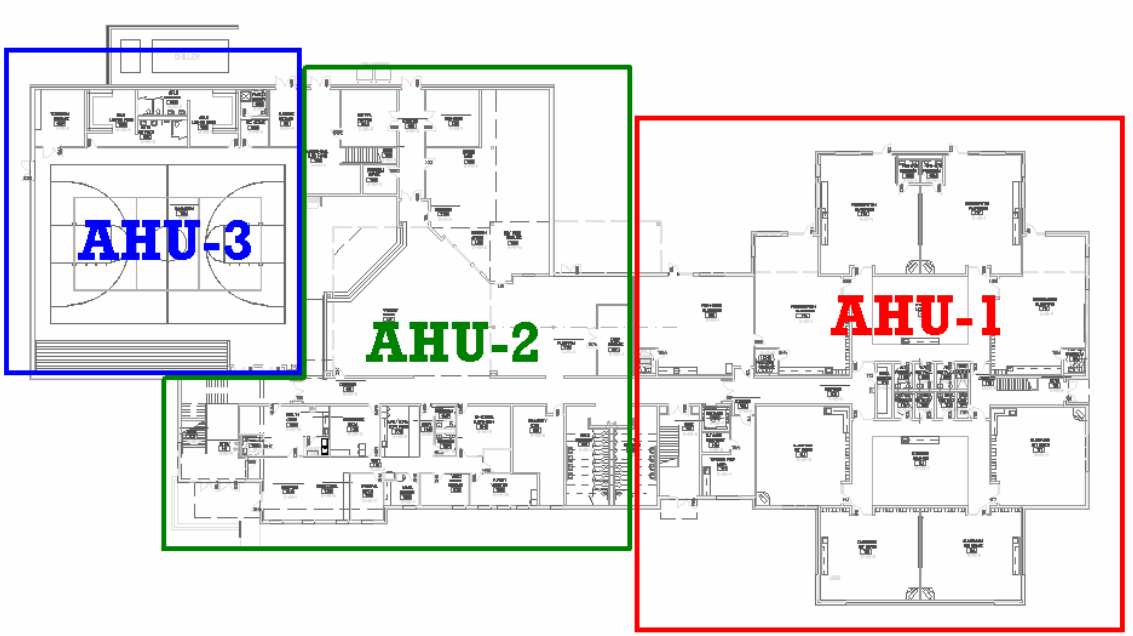
- Main Switch Board
  2000a, 480Y/277, 3P, 4W
- Primary Service
  480Y/277, 3P, 4W
- Secondary Service
  208Y/277, 3P, 4W



- AHU-1 Classrooms
- AHU-2 Offices/ Cafeteria
- AHU-3 Gymnasium

One 170 ton Chiller

Two 1500 Mbtu/hr
Natural Gas Boilers

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# Presentation Topics

- ✓ Building Overview
- ❑ **Ice Storage System Design and Analysis**
  - ❑ Location of Ice Storage Tanks
  - ❑ Electrical Equipment Downsizing
  - ❑ Cost Payback Analysis
  - ❑ Conclusion



# Ice System Research

- Building Engineer
- CALMAC Representative
- ASHRAE Design Guide

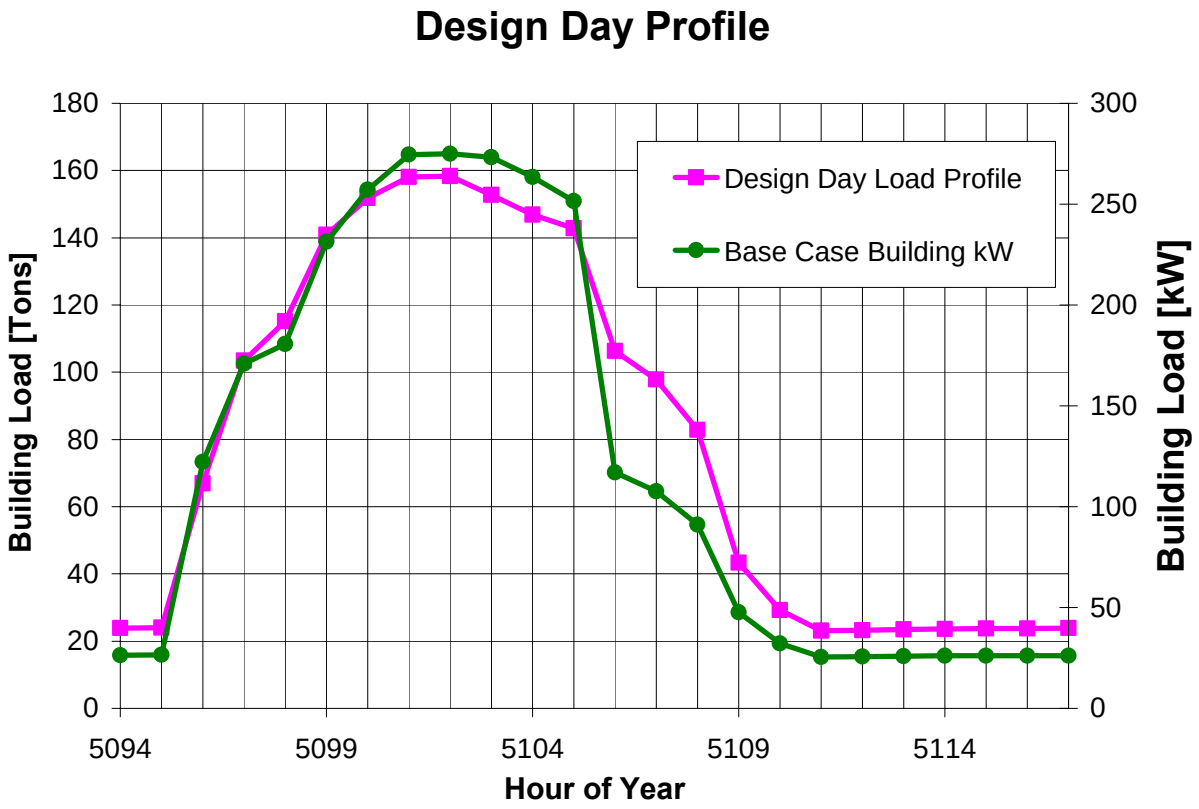


# Ice System Strategy

- Chiller Priority
- Chiller Upstream
- Internal Freeze – Internal Melt
- Ice Tanks in Parallel
- Primary/Secondary



- 158 Ton Max Load
- 22 Ton Base Load
- 1910 Ton-Hrs
- Similar Electric and Thermal Load Peak

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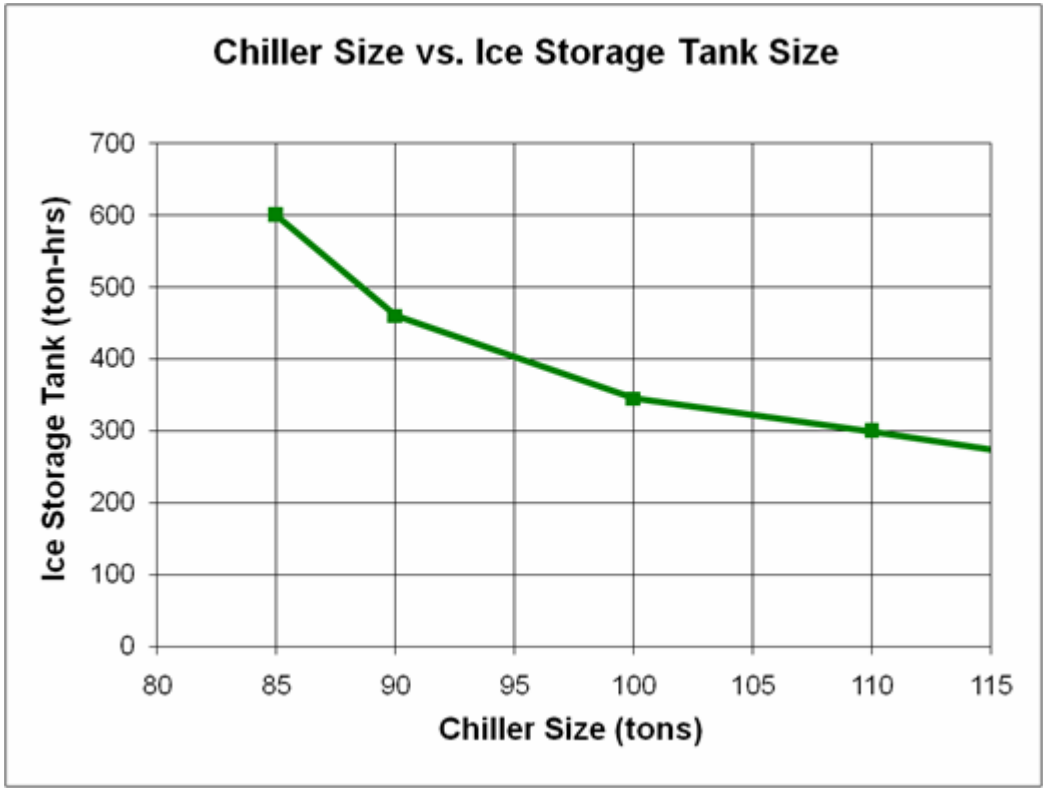
- 3 Cases Analyzed
  - 85 ton
  - 90 ton
  - 100 ton

- 90 ton Quickest Return

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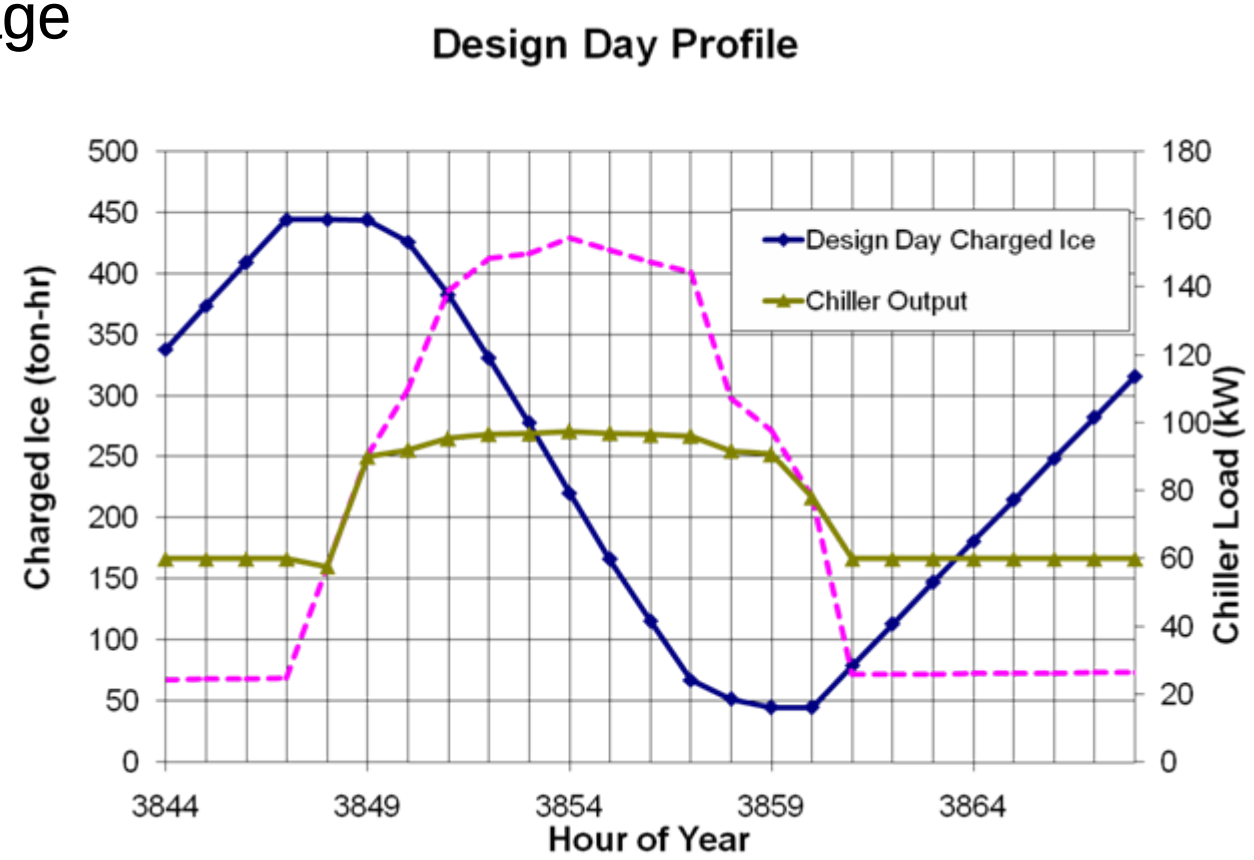
- 486 ton-hrs Ice Storage
- 90 ton Chiller
- 57 ton/hr Max Discharge Rate
- 36 ton/hr Max Charge Rate





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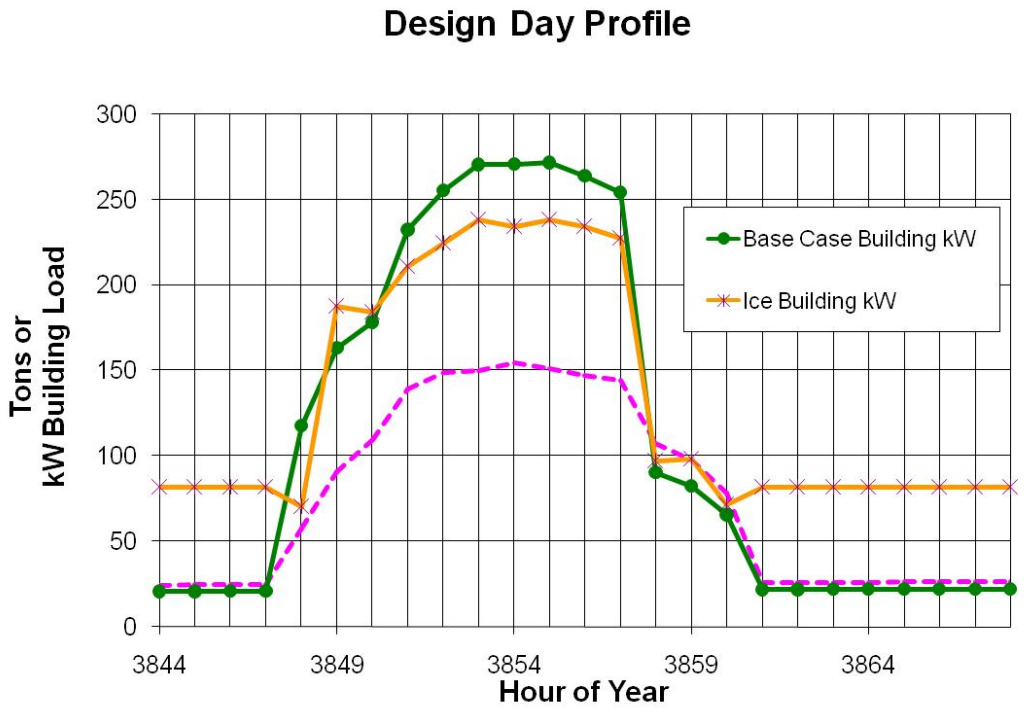
- From 271 kW to 238 kW
- Lower On-Peak Energy Usage
- Higher Off-Peak Energy Usage
- Higher Overall Energy Usage

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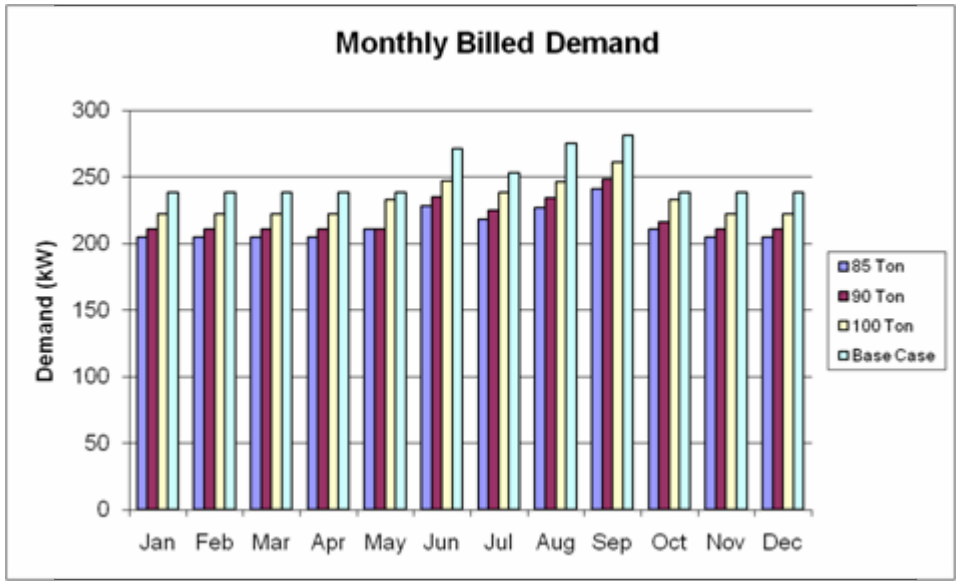


- Reduced Electrical Demand
- Drastically Reduced Billed Demand

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| Annual kW-h | | | |
|---|---|---|---|
| 85 | 90 | 100 | Base Case |
| 535795 | 530902 | 539144 | 513111 |

| Demand Peak kW | | | |
|---|---|---|---|
| 85 | 90 | 100 | Base Case |
| 241 | 248 | 261 | 281 |

| Annual Electric Bill | | | | |
|---|---|---|---|---|
| 85 | 90 | 100 | Base Case | |
| 35507 | 36162 | 37911 | 39486 | Annual Bill ($) |
| 10% | 8% | 4% | 0% | % Annual Savings |
| 0.066 | 0.068 | 0.070 | 0.077 | $/kW |

- 3% Higher kW-hr
- 12% Lower kW
- 8% Annual Savings

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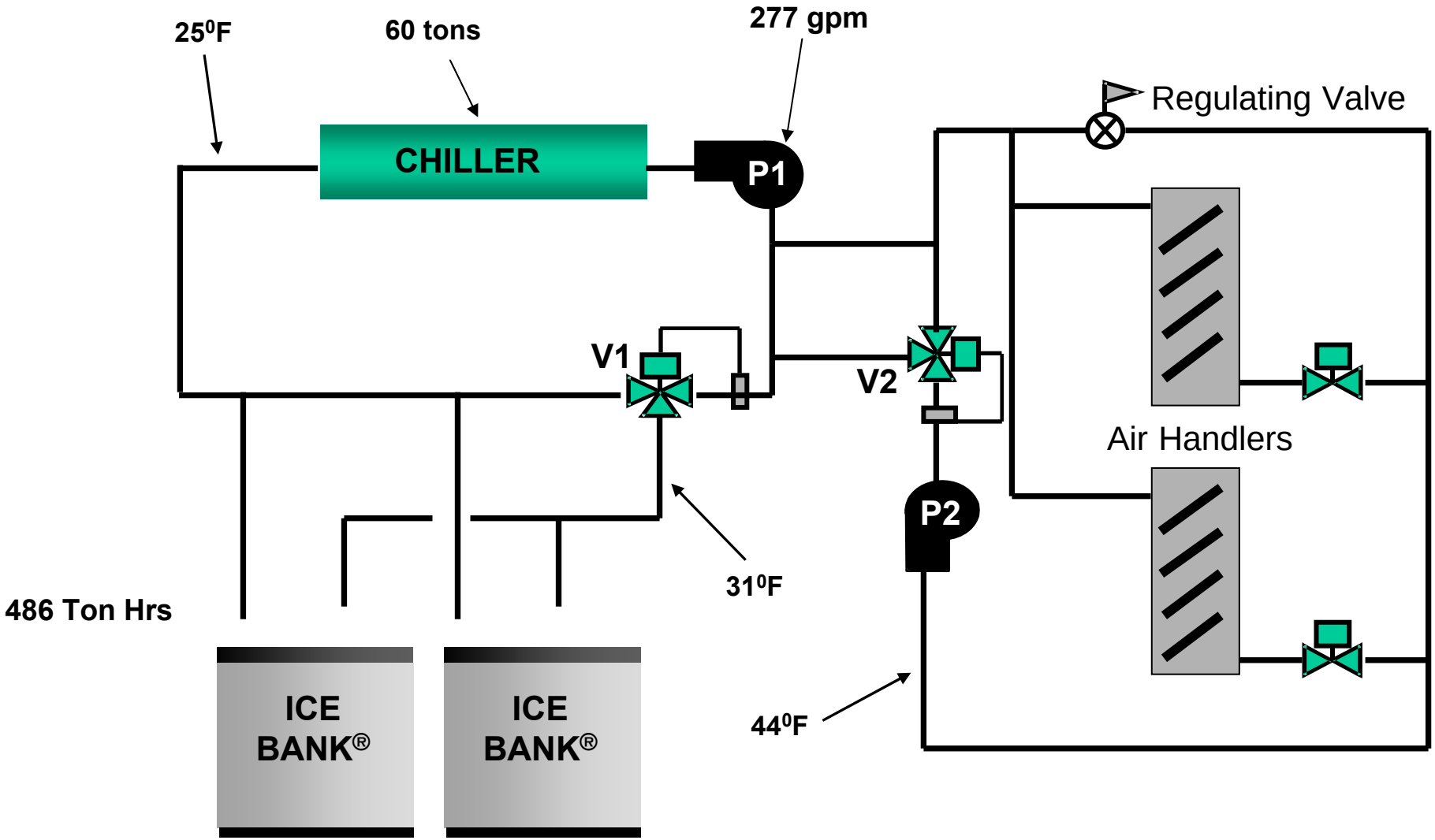
# Ice Storage System Piping Diagram Charging Cycle





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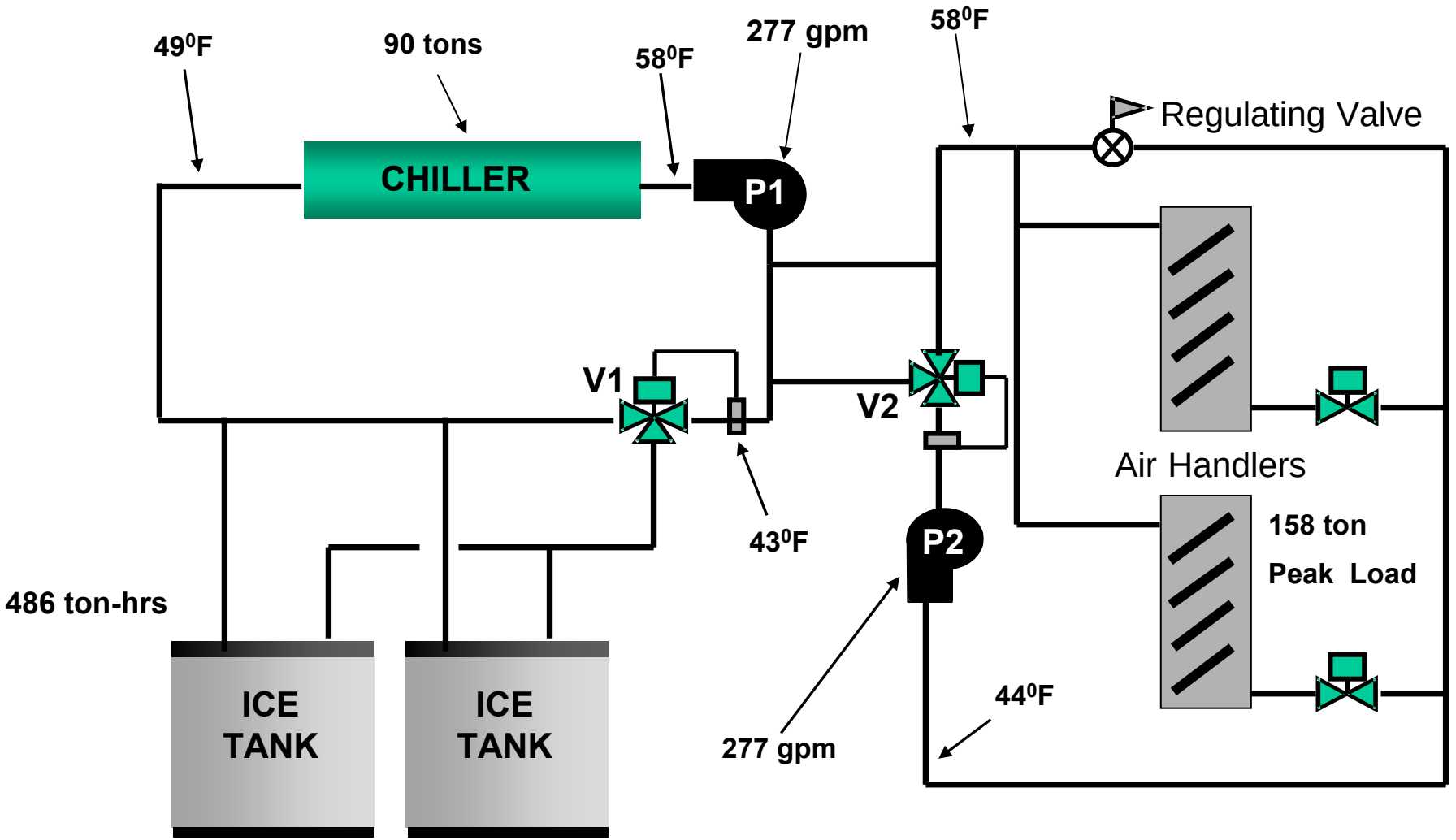
| Chiller Conditions | 90 tons | | | | | | | | IPLV |
|---|---|---|---|---|---|---|---|---|---|
| | Low T | High T | tons | kW | COP | COPcarnot | η Carnot | kW/ton | kW/ton |
| Reference | 499.7 | 544.7 | 89.9 | 88.9 | 3.6 | 11.1 | 0.3 | 1.1 | |
| Charging | 484.7 | 544.7 | 60.0 | 81.5 | 2.6 | 8.1 | 0.3 | 1.4 | 1.3 |
| Discharging | 503.7 | 554.7 | 90.8 | 99.8 | 3.2 | | | 1.1 | 0.9 |
| As Designed | 509.7 | 554.7 | | | | | | 1.1 | 0.8 |

- Lower supply temperature means higher kW/ton
- Smaller chiller means higher kW/ton
- Increased IPLV



# Ice Storage System Piping Diagram Discharge Cycle





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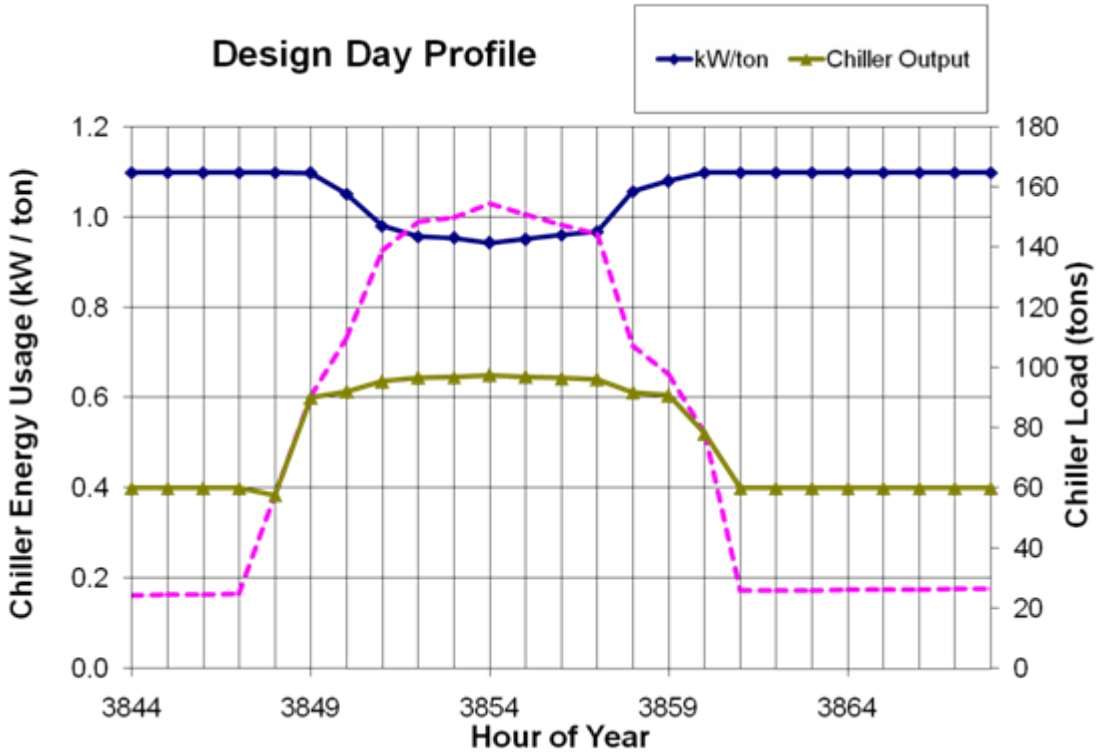
- Floating Chiller Leaving T
  Only if chiller load capacity is exceeded.
- Increased Chiller Tonnage
- Increased Chiller kW
- Decreased kW / ton

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# Reliability

- Base Case One Chiller, Has No Redundancy

- Ice Storage Has Non-Design Day Redundancy
  - Maintain System During Maintenance or Breakdown
  - Up to 486 ton-hrs



# Presentation Topics

- ✓ Building Overview
- ✓ Ice Storage System Design and Analysis
- ❑ **Location of Ice Storage Tanks**
- ❑ Electrical Equipment Downsizing
- ❑ Cost Payback Analysis
- ❑ Conclusion



# Ice Storage Location

- Next to Chiller
- Away from Child Play Areas
- 8’-5” x 26’-6”
- Minimal Architectural or Landscaping Effect


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# Presentation Topics

- ✓ Building Overview
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- ✓ Location of Ice Storage Tanks
- ❑ **Electrical Equipment Downsizing**
- ❑ Cost Payback Analysis
- ❑ Conclusion



- Reduced Over-Current Device
- Reduced Conductor Size
- Reduced Conduit Size
- $6,000 Reduced First Cost

| Chiller | MCA | MOP | Time Delay | Qty | Wire Gauge | Ground | Conduit |
|---|---|---|---|---|---|---|---|
| 80 | 164 | 200 | 225 | 1 | 4/0 | #2 | 2" |
| 90 | 194 | 250 | 250 | 1 | 250 | #2 | 2-1/2" |
| 100 | 218 | 250 | 300 | 1 | 300 | #2 | 2-1/2" |
| 170 | 333 | 450 | | 2 | 350 | #1 | 2-1/2" |



# Presentation Topics

- ✓ Building Overview
- ✓ Ice Storage System Design and Analysis
- ✓ Location of Ice Storage Tanks
- ✓ Electrical Equipment Downsizing
- ❑ **Cost Payback Analysis**
- ❑ Conclusion



- 6.0 % Interest
- $3,324/yr Savings
- 2.91 Year Payback

| | Case | | |
|---|---|---|---|
| | 100 ton | 90 ton | 85 ton |
| Extra First Cost | 7876 | 8633 | 25046 |
| Annual Savings | 1575 | 3324 | 3979 |
| i | 0.060 | 0.060 | 0.060 |
| n | 6.12 | 2.91 | 8.14 |
| PV | 7876 | 8633 | 25046 |



# Presentation Topics

- ✓ Building Overview
- ✓ Ice Storage System Design and Analysis
- ✓ Structural Slab Addition to Building
- ✓ Electrical Equipment Downsizing
- ✓ Cost Payback Analysis
- ❑ **Conclusion**



# Conclusion

- Cost Payback Analysis
  - 2.91 Year Payback
- Increased Reliability
- Effect on Surrounding Community
  - On-Peak Energy Usage
  - Energy Consumption
- Ice Storage System Would be Beneficial



# Presentation Topics

- ✓ Building Overview
- ✓ Ice Storage System Design and Analysis
- ✓ Location of Ice Storage Tanks
- ✓ Electrical Equipment Downsizing
- ✓Cost Payback Analysis
- ✓ Conclusion

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# Acknowledgments


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| Jamie White | LLI Engineering |

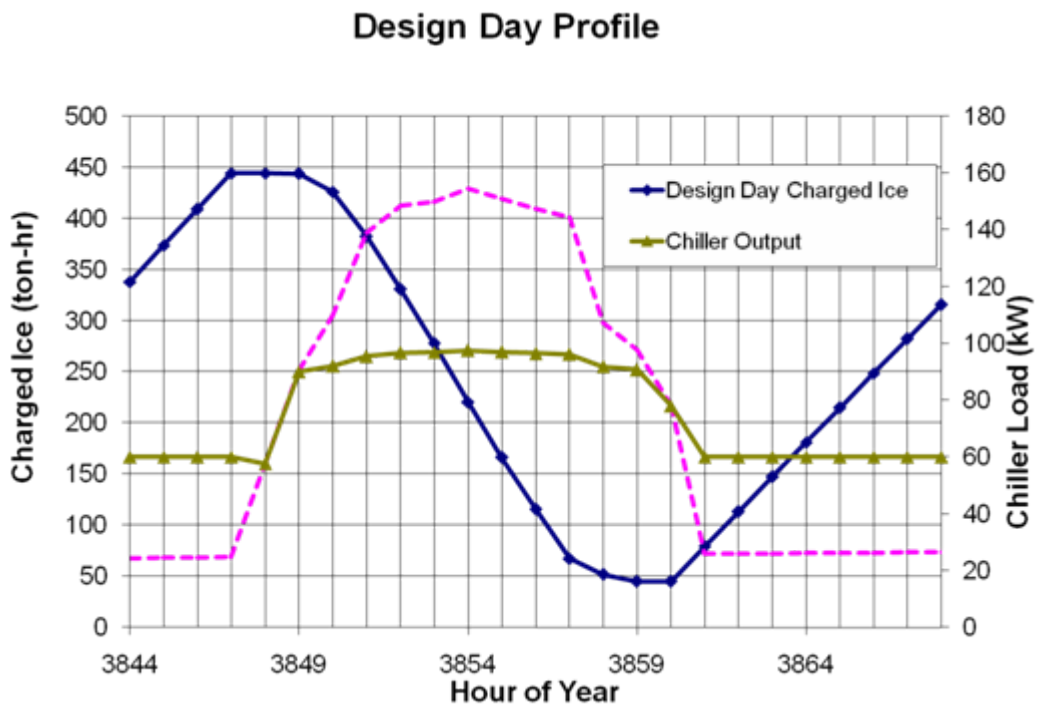
# Summary

Compared with 170 ton Base Case

Greater Reliability

Over Life Cycle Cost Reduction

Load Leveling System





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