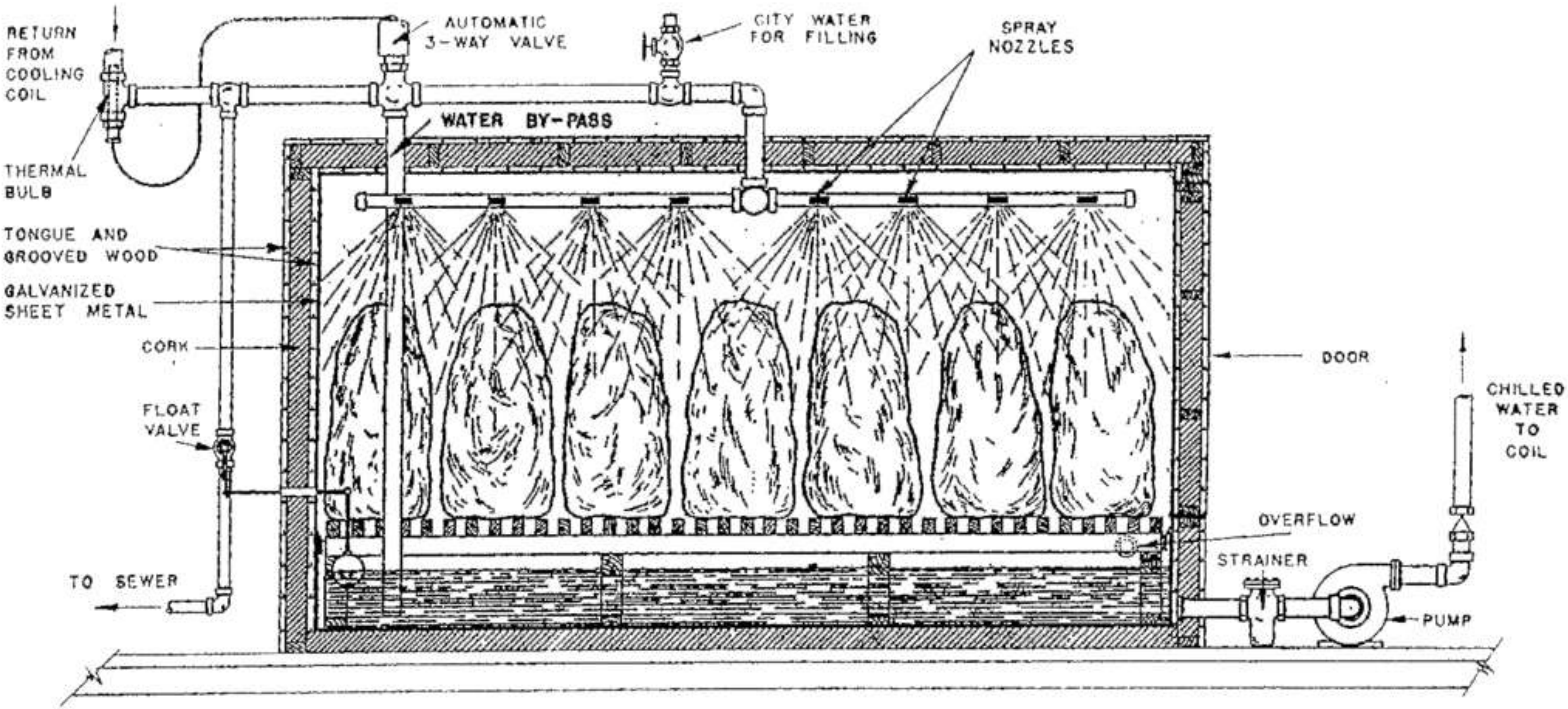
Ice Thermal Storage Systems

Greg Henderson
Director, Global Thermal Storage

Baltimore Aircoil Company

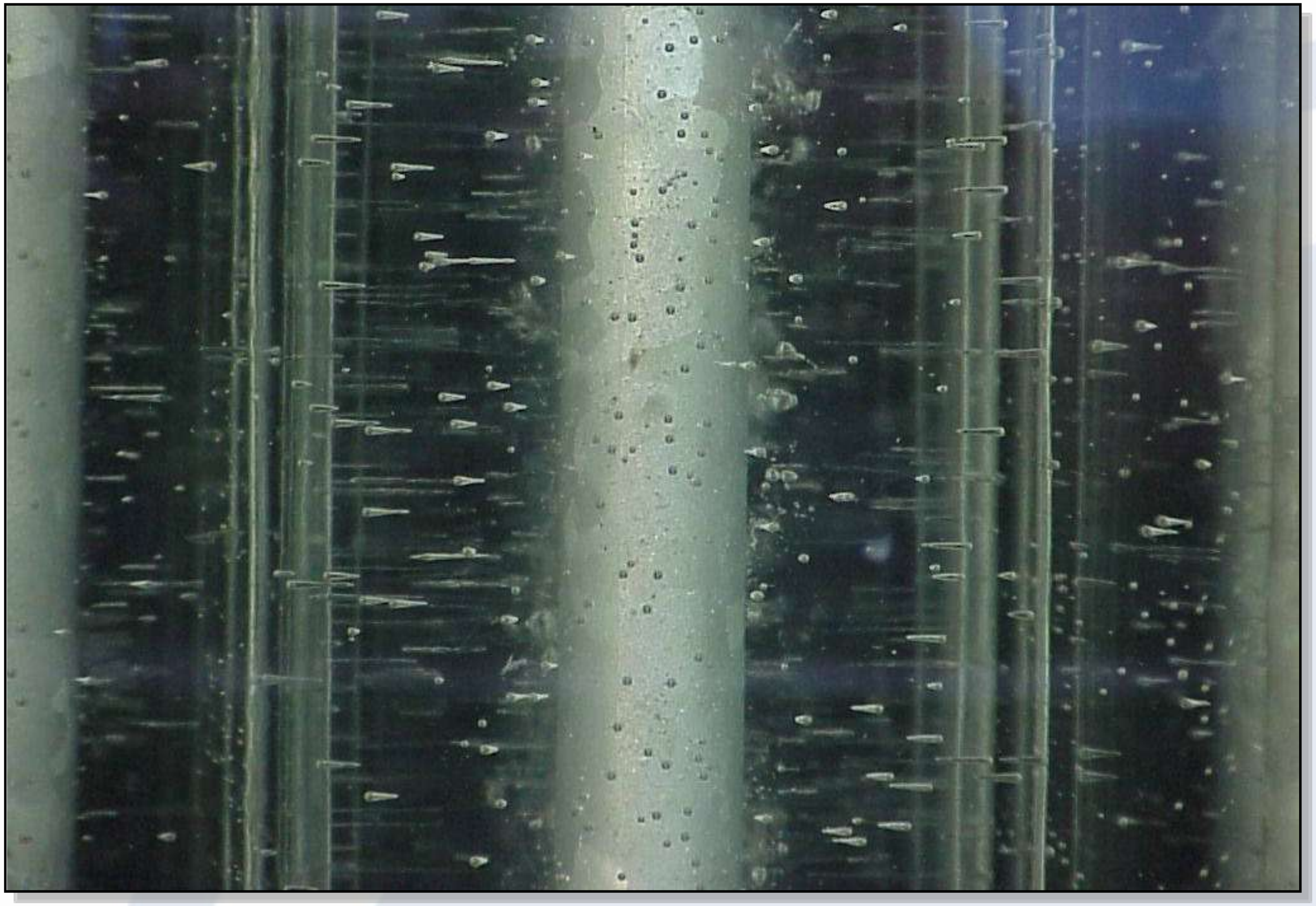
Agenda

- Ice storage basics
- Ice storage design considerations
  – Full and partial storage systems
  – Internal and external melt systems
- Ice storage installations and applications

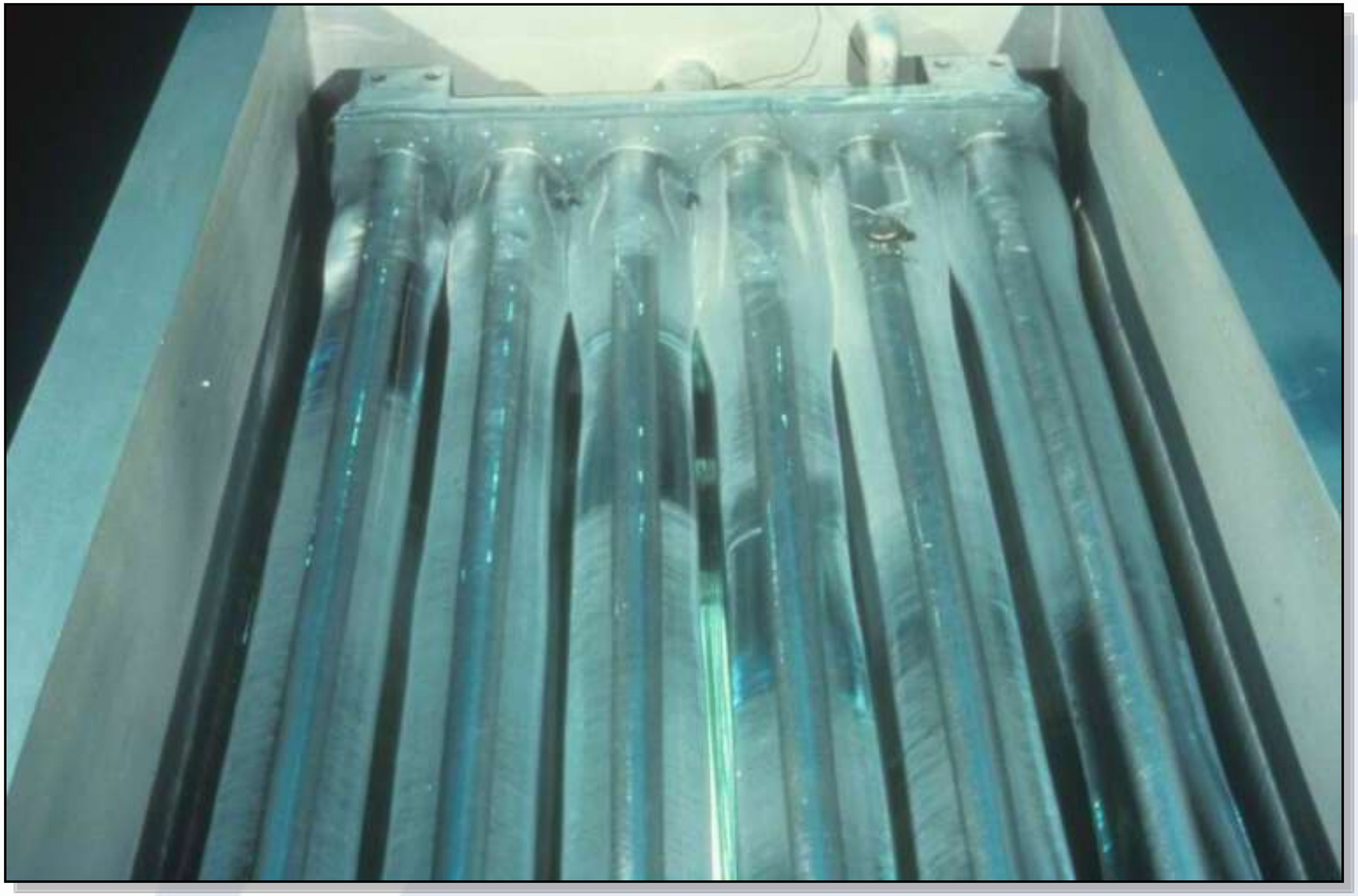


68. Ice Bunker Air Conditioning System, 1934.
Trane Air Conditioning Manual, The Trane Co, La Crosse, Wisconsin, 1934, p200.

Ice Build on Ice Coil Tube



Ice Build on Ice Coil



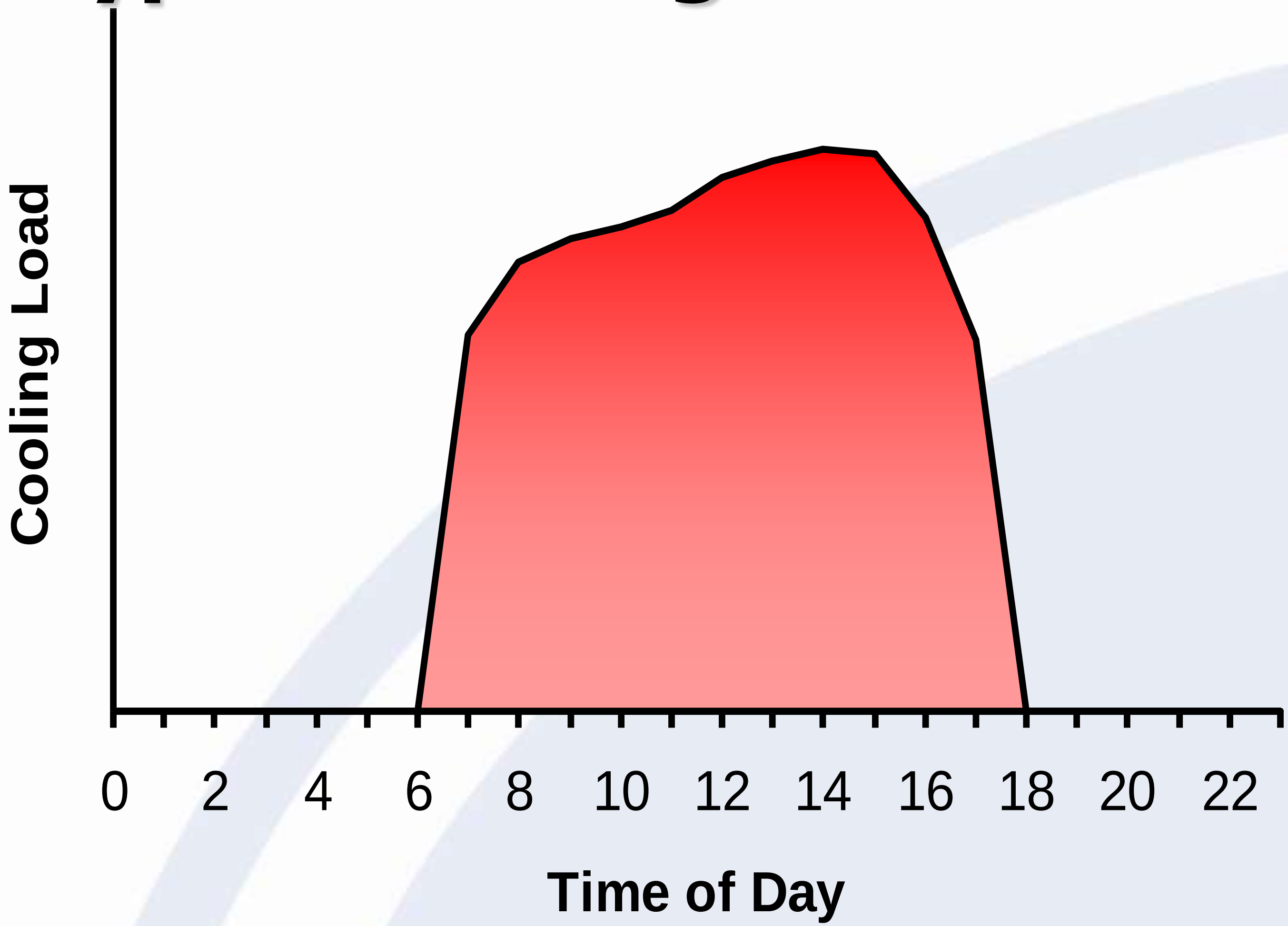
What is Ice Storage?

- 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

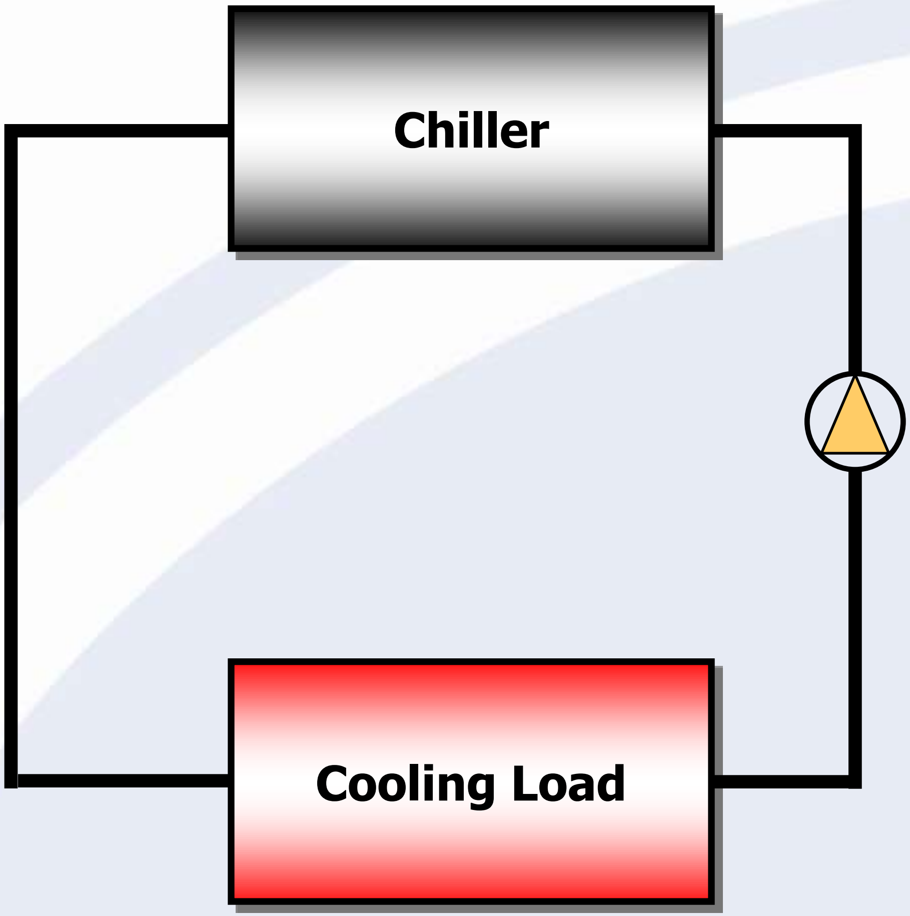
Ice Thermal Storage

How does it work?

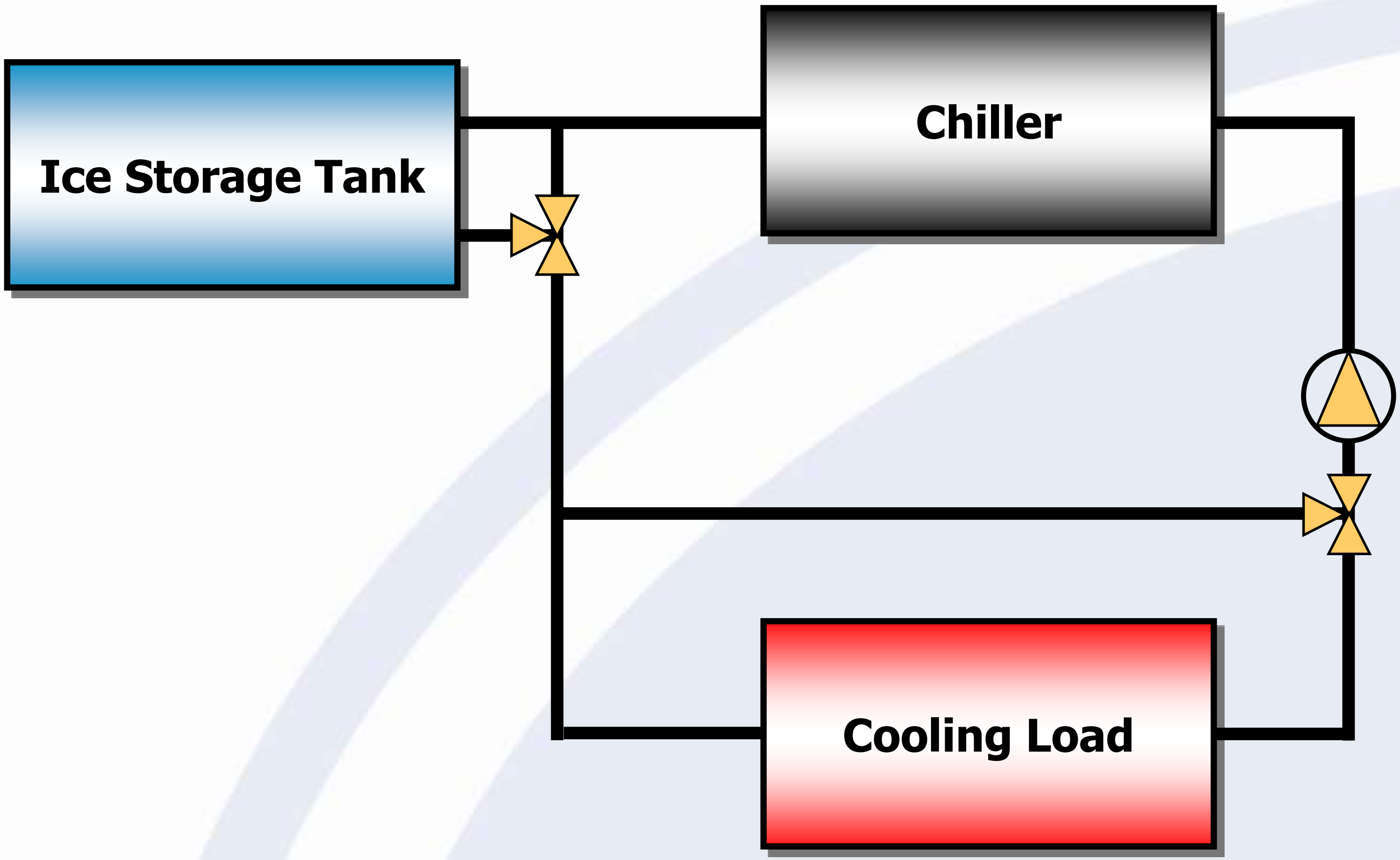
Typical Cooling Load Profile



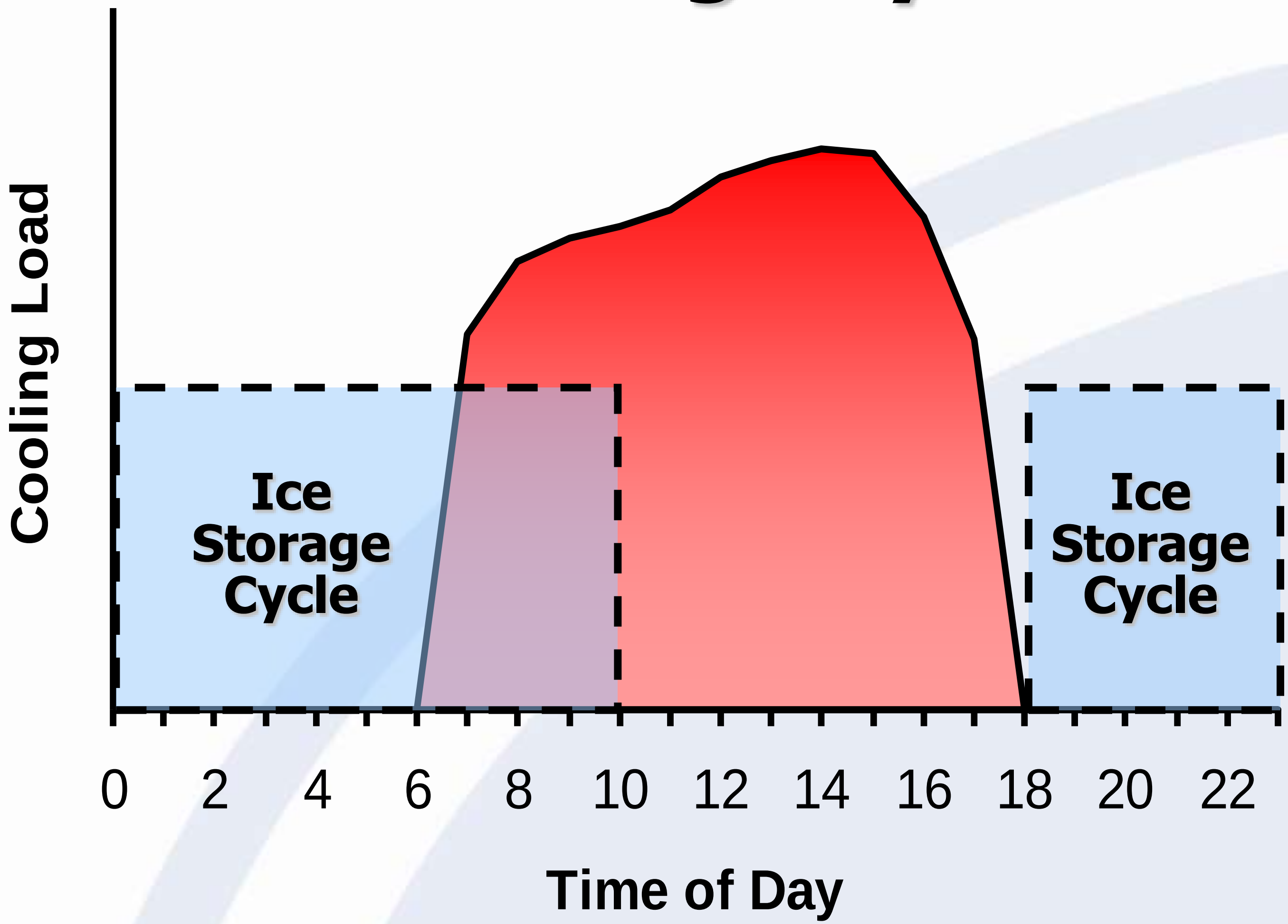
Conventional System



Ice Storage System



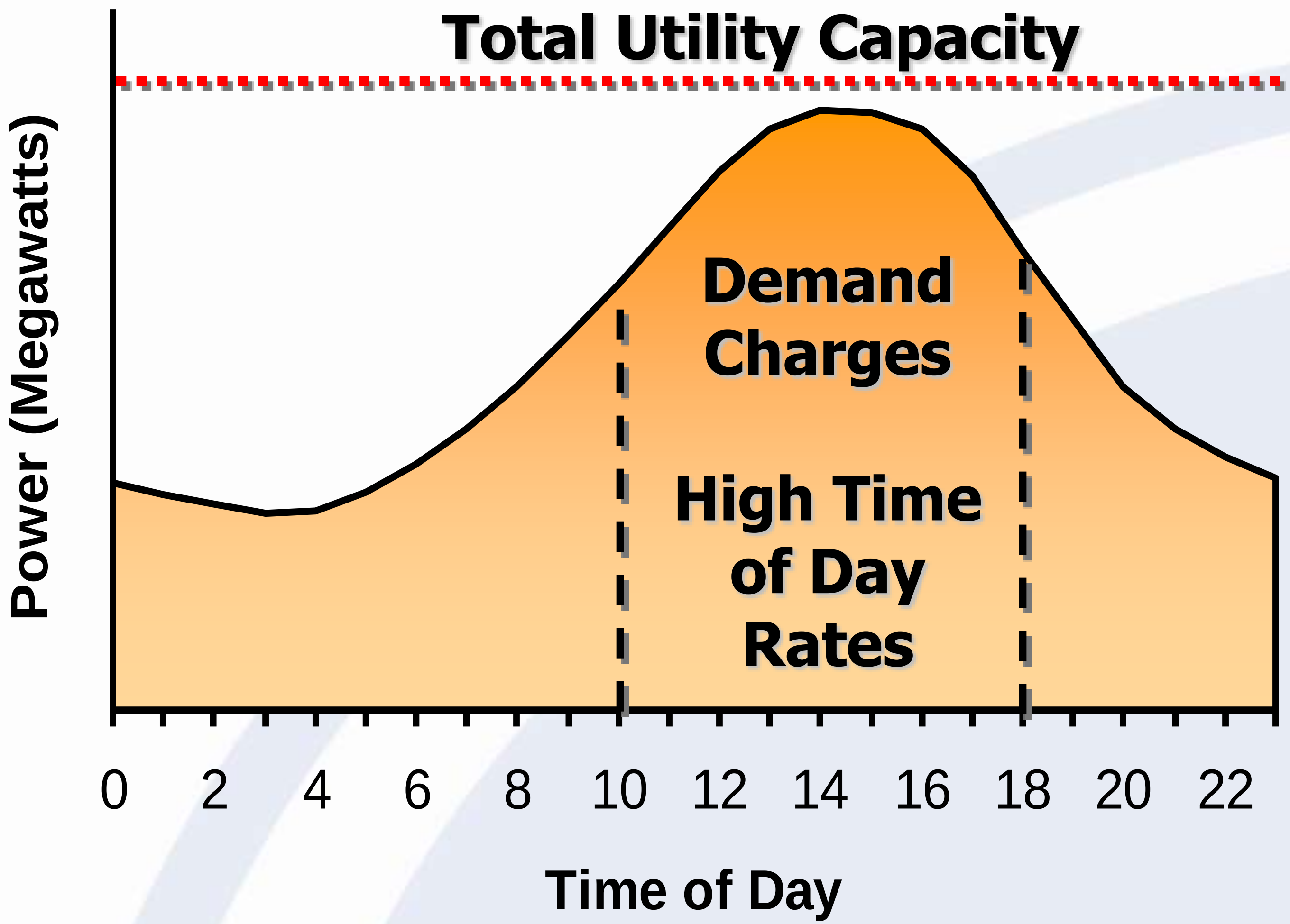
Ice Storage Cycle



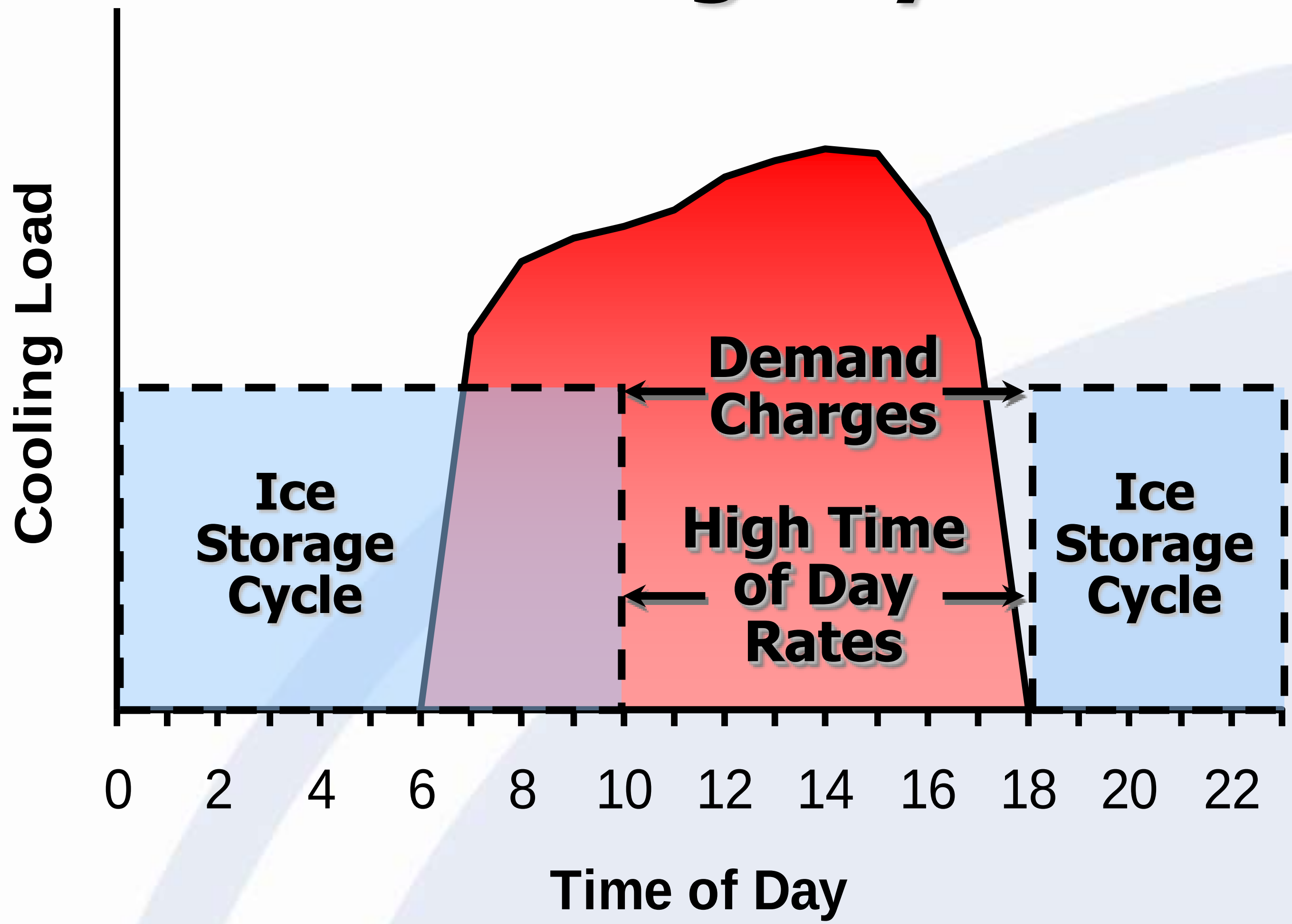
Advantages of Thermal Energy Storage

- 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



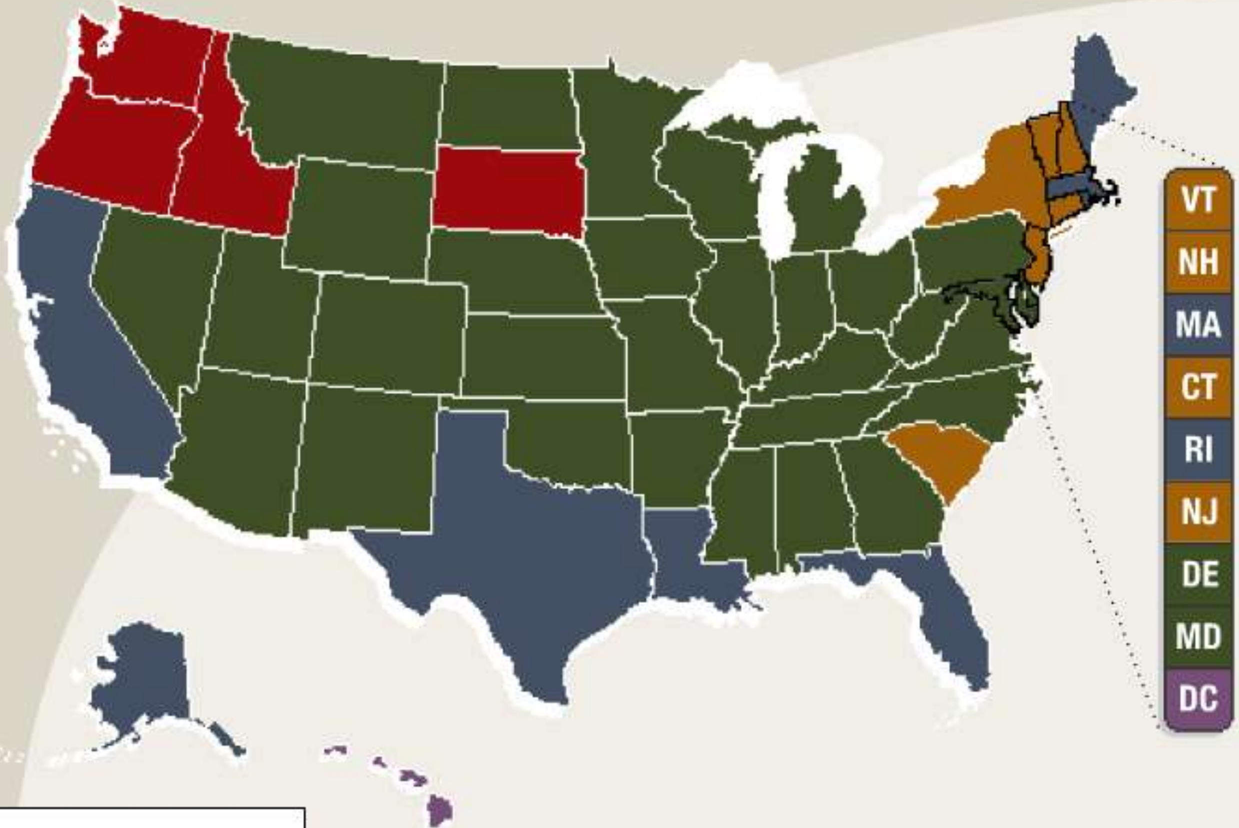
Ice Storage Cycle



ELECTRICITY GENERATION

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.



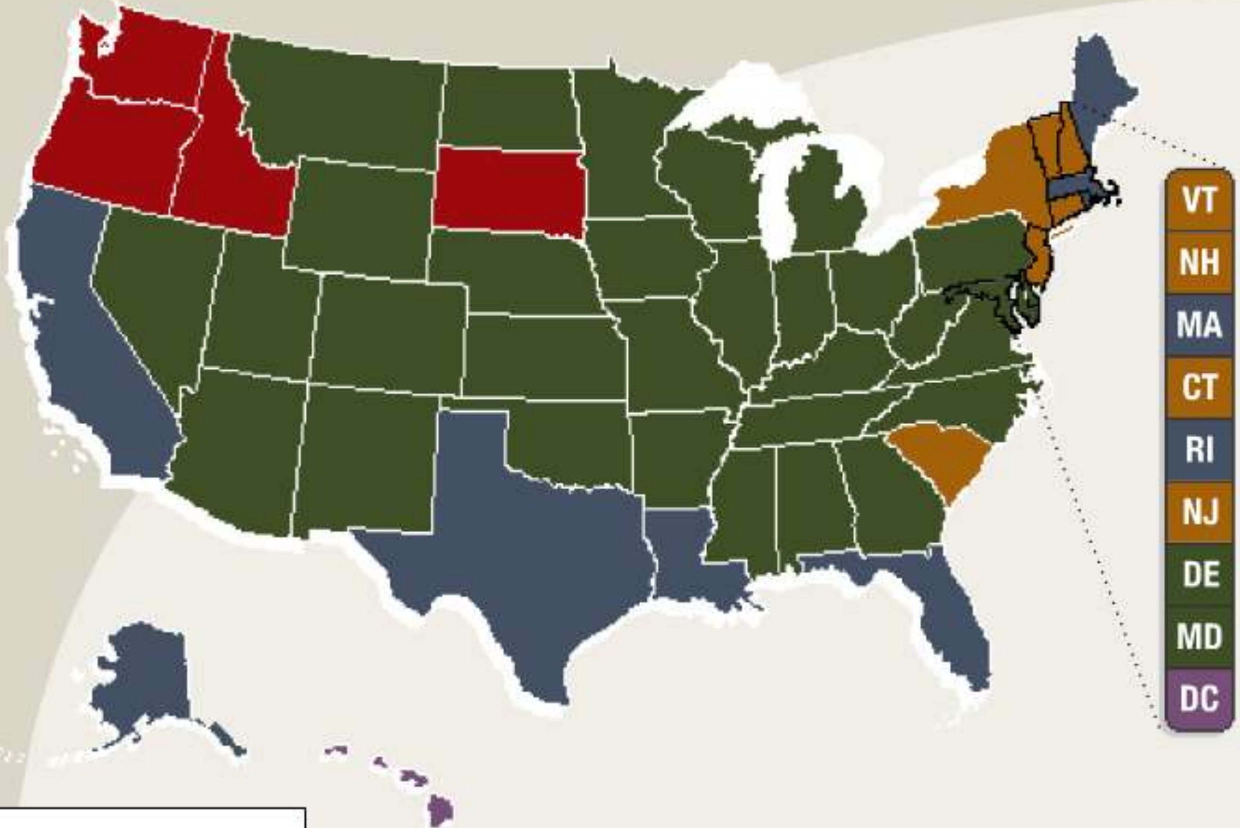
Note: Energy source figures for each state do not include pumped storage or categories that comprised less than one-tenth of 1 percent of the state total.

KEY: Coal | Natural gas | Nuclear | Petroleum | Hydroelectric

VERMONT

BACK TO INTRO >

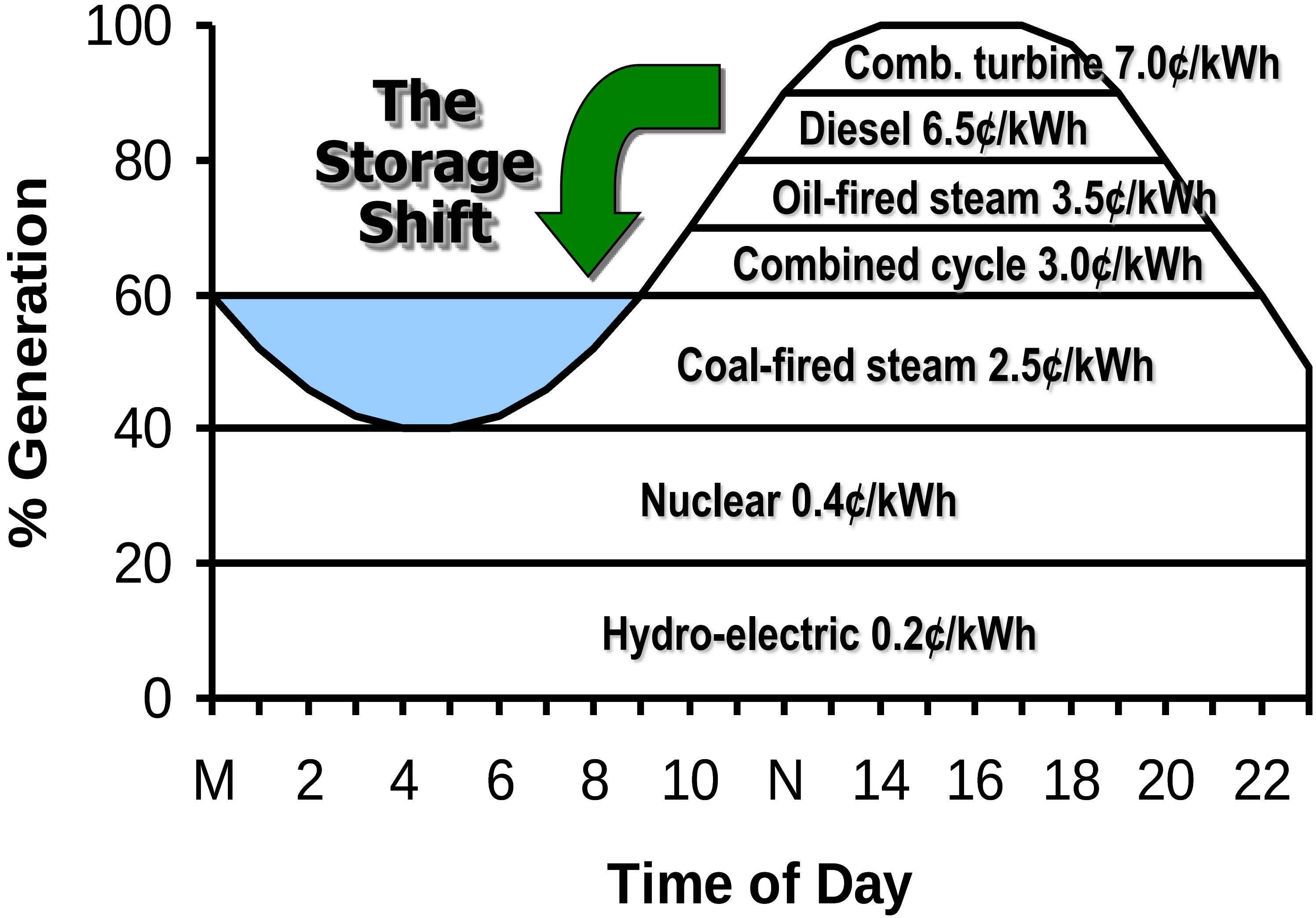
Energy source	Amount Generated (megawatt-hours)	Percent of state total
Petroleum	22,607	0.4
Nuclear	4,444,152	73.7
Hydroelectric	1,154,038	19.1
Other Renewables	405,136	6.7
TOTAL	**6,027,962**	



KEY: Coal | Natural gas | Nuclear | Petroleum | Hydroelectric

SOURCE: U.S. ENERGY INFORMATION ADMINISTRATION

Electric Generation Fuel Sources



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

Source: *Source Energy and Environmental Impacts of Thermal Energy Storage*, California Energy Commission - February 1996

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

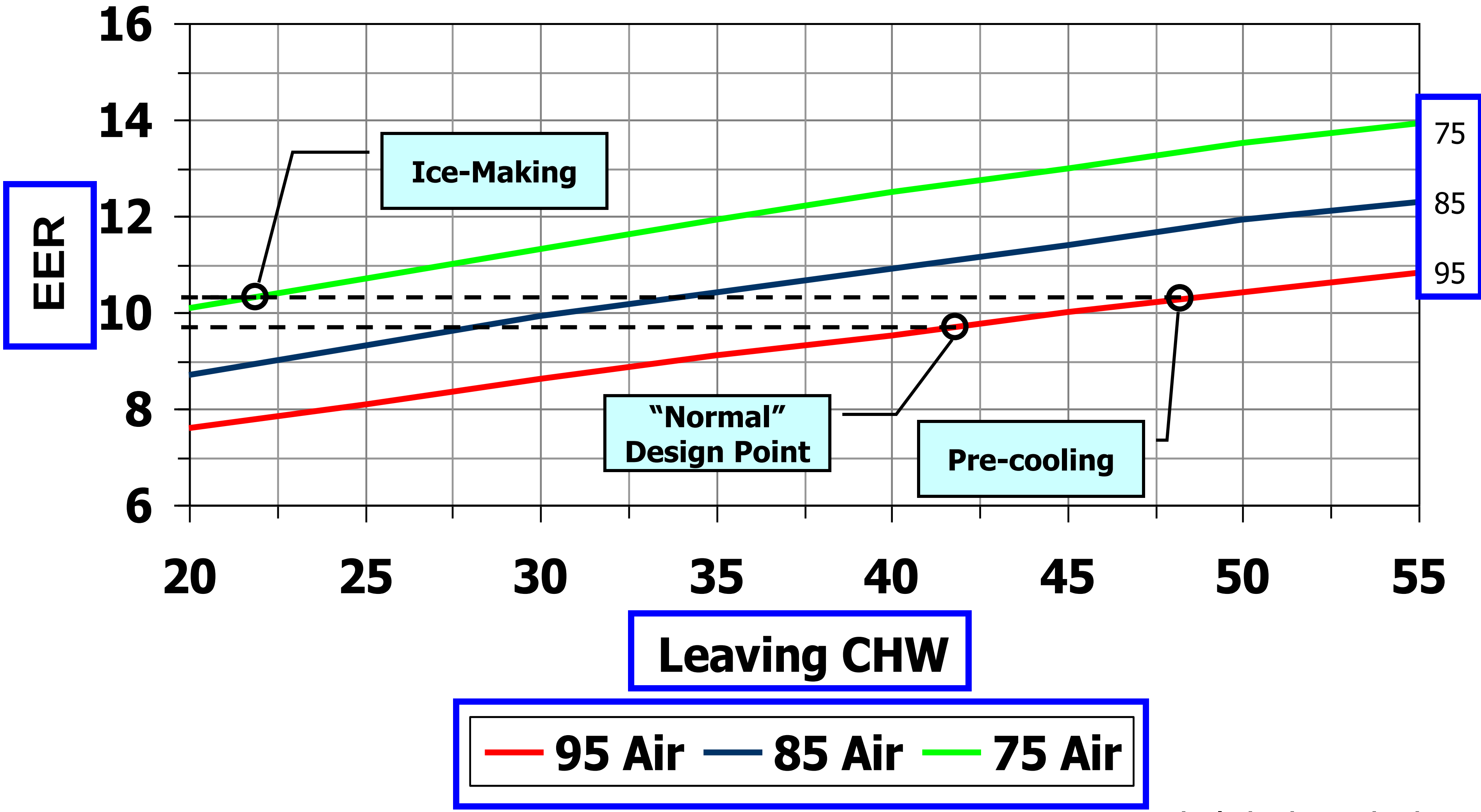
Advantages of Ice Thermal Storage

- Reduced equipment costs
- Reduced energy and operating costs
- Colder supply water temperature

Ice Thermal Storage Uses Less Energy

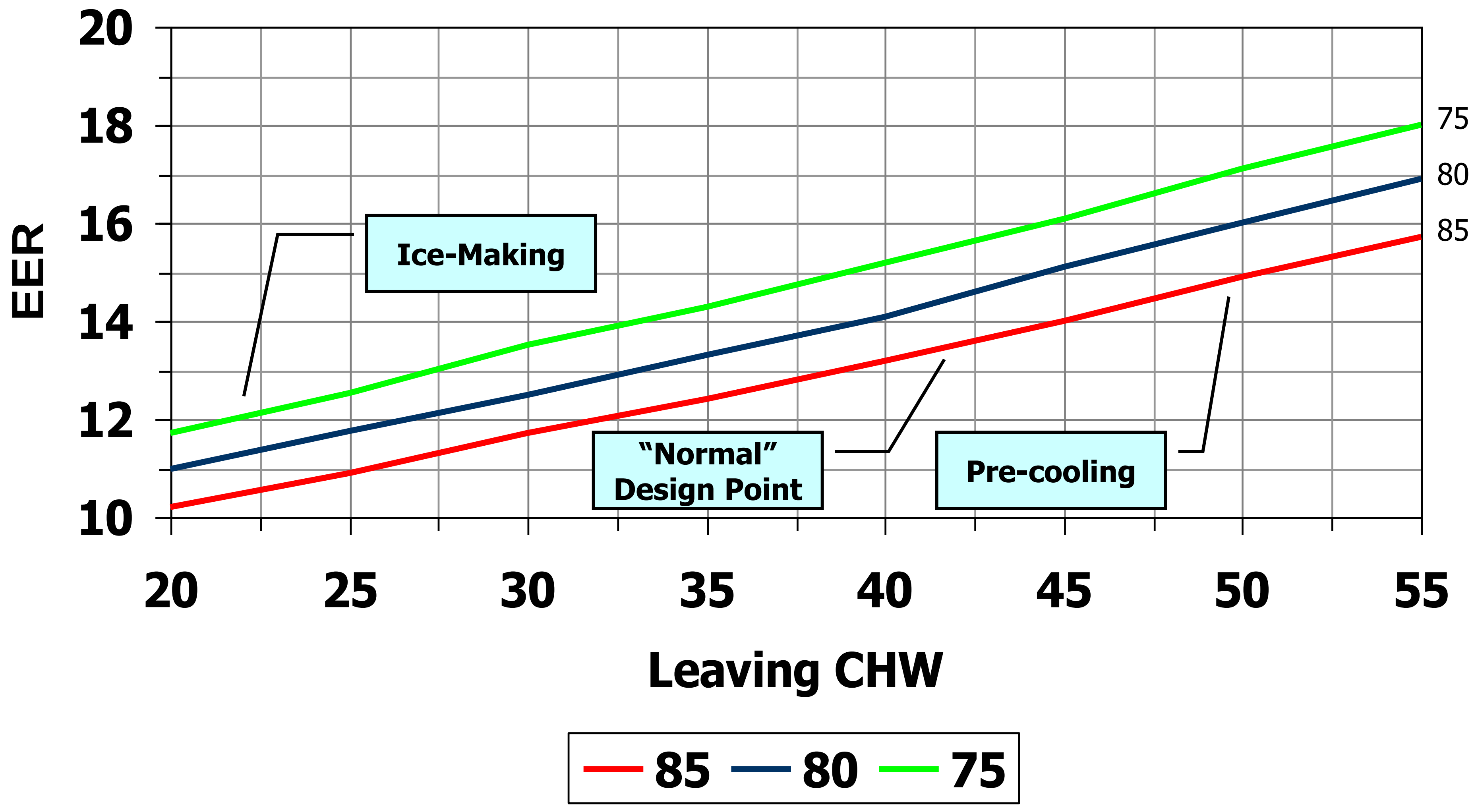
- During daytime, chillers operate at higher supply temperatures and greater efficiency when piped upstream of the ice storage
- At night, chillers operate when ambient temperatures are lower
- Pump and fan energy can be less when colder system supply temperatures are used

EER of Air Cooled Chillers*



* includes heat rejection

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

U.S. GREEN BUILDING COUNCIL

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LEADERSHIP IN ENERGY & ENVIRONMENTAL DESIGN

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


CAT

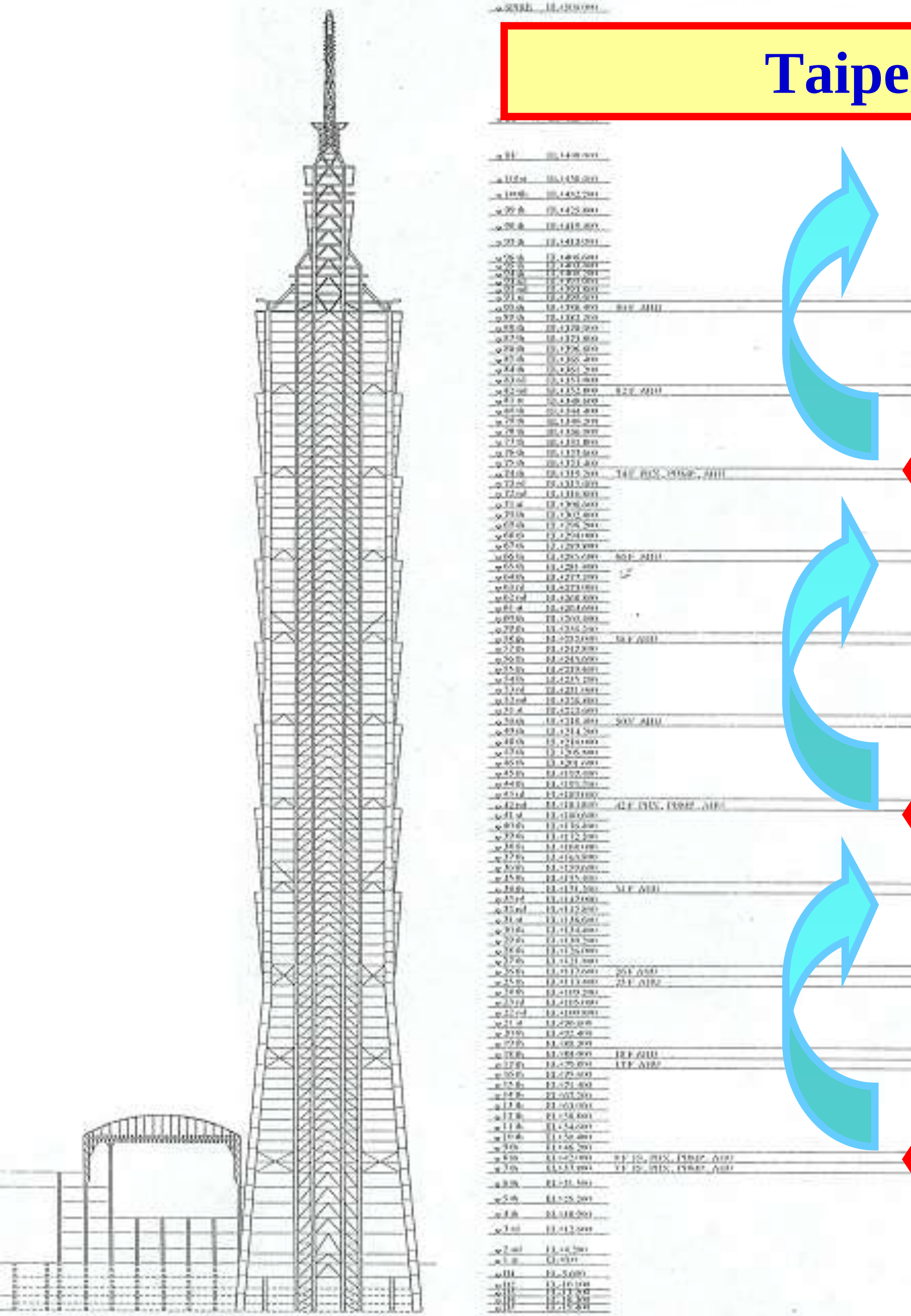
Burj Dubai Tower

- 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

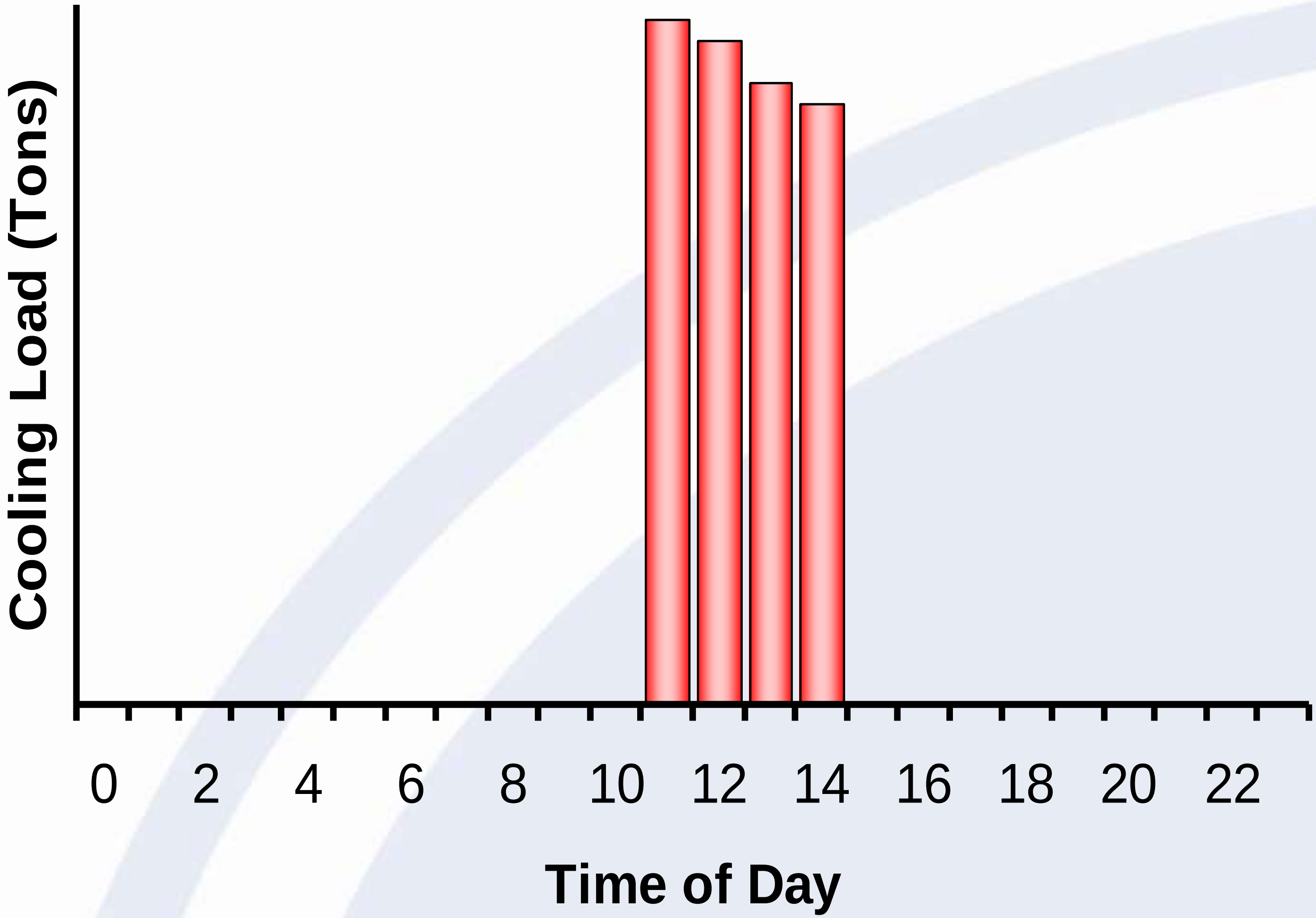
- Commercial A/C and industrial
- District cooling
  - Colleges and universities
  - Corporate campuses
  - Hospitals
  - Convention centers
  - Sports arenas
  - Utilities

Ice Thermal Storage Systems

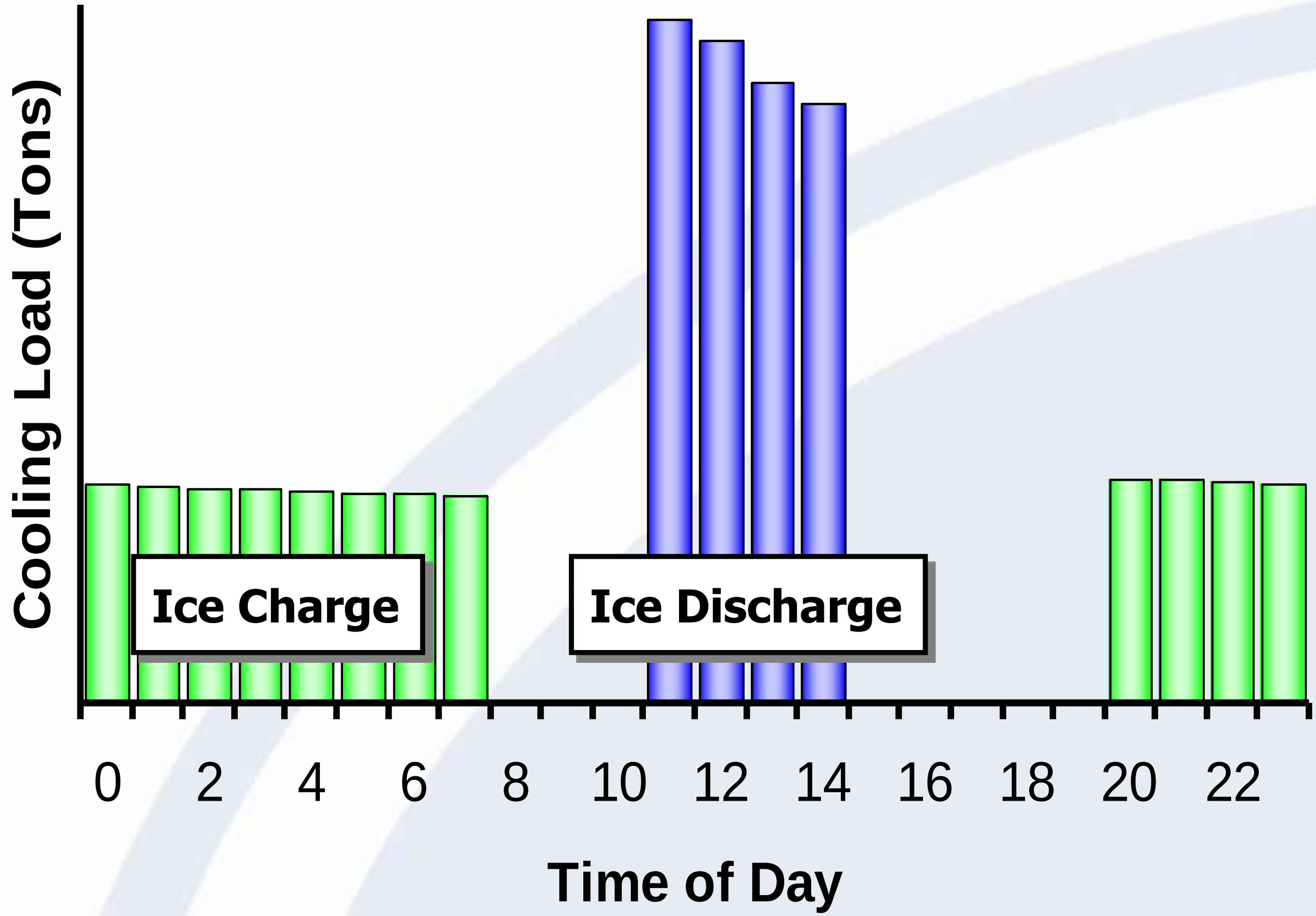
Design Considerations

Full Storage
vs.
Partial Storage

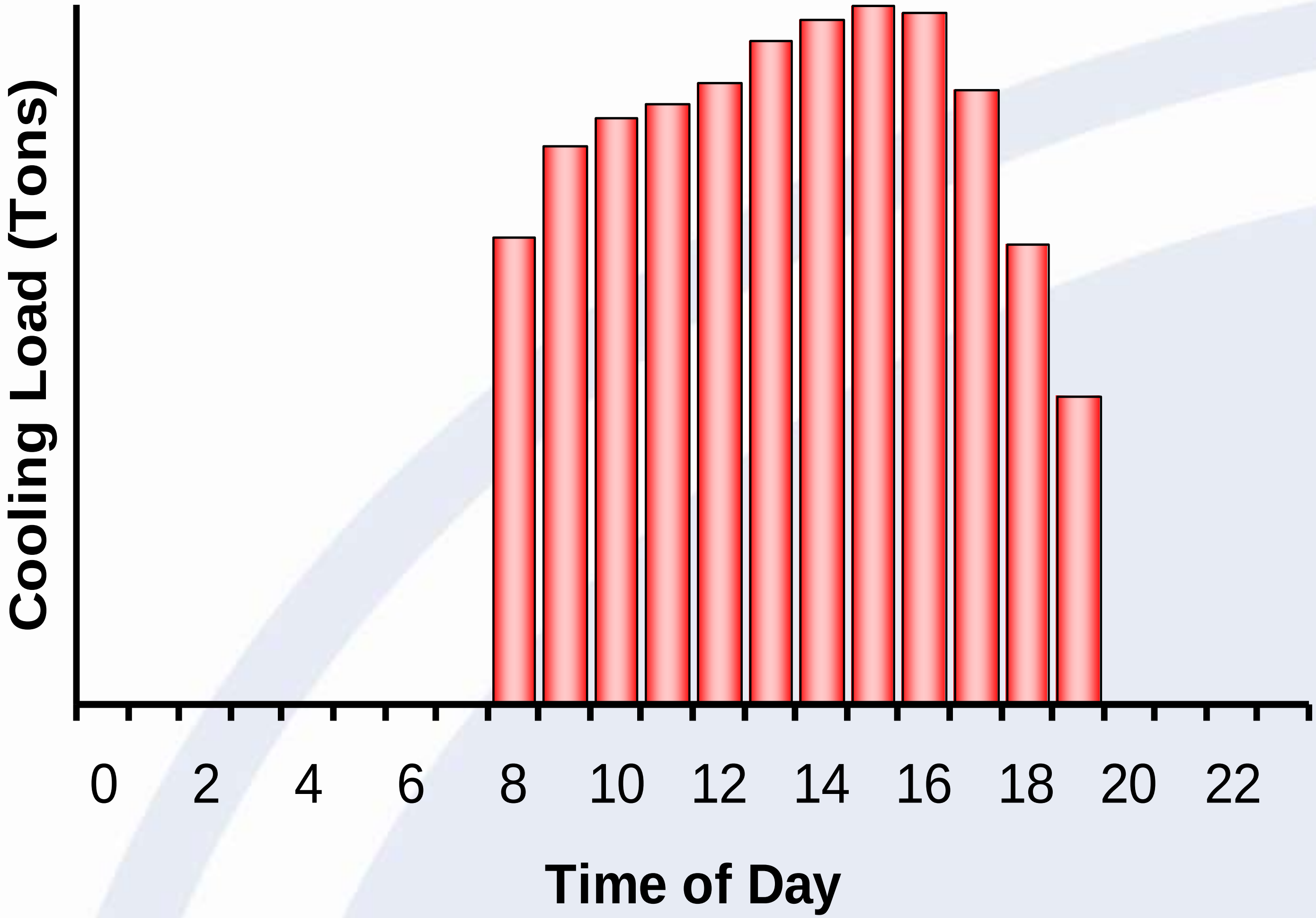
Batch Cooling or Process Load Profile



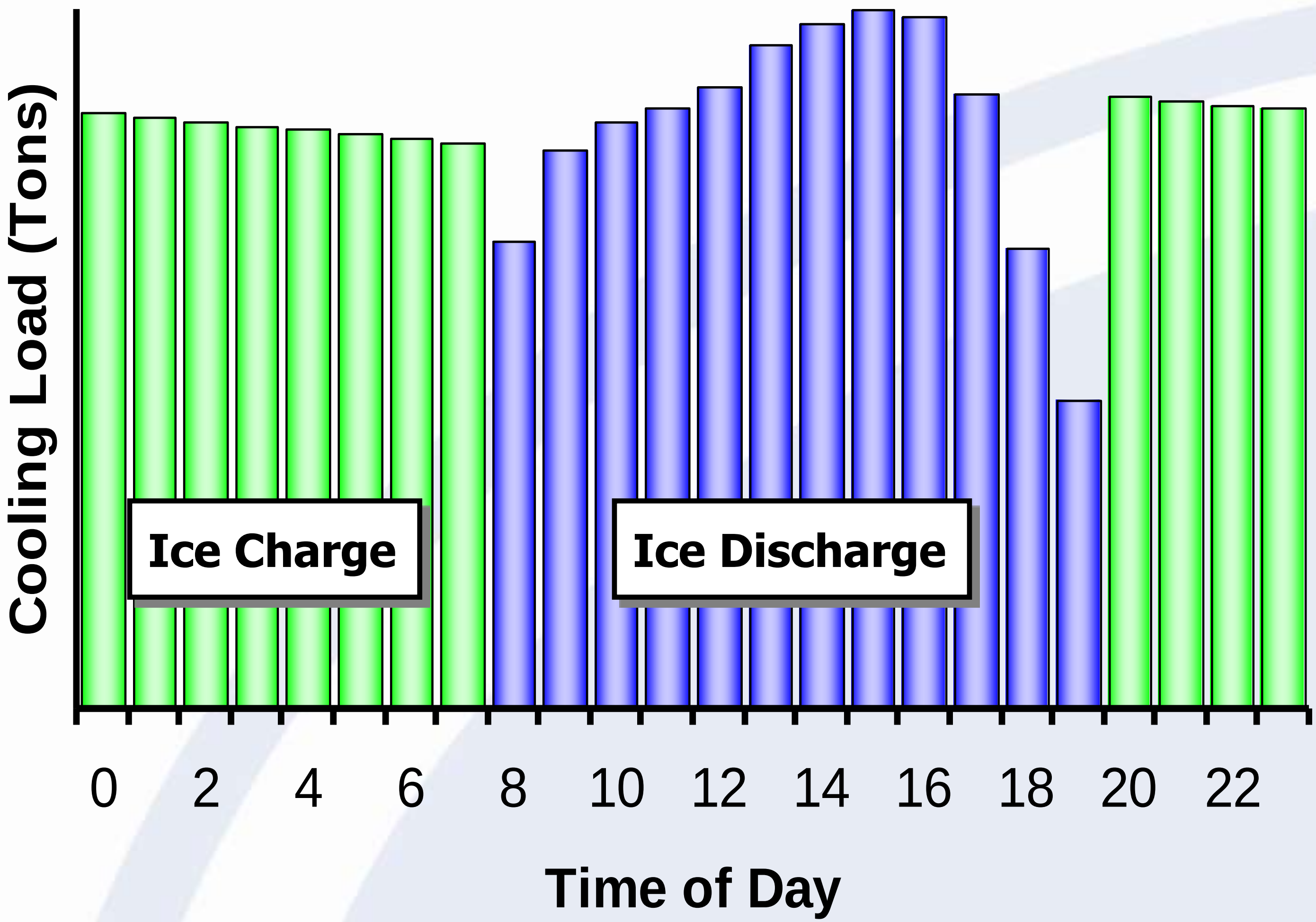
Full Ice Storage
Batch Cooling or Process Application



Air Conditioning Load Profile



Full Ice Storage
Air Conditioning Application



Ice Thermal Storage System Design
Full Ice Storage

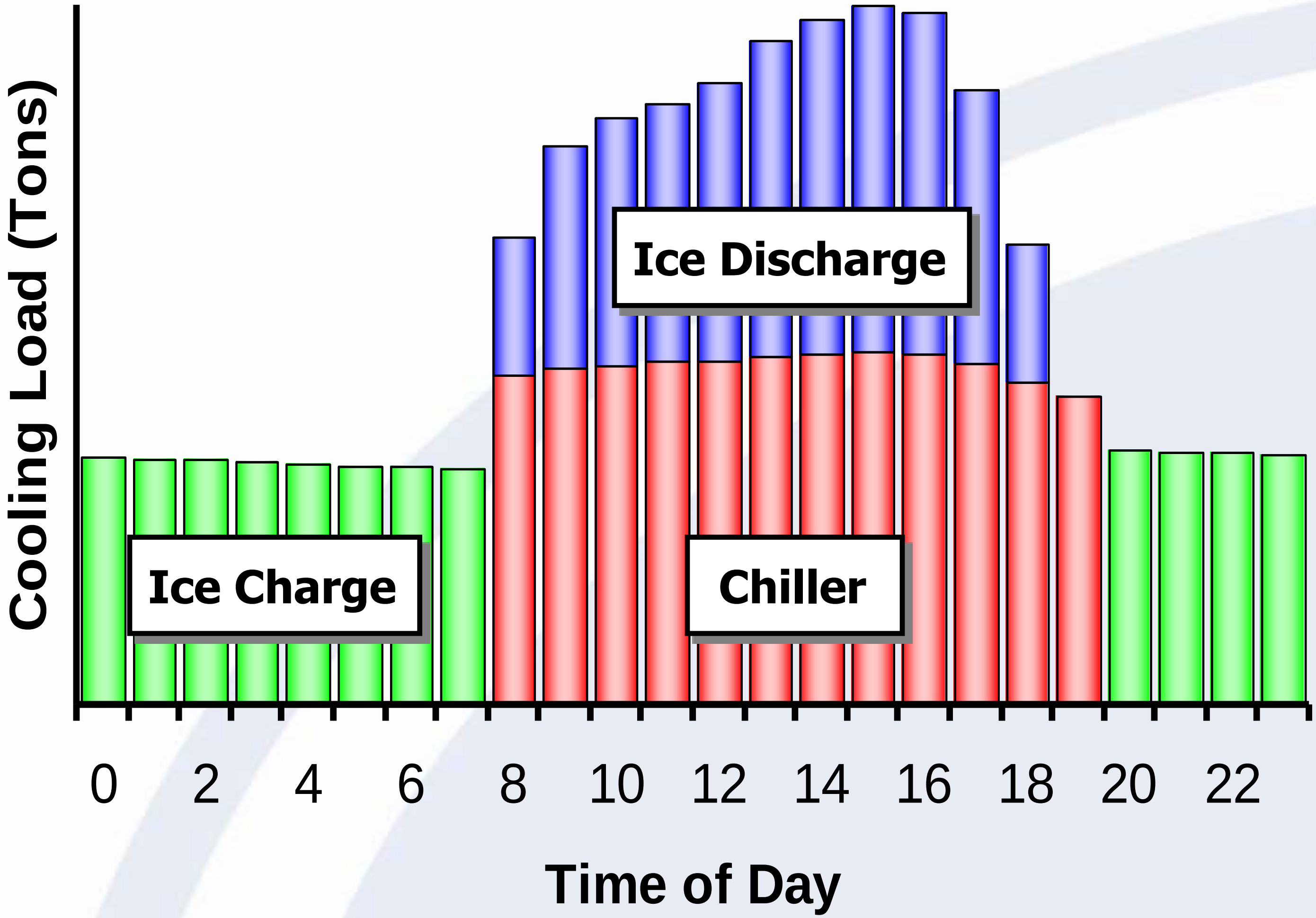
Advantages

- 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

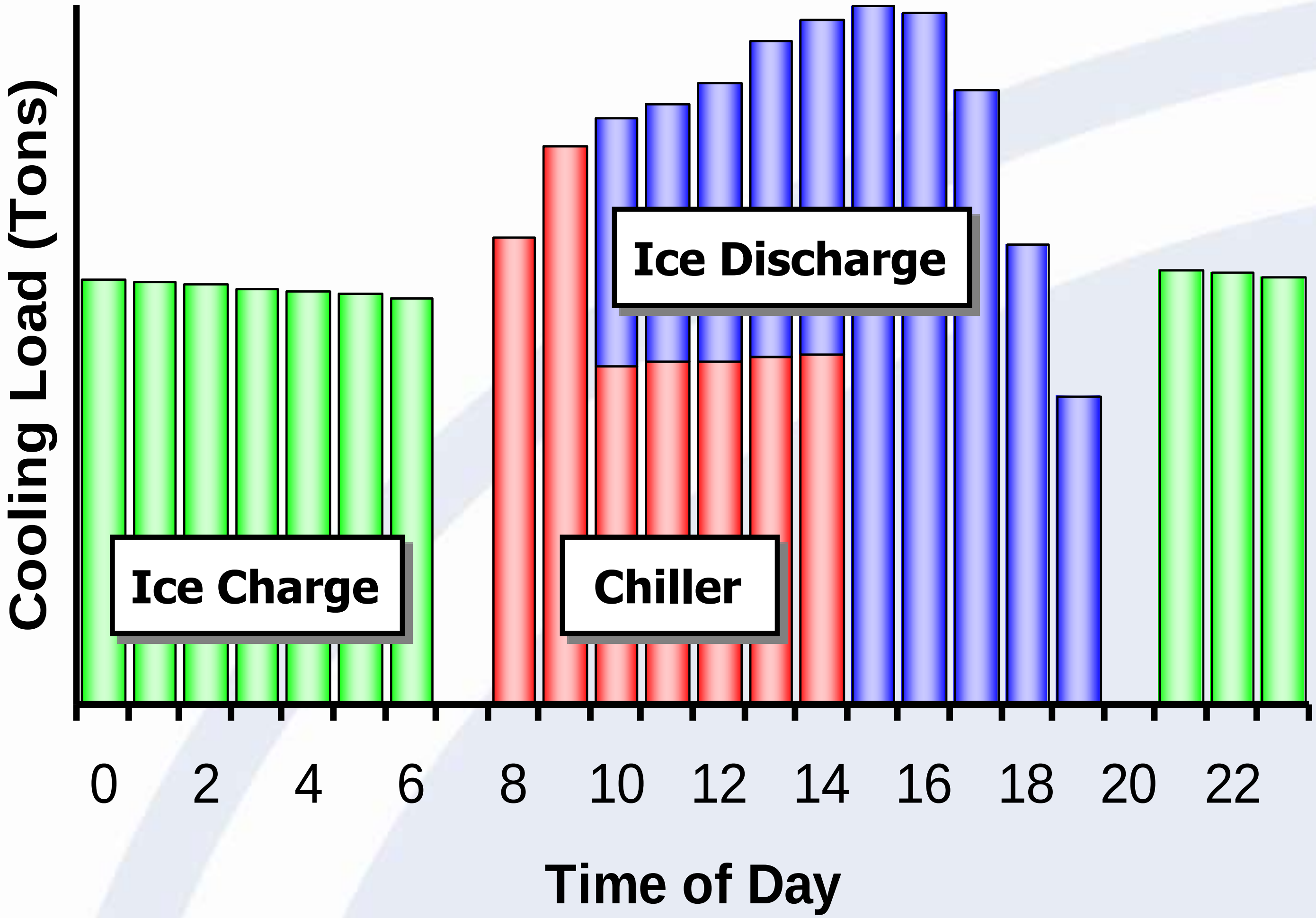
Disadvantages

- Largest storage volume required
- Larger chiller required
- Most expensive thermal storage design

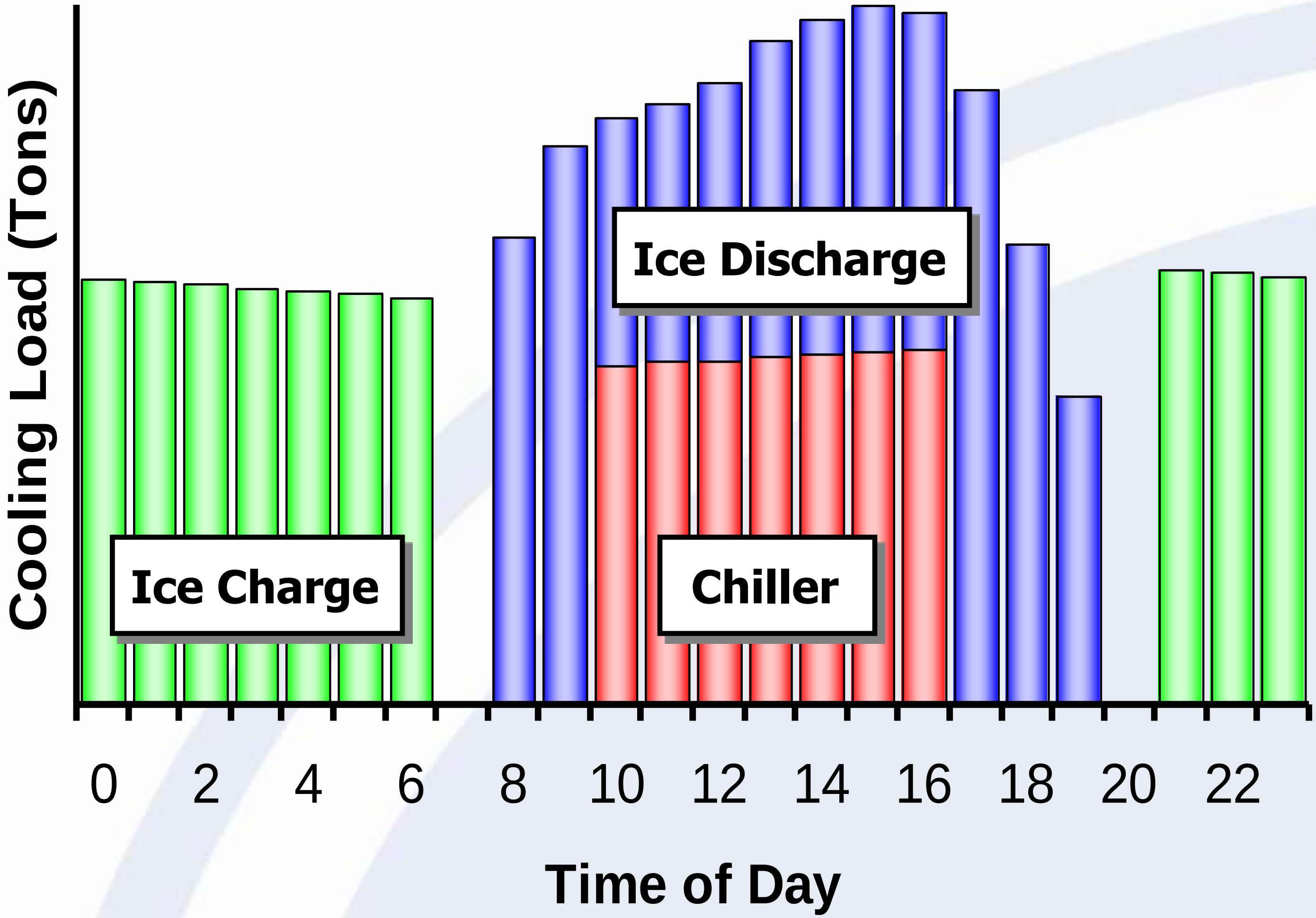
Partial Ice Storage
Air Conditioning Application

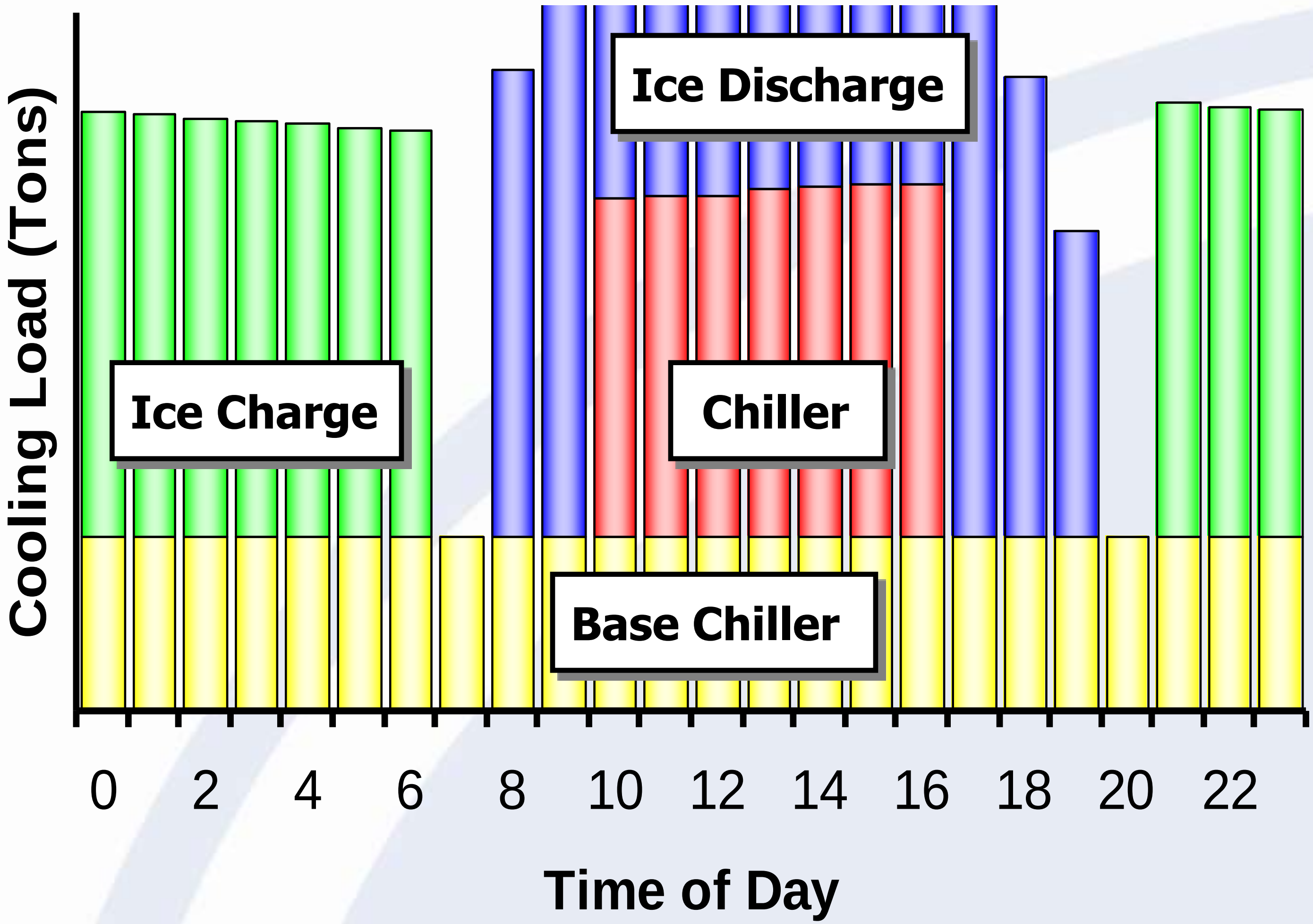


Partial Ice Storage
Air Conditioning Application



Partial Ice Storage
Air Conditioning Application




Ice Discharge
Ice Charge
Chiller
Base Chiller
Cooling Load (Tons)
0
2
4
6
8
10
12
14
16
18
20
22
Time of Day

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

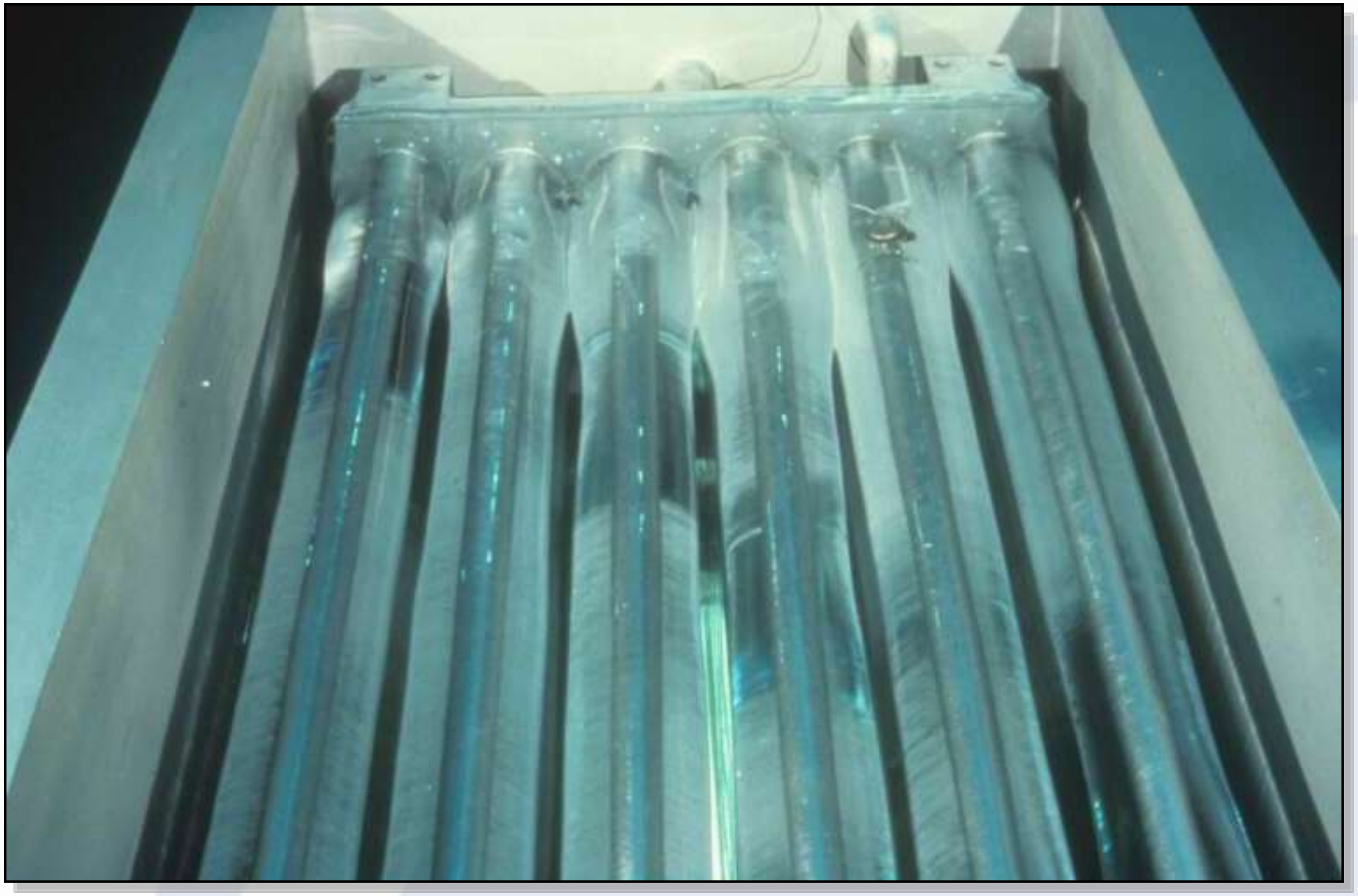
Indirect vs. Direct
Contact Cooling

Ice Storage System Types

Direct Contact Cooling

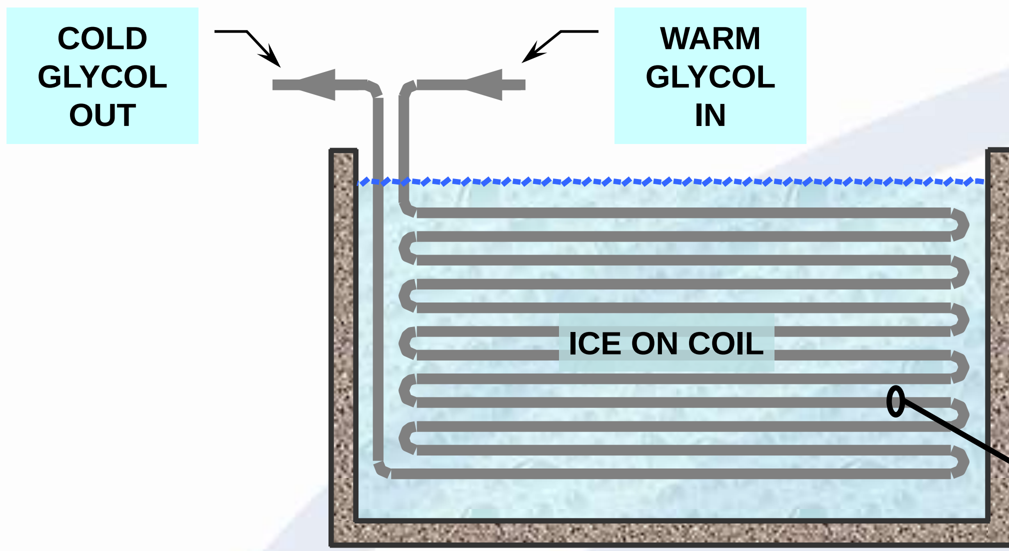
Indirect Contact Cooling

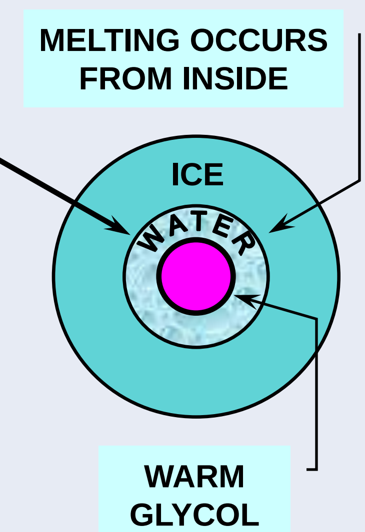
Ice Thermal Storage
Ice-on-Coil Technology



Ice Thermal Storage System Design
Ice on Coil - Internal Melt

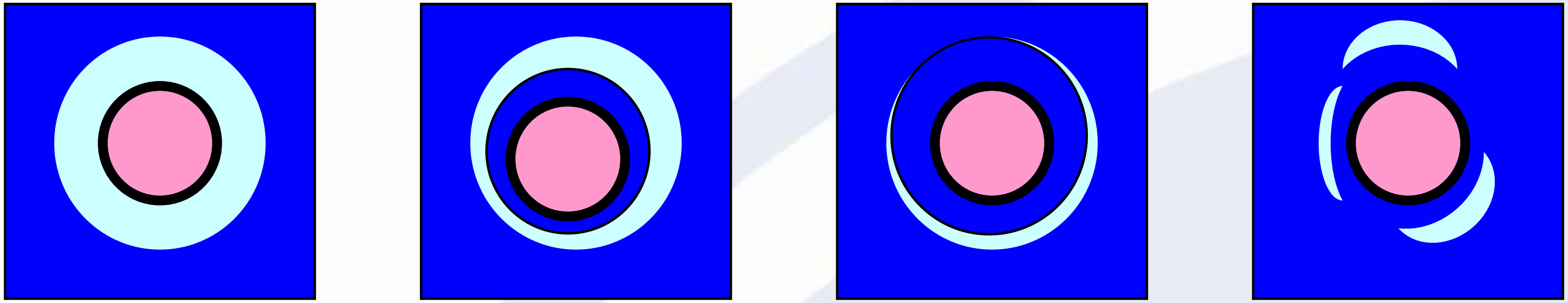
Indirect



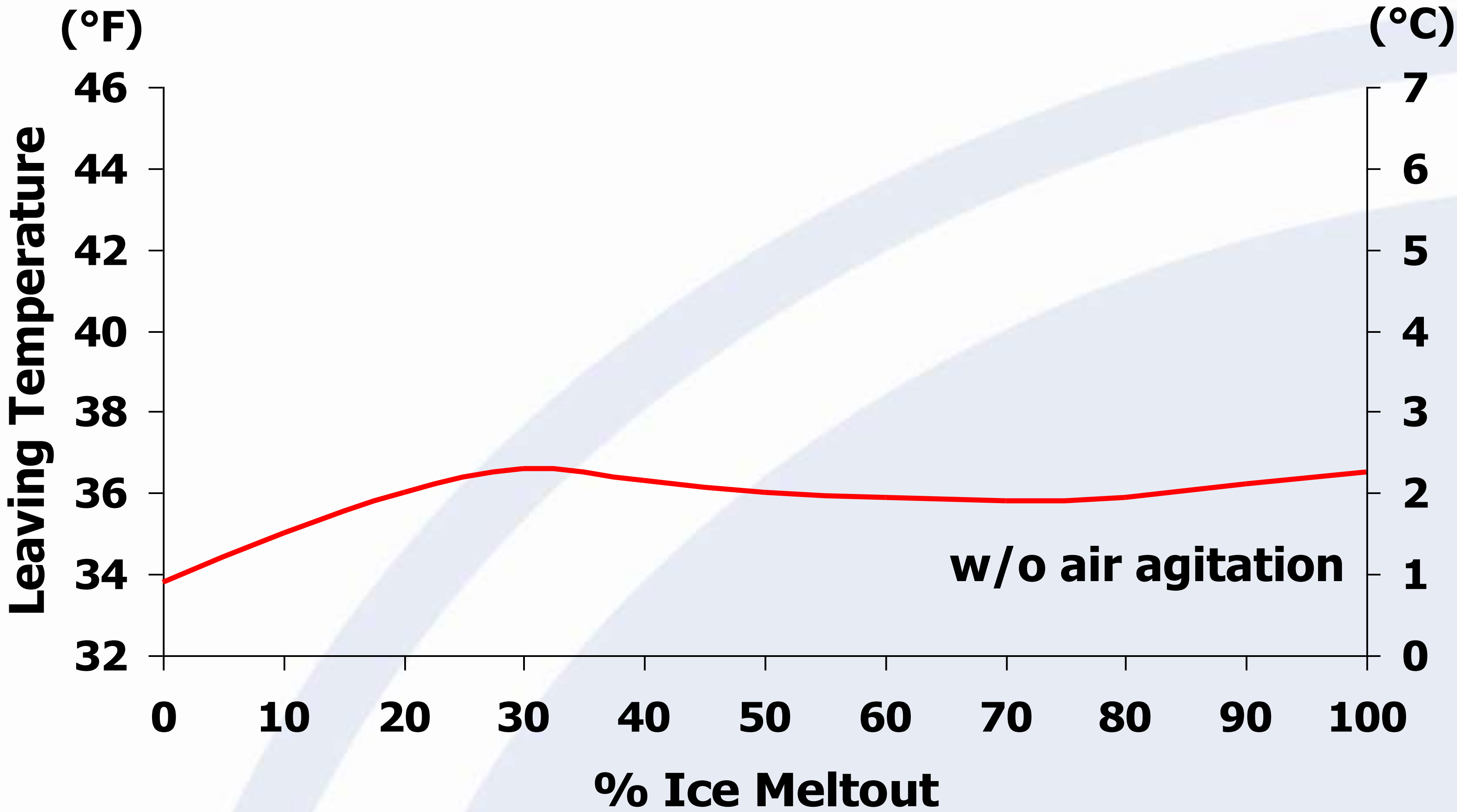


- Cold glycol solution is circulated through the coil to the A/C system
- Warm glycol solution, circulating through the coil, is cooled indirectly by the melting ice

Ice Storage Design
Internal Melt (Indirect Contact)



Ice Storage Design
Internal Melt Performance*

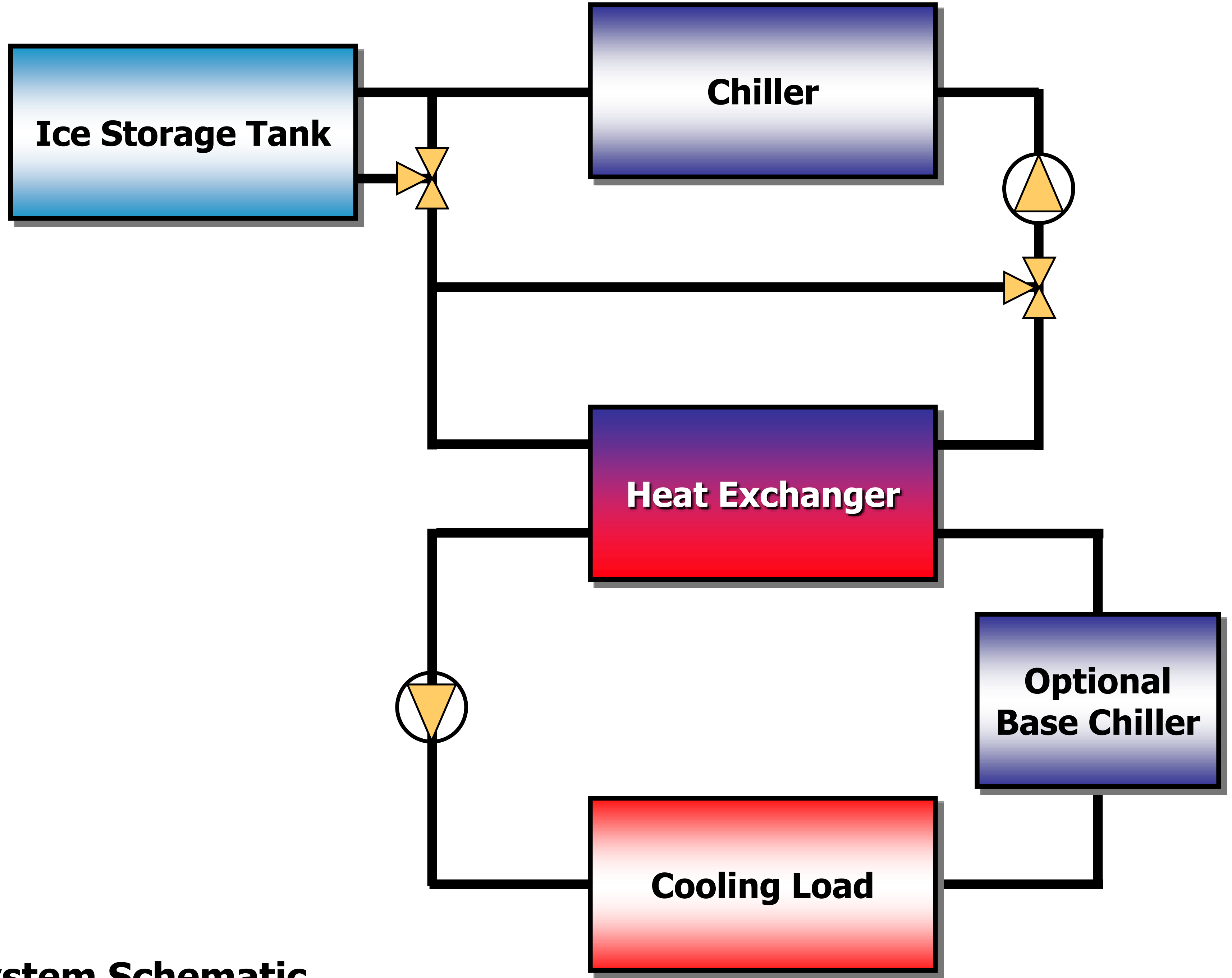


*10 hour, constant load

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

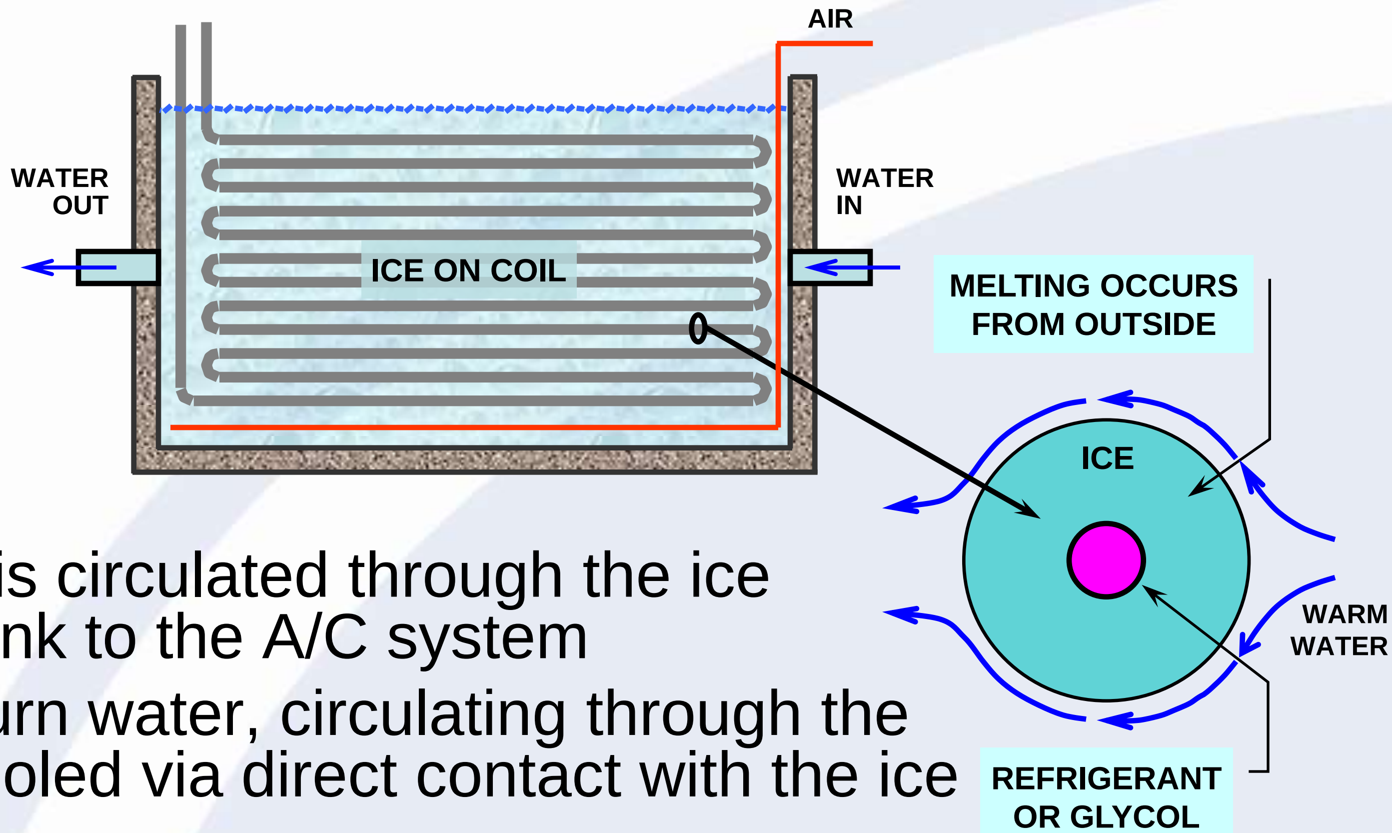
Ice Storage Design
Internal Melt (Indirect Contact)

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

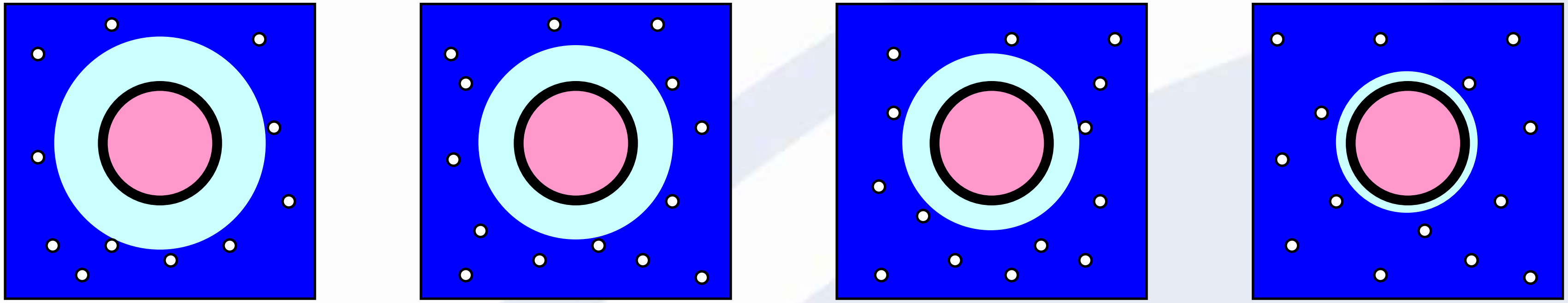
Ice Thermal Storage System Design
Ice on Coil - External Melt

Direct

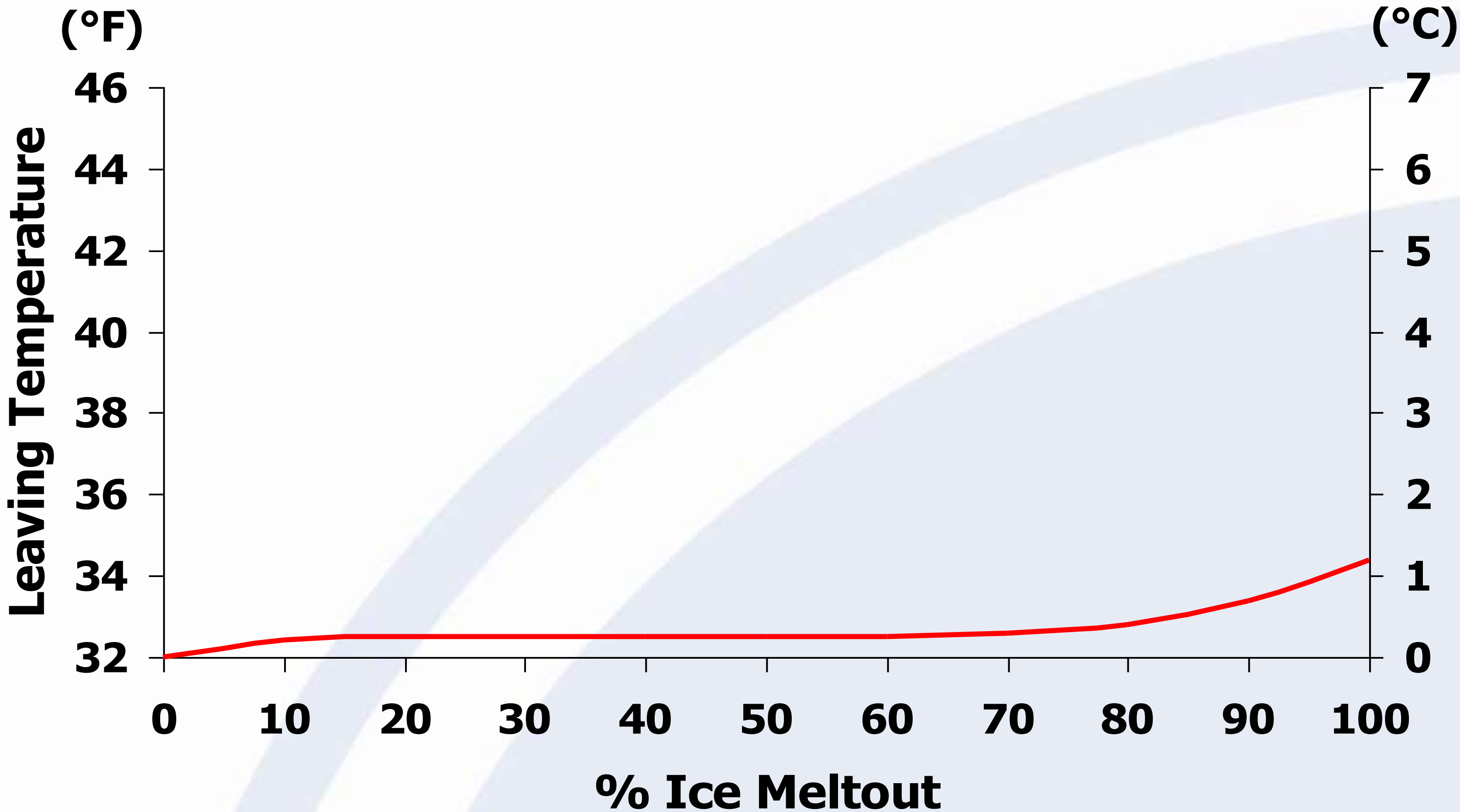


- Ice water is circulated through the ice storage tank to the A/C system
- Warm return water, circulating through the tank, is cooled via direct contact with the ice

Ice Storage Design
External Melt (Direct Contact)

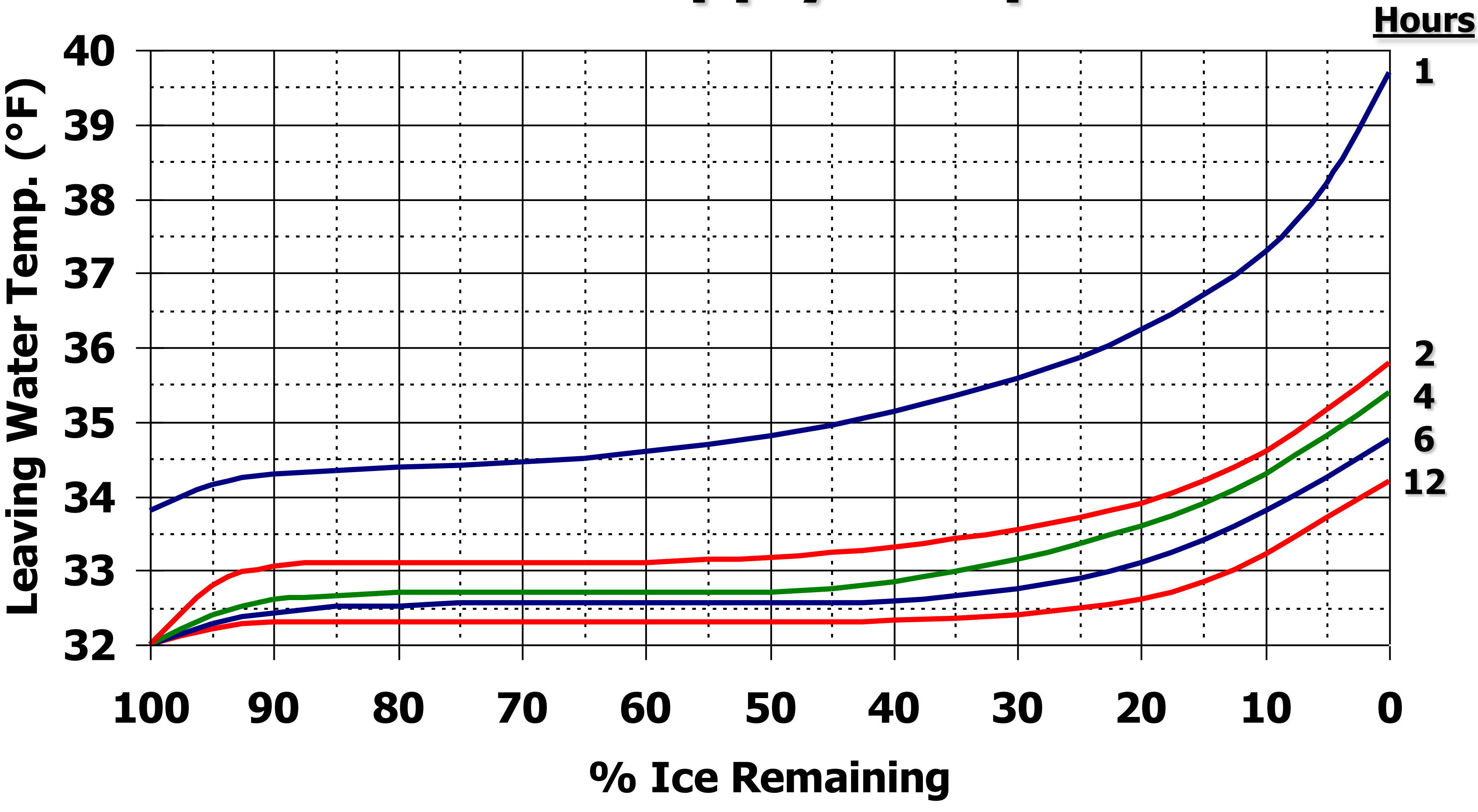


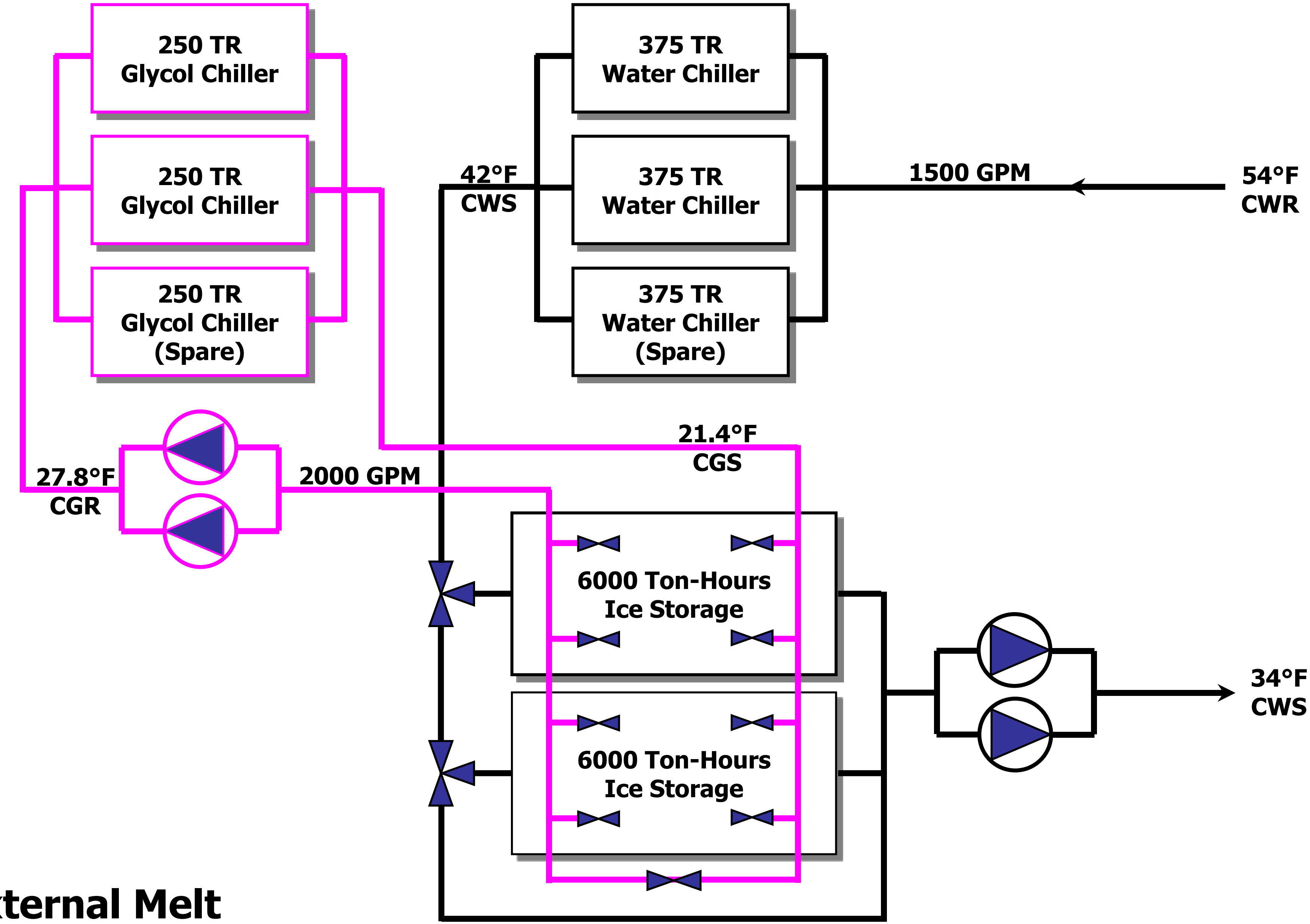
Ice Storage Design
External Melt Performance*



*10 hour, constant load

External Melt Supply Temperatures





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


BAC

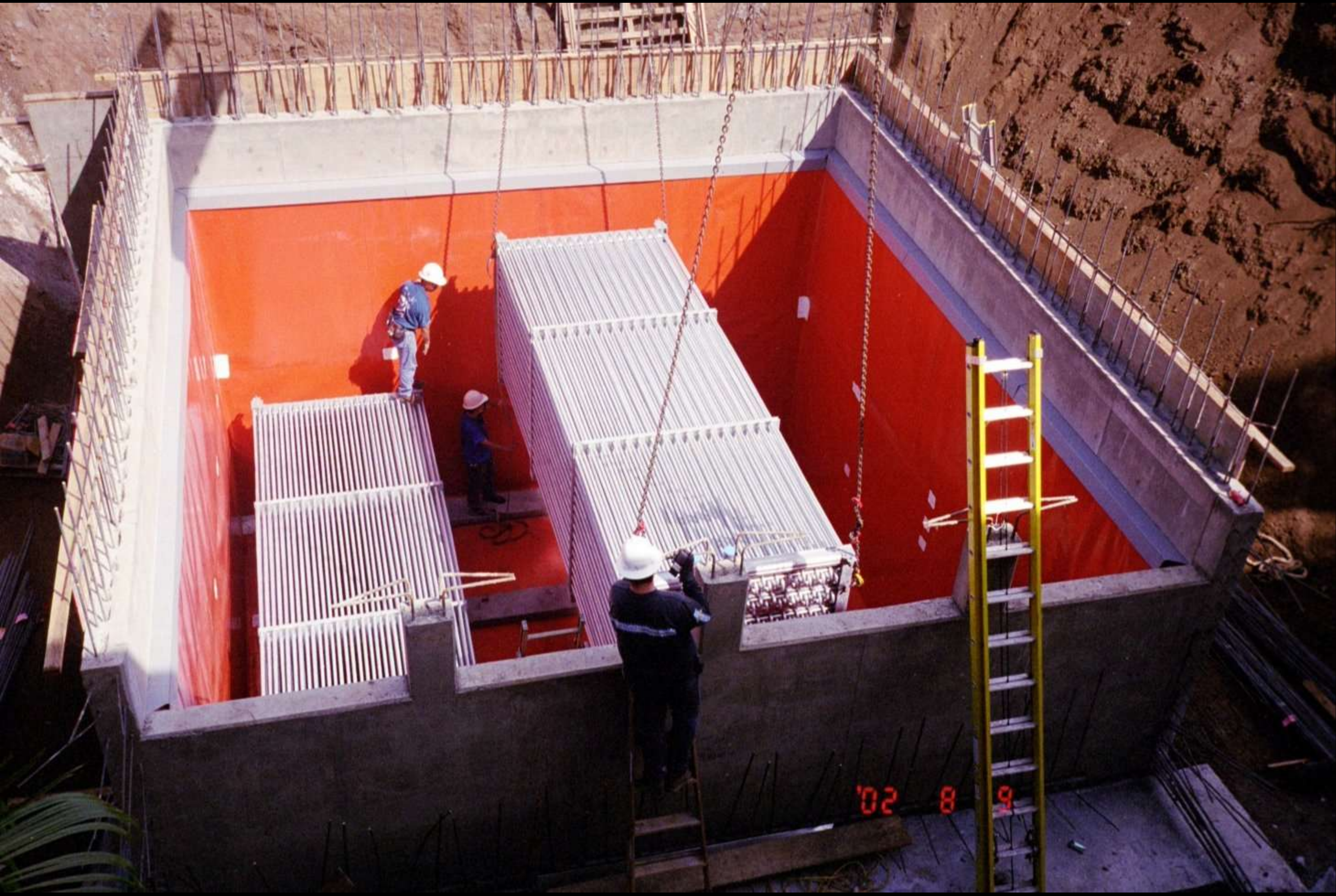

BAC

Maryknoll Grade School
Honolulu, Hawaii

Below-Grade Concrete Tank

2,000 Ton-Hours Ice Storage

District Cooling Retrofit


'02 8 9


DEERE
310SG
TURBO 4x4


'02 9 3

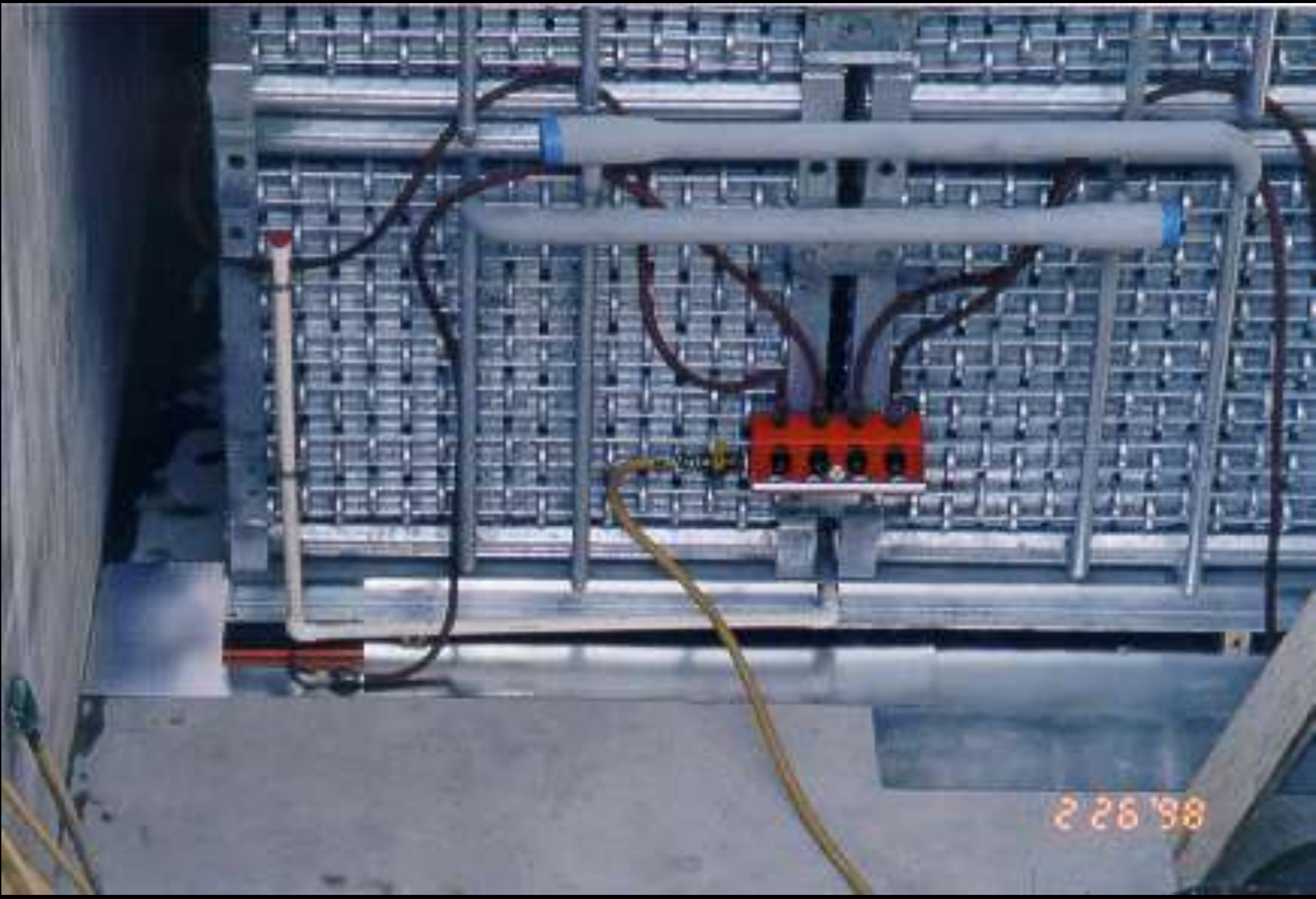

'02 11 7


EXIT
XEROX

Maryland Stadium Authority
Oriole Park at Camden Yards
Ravens Stadium at Camden Yards
Baltimore, Maryland

Buried Concrete Tank

13,000 Ton-Hours Ice Storage


2 26 '98


Ses SANDWICHS
Ouvert Jour
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)

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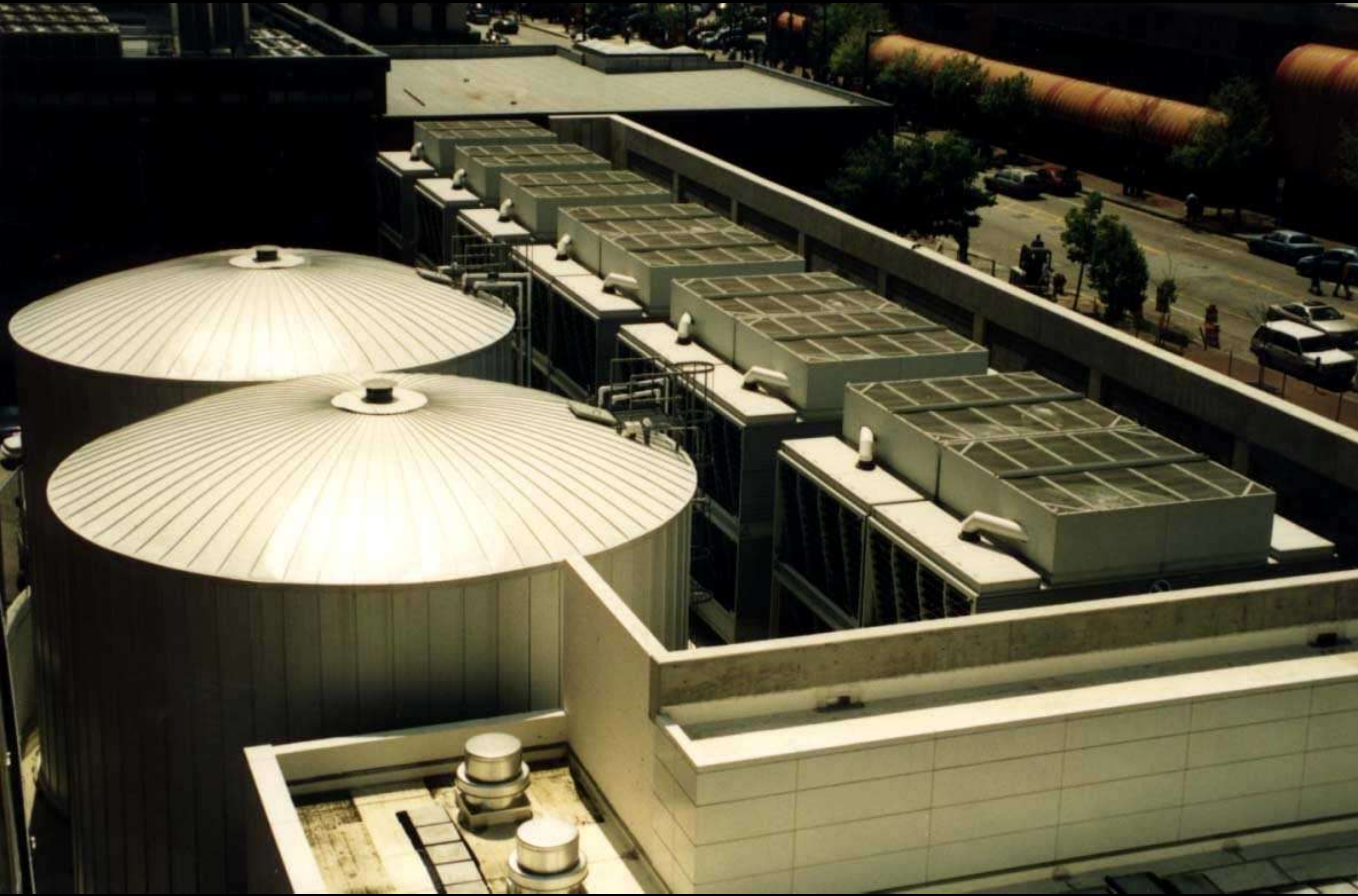


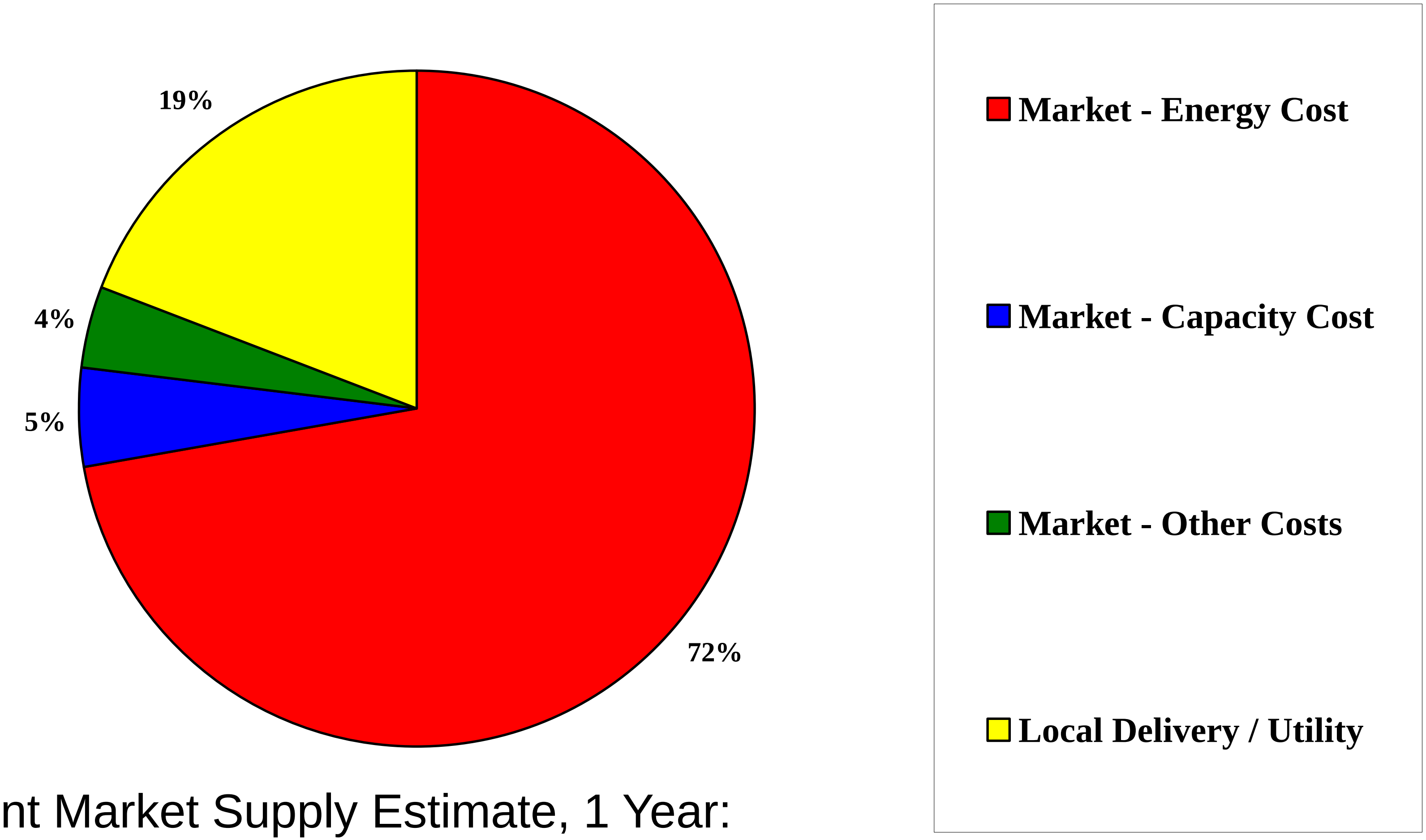
Comfort Link Market Center Chilling Station – Completion (1999)

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



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

South River CONSULTING

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

Energy Cost Operating Strategy

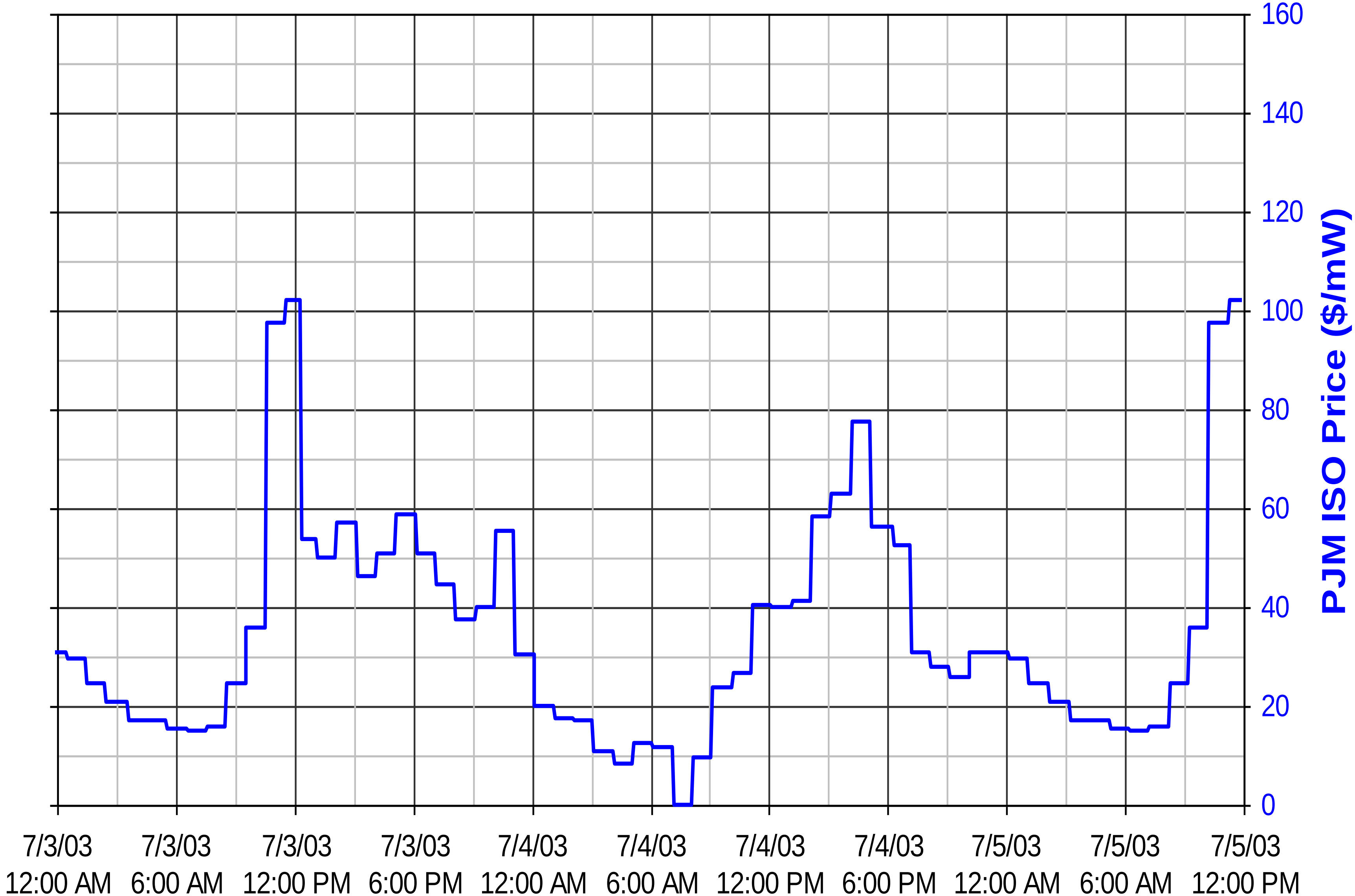


Chart courtesy of Comfort Link

Energy Cost Operating Strategy

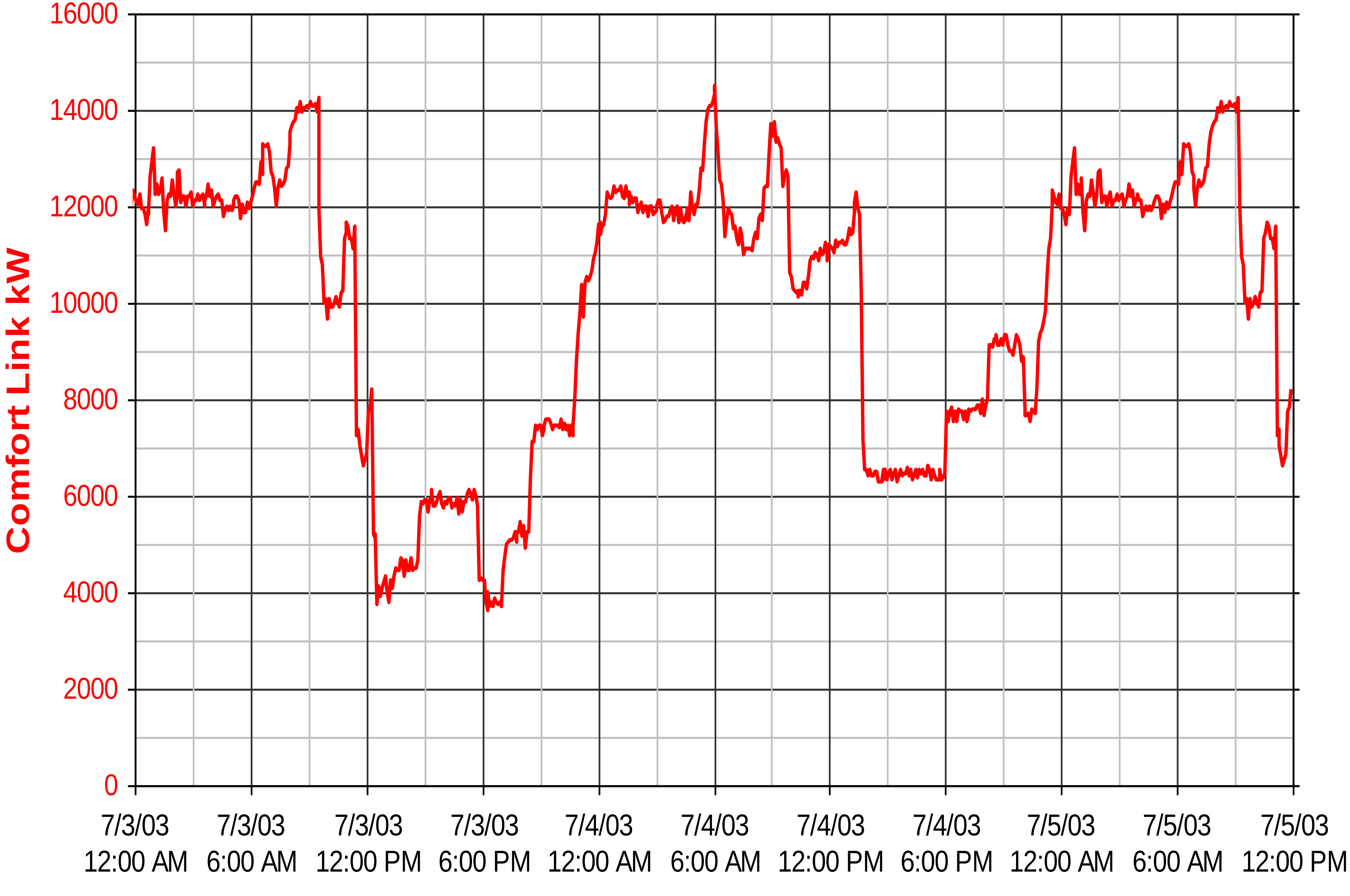


Chart courtesy of Comfort Link

Energy Cost Operating Strategy

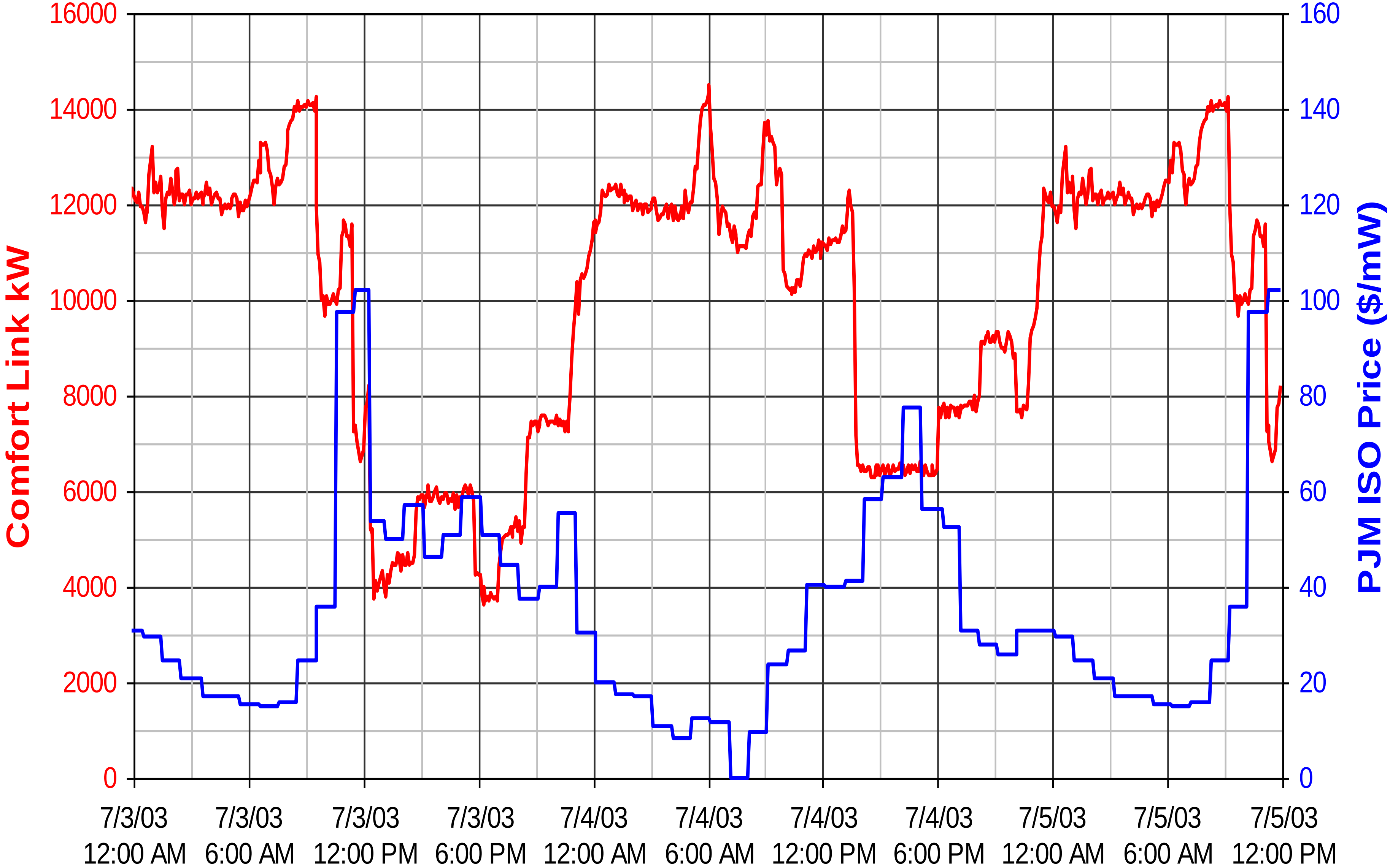
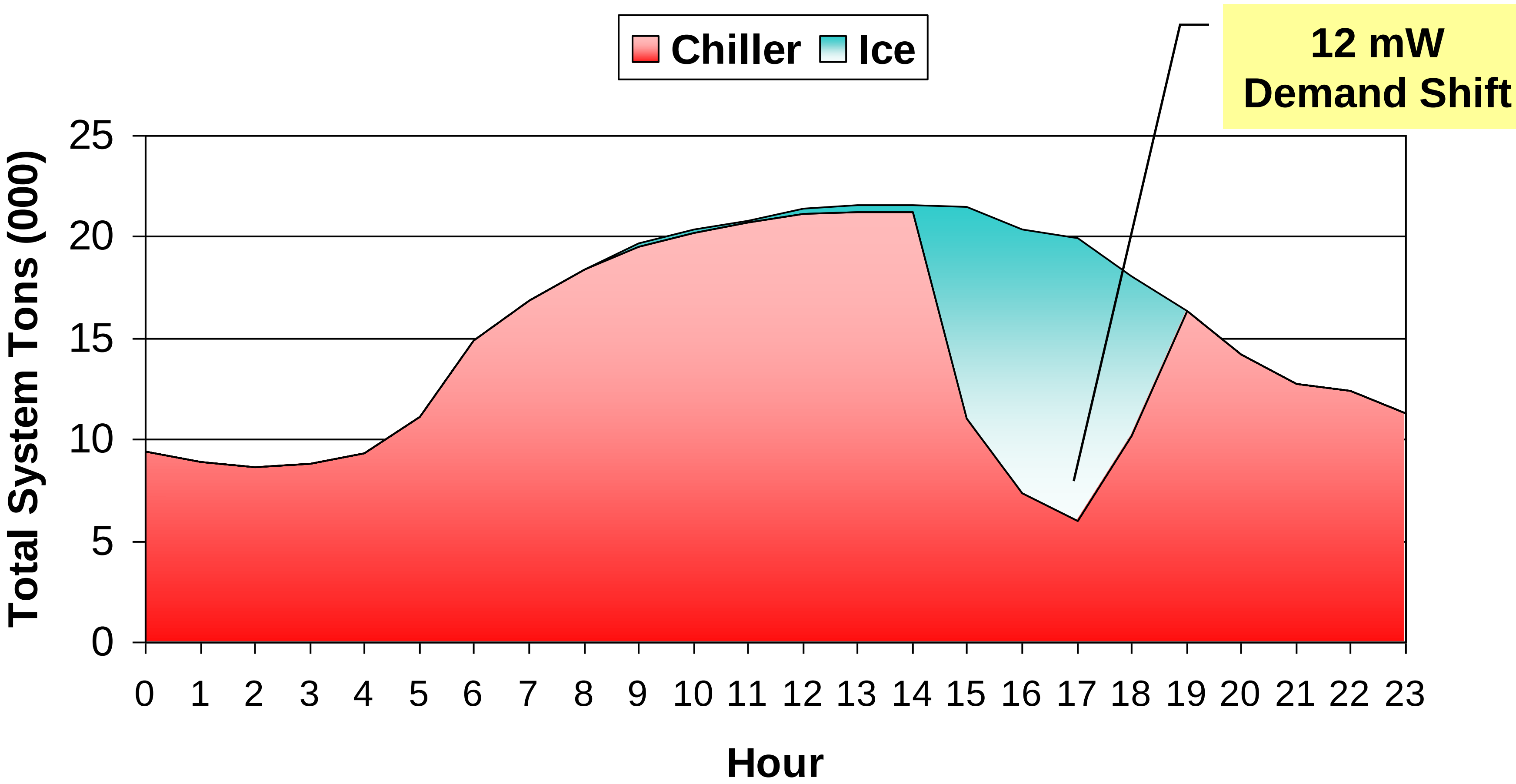


Chart courtesy of Comfort Link

Demand Limiting Operating Strategy

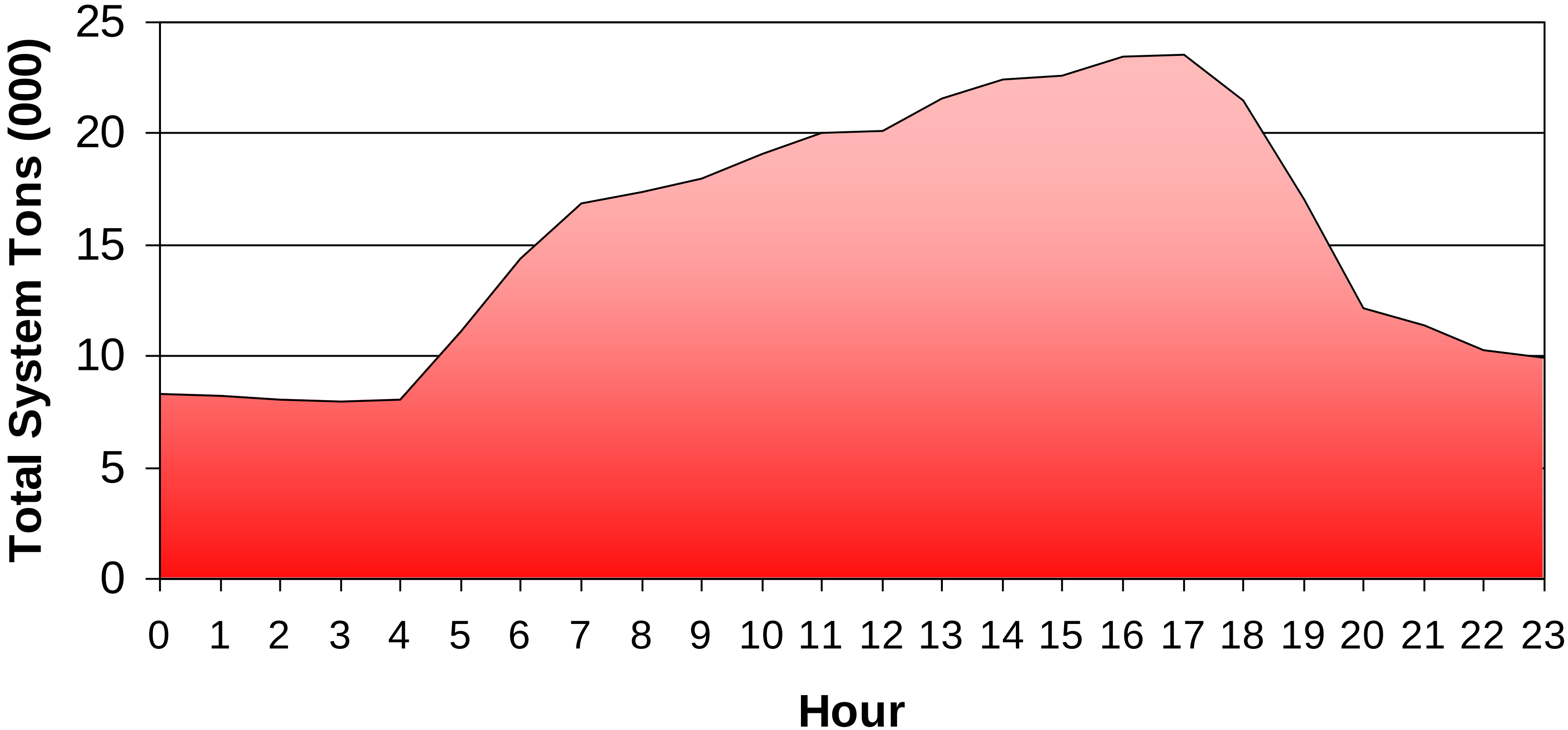


June 27, 2007
High of 100°F (37.8°C)
Low of 80°F (26.7°C)

Chart courtesy of Comfort Link

Load Leveling Operating Strategy

(1) 1750 TR chiller out of service

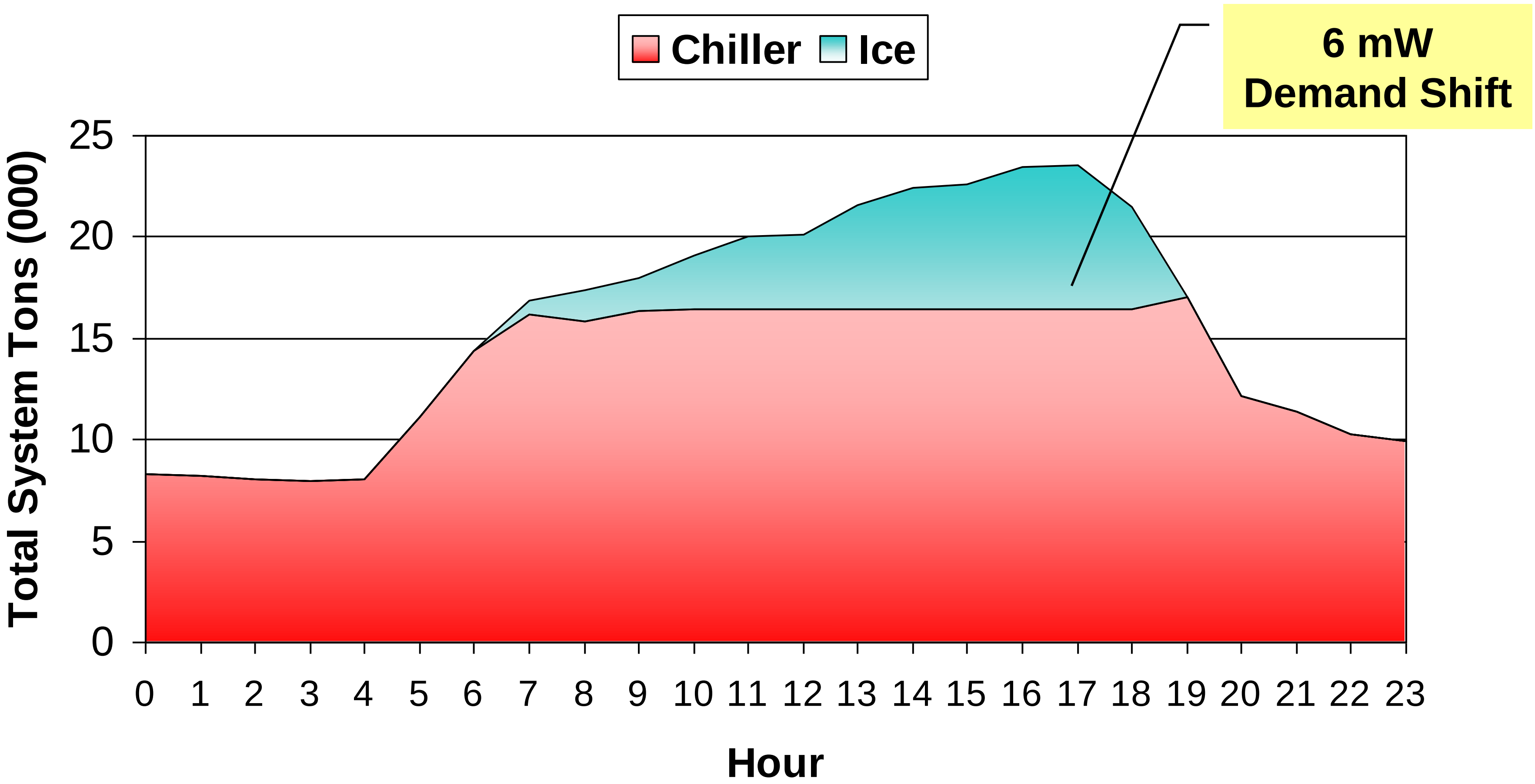


August 8, 2007
High of 108°F (42.2°C)
Low of 86°F (30.0°C)

Chart courtesy of Comfort Link

Load Leveling Operating Strategy

(1) 1750 TR chiller out of service

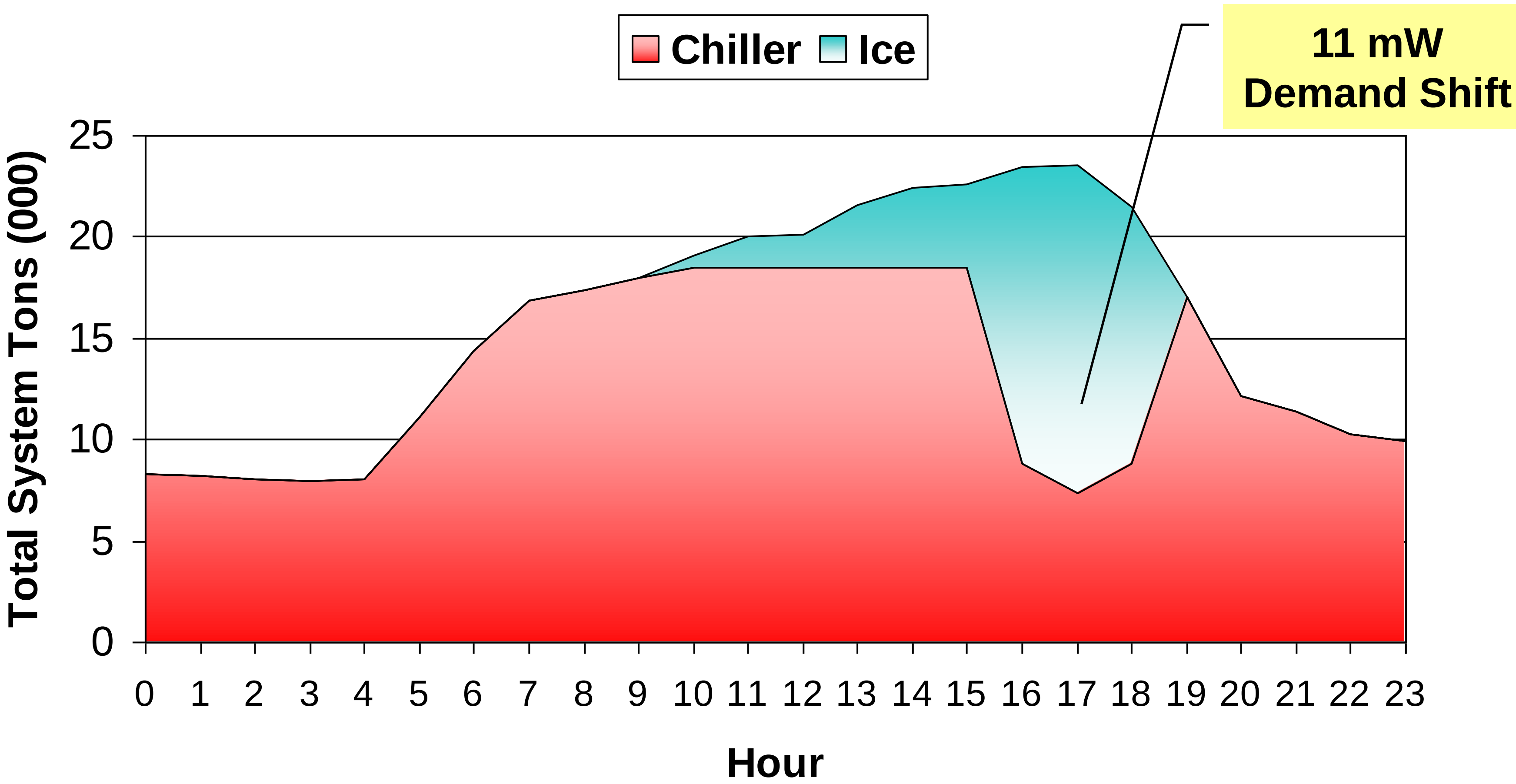


August 8, 2007
High of 108°F (42.2°C)
Low of 86°F (30.0°C)

Chart courtesy of Comfort Link

Demand Limiting Operating Strategy

Predicted performance with all chillers in service



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High of 108°F (42.2°C)
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Chart courtesy of Comfort Link

Ice Thermal Storage Systems

Greg Henderson
Director, Global Thermal Storage