THERMAL ENERGY STORAGE

A VITAL INGREDIENT IN A LOW CARBON FUTURE

Mark M. MacCracken, PE, LEED^{AP}, Pte

CALMAC Mfg. Corp.
Fair Lawn, NJ
www.Calmac.com

Benefits of Thermal Energy Storage

Reduces Peak Demand at most critical time 20-40%

Reduces consumer's energy costs 10-20%

May reduce energy usage at the building up to 14%

Reduces source energy usage at power plant 8-34%

Reduces emissions

Increases Load Factor of Grid and Buildings

Is Critical to Large Scale Viability of Renewables

Cool Energy Storage

What is it?

Why is it Vital for a Low Carbon Future?

How does it work?

Why is it Green?

Other “Green” Advantages

Applications/Case Studies

Storage is Natural

Most common TES System

4.5 kW
Heater

Water Heater (Electric)

Assume one low- flow shower
((2.5gpm x 8.33 lb/gal x (110- 60))
x 60 minutes/hr / 3,414 Btu/kW =

18.3 kW

Have you ever hosted a party?

Off Peak Cooling

How many lbs. of ice do you need each day to cool each person in the average office building?

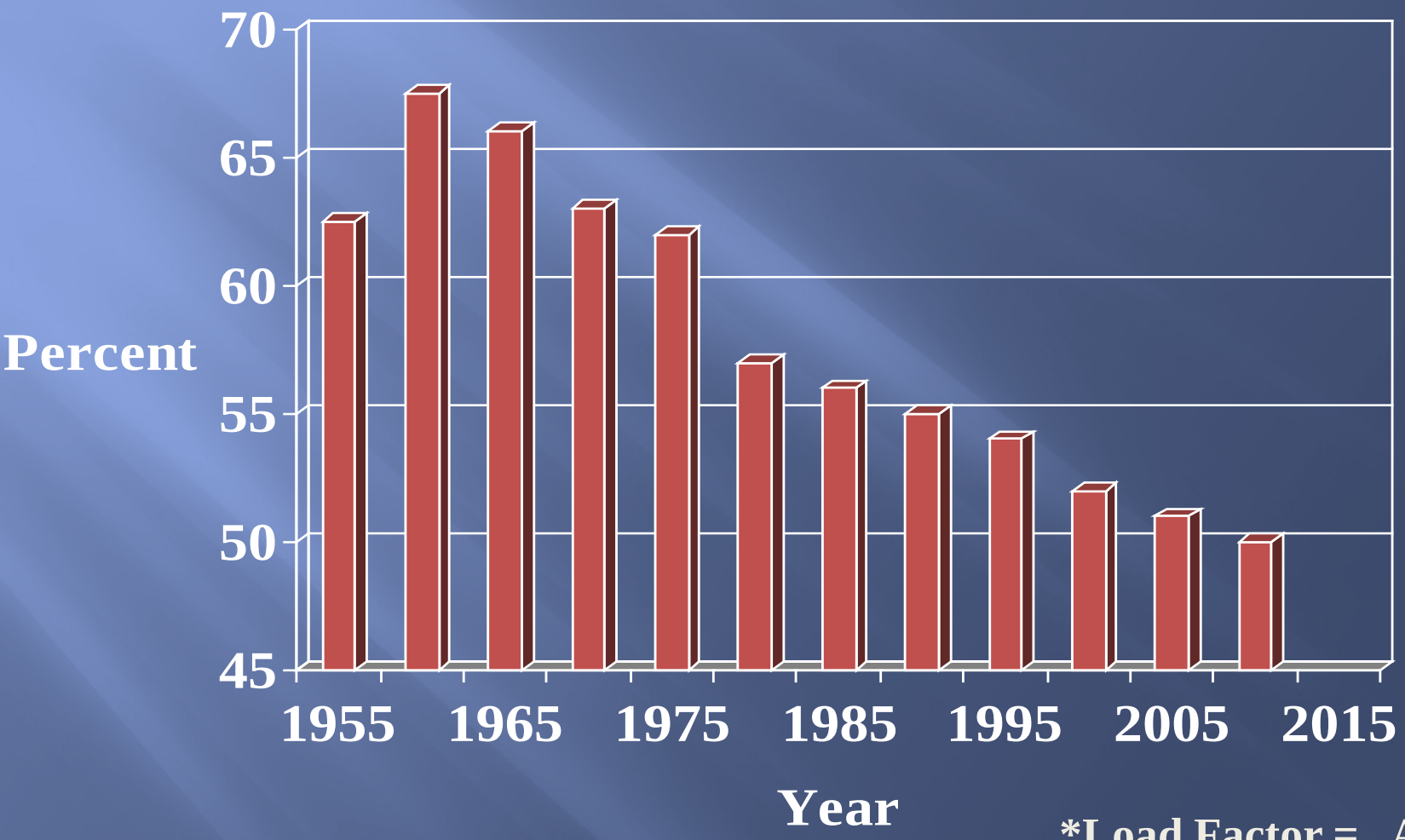
300 ft^2/ton **400 ft^2/ton** **500 ft^2/ton**

100 ft^2/per person **200 ft^2/per person**

100 ft^2/pp / 400 x 8hr = 2 ton-hrs = 160 lbs of Ice/Person/Day

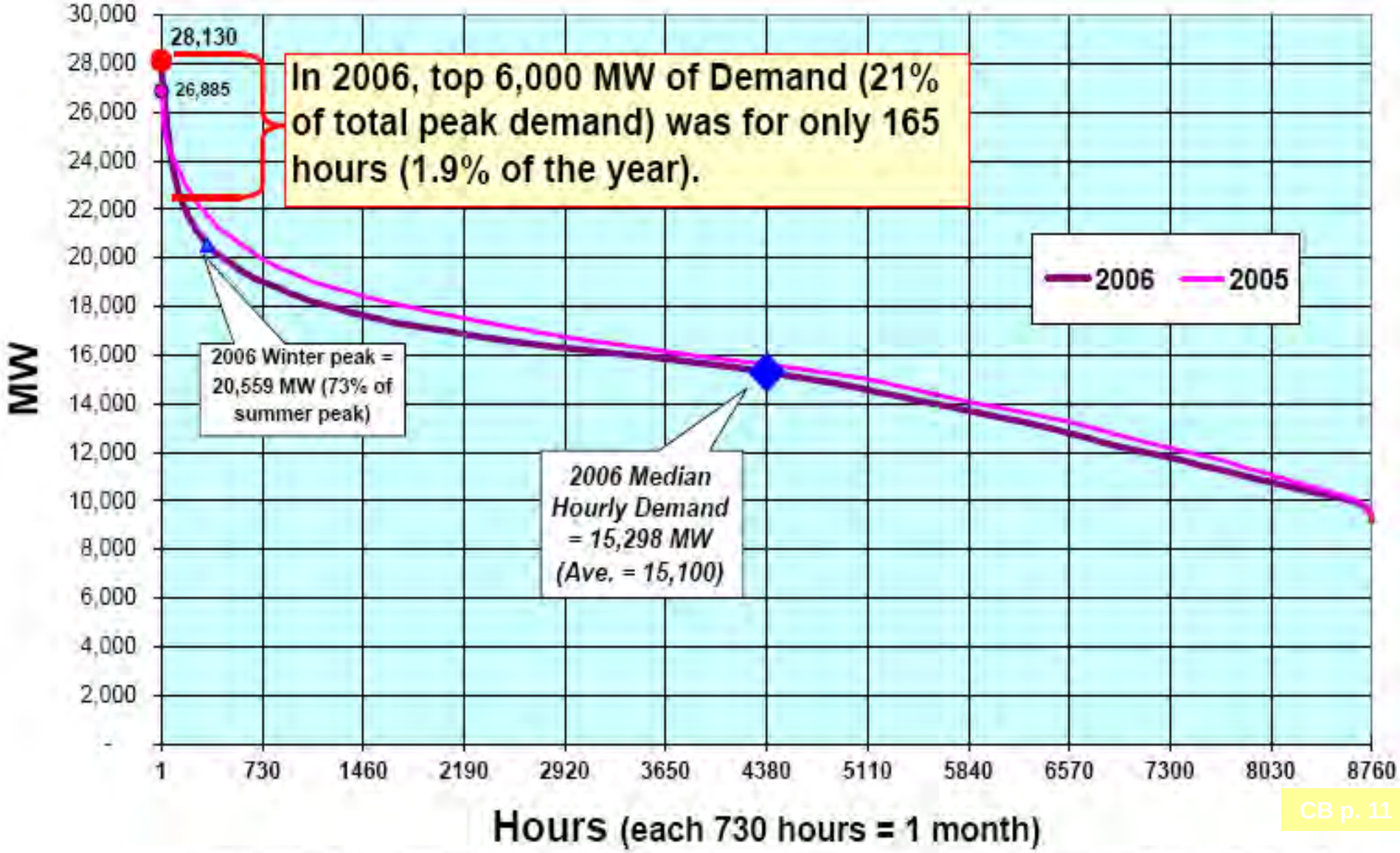
200 ft^2/pp / 400 x 10hr. = 5 ton-hrs = 400 lbs of Ice/Person/Day

Utility Load Factors* in the USA



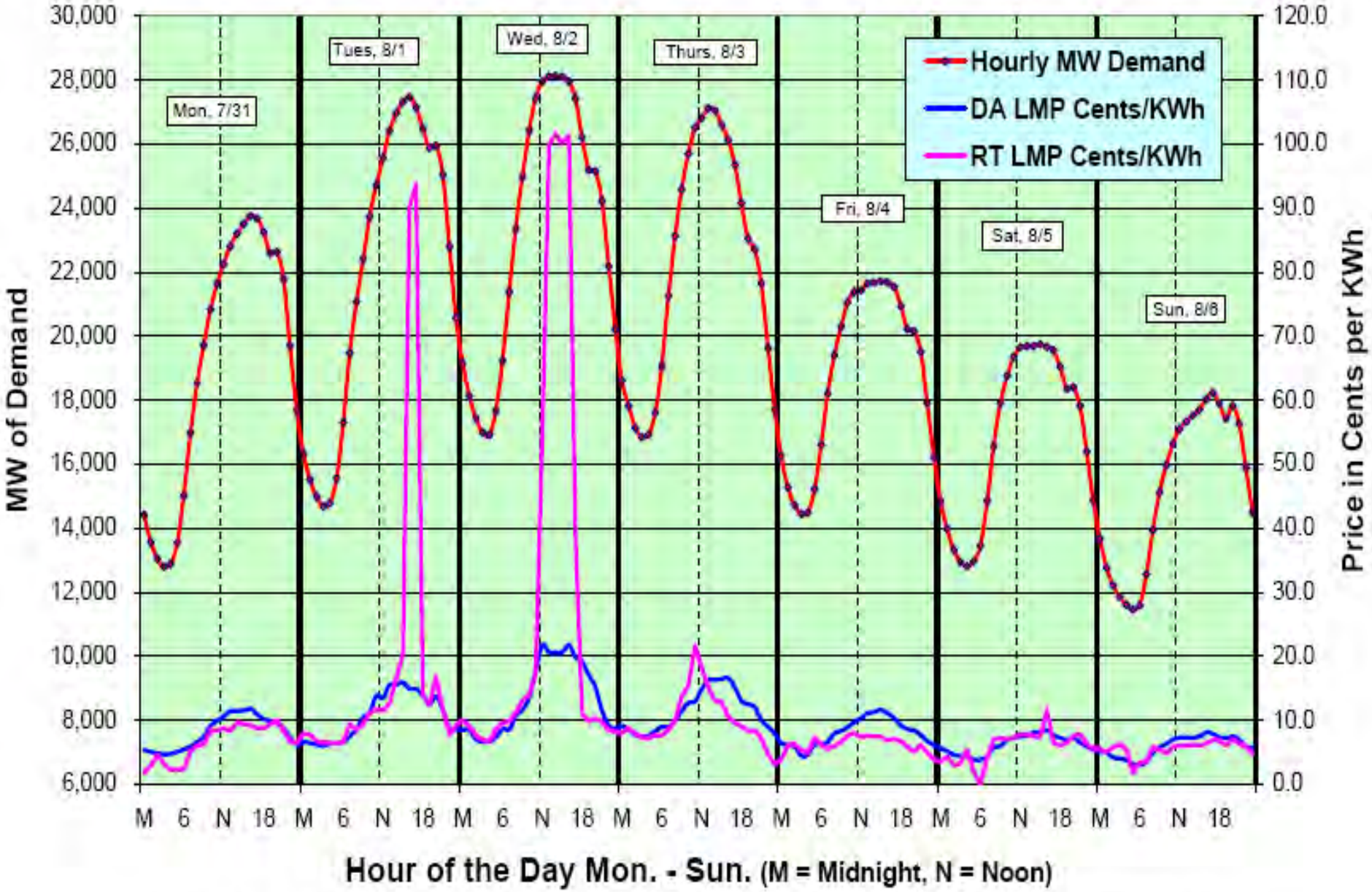
$$*\text{Load Factor} = \frac{\text{Avg. Load}}{\text{Peak Load}}$$

ISO-New England 2005 & 2006 Hourly MW Load Duration Curve



Graph by Clifton Below, NHPUC, from: 2006_smd_hourly.xls and 2005_smd_hourly.xls available at: http://www.iso-ne.com/markets/hstdata/znl_info/hourly/index.html

ISO-NE Hourly Demand & Price Week of 7/31-8/6/06



Graph by Clifton Below, NHPUC, from: 2006_smd_hourly.xls, available at: http://www.iso-ne.com/markets/hstdata/znl_info/hourly/index.html

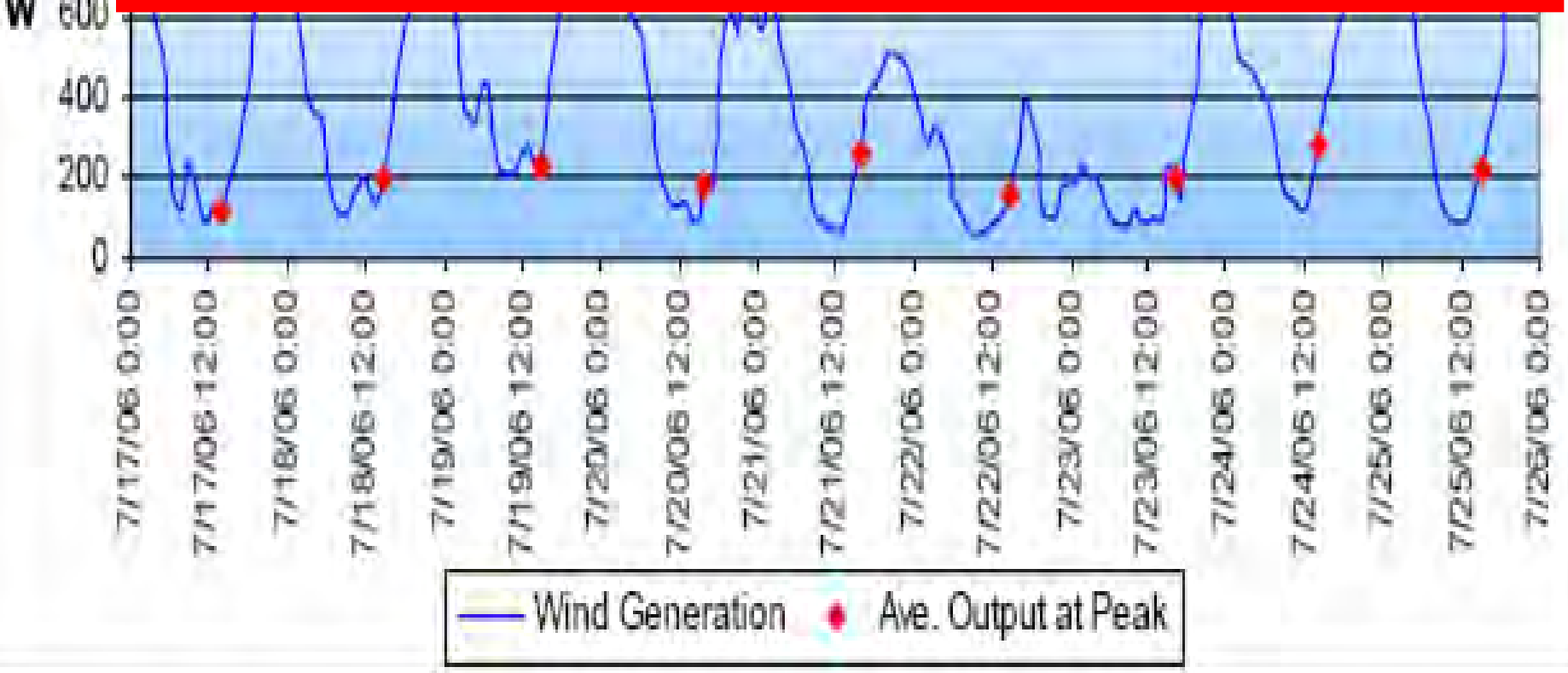
Stored Energy

Energy

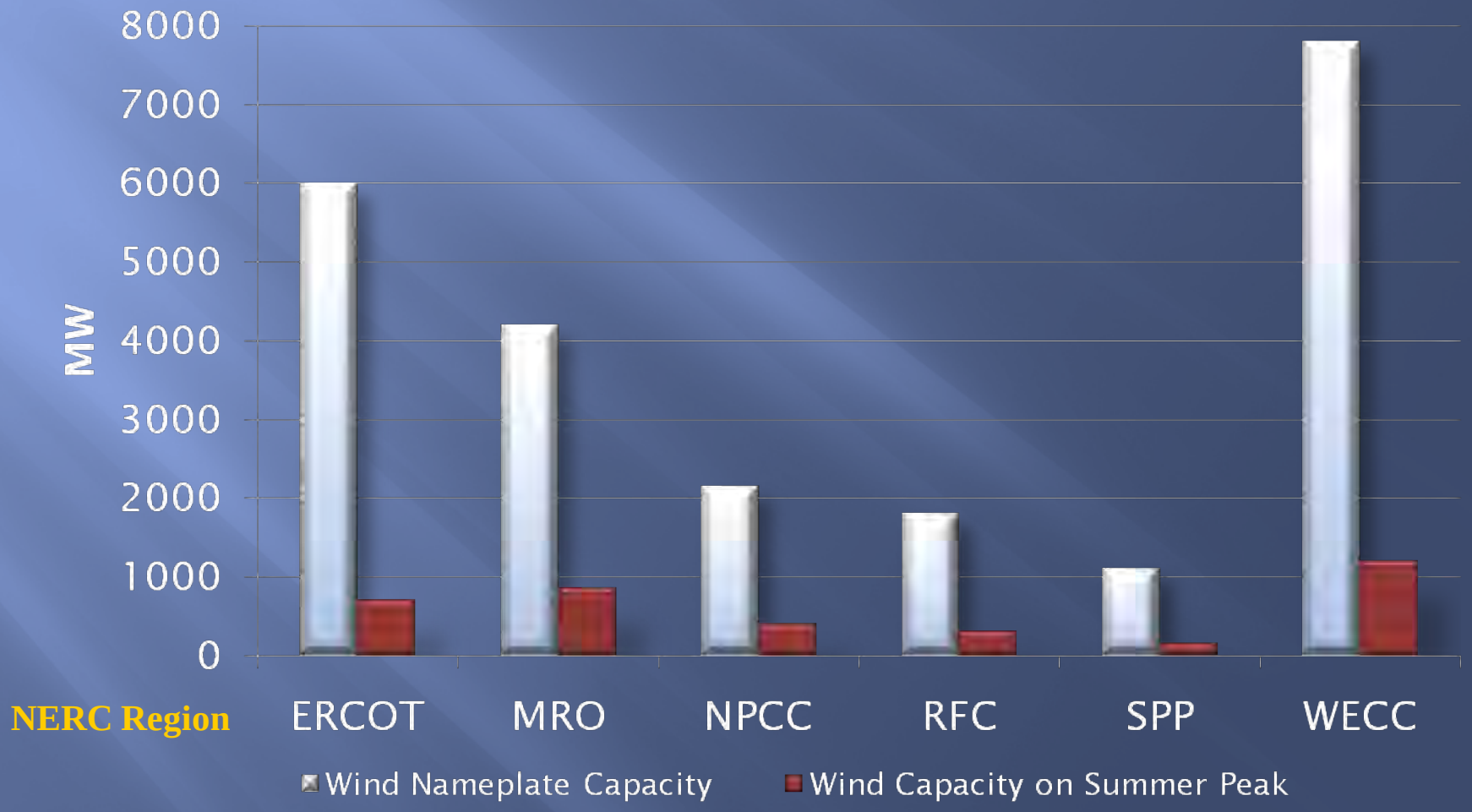
Where is the Storage?

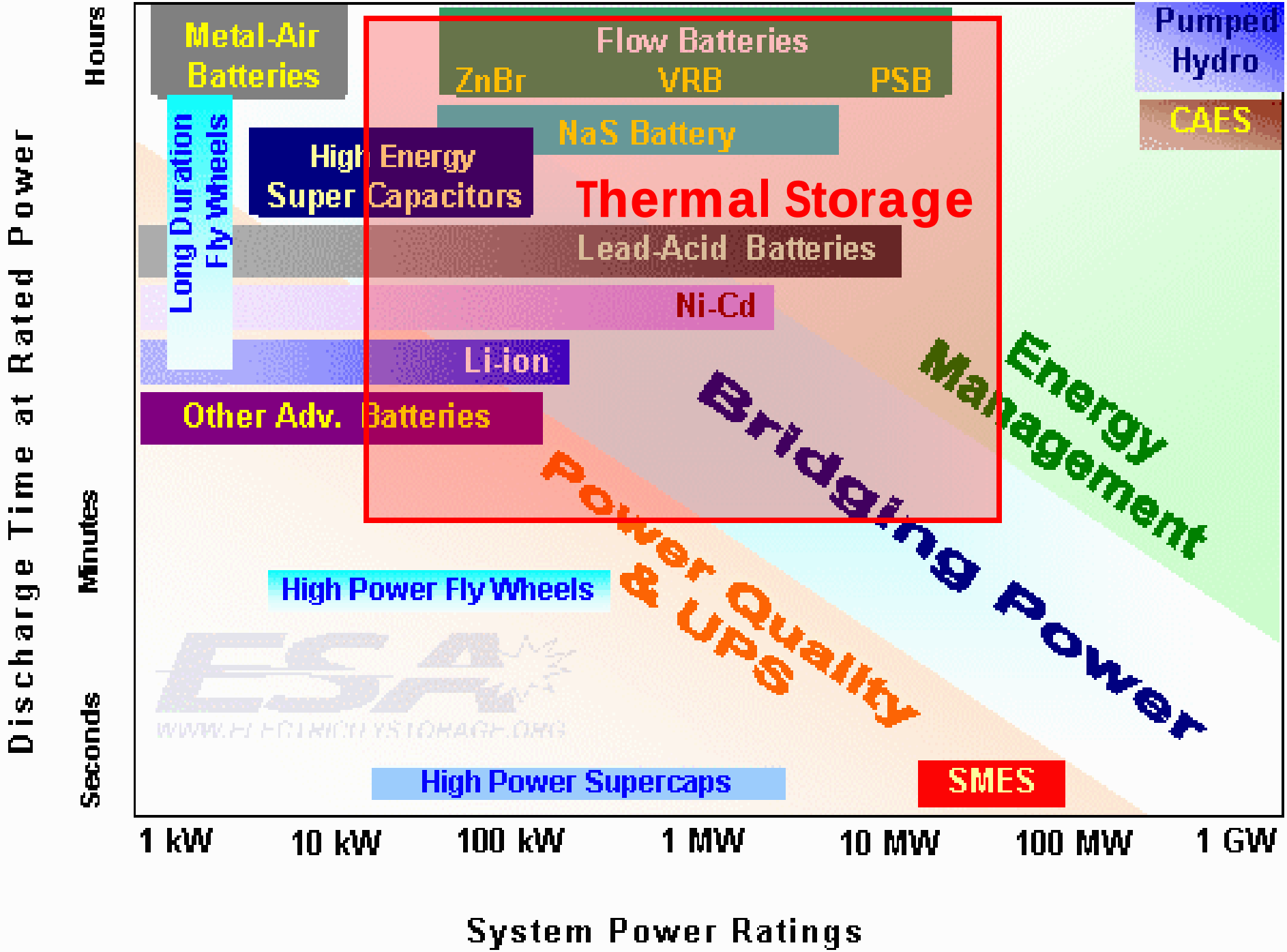
Wind Generation and Output at Peak

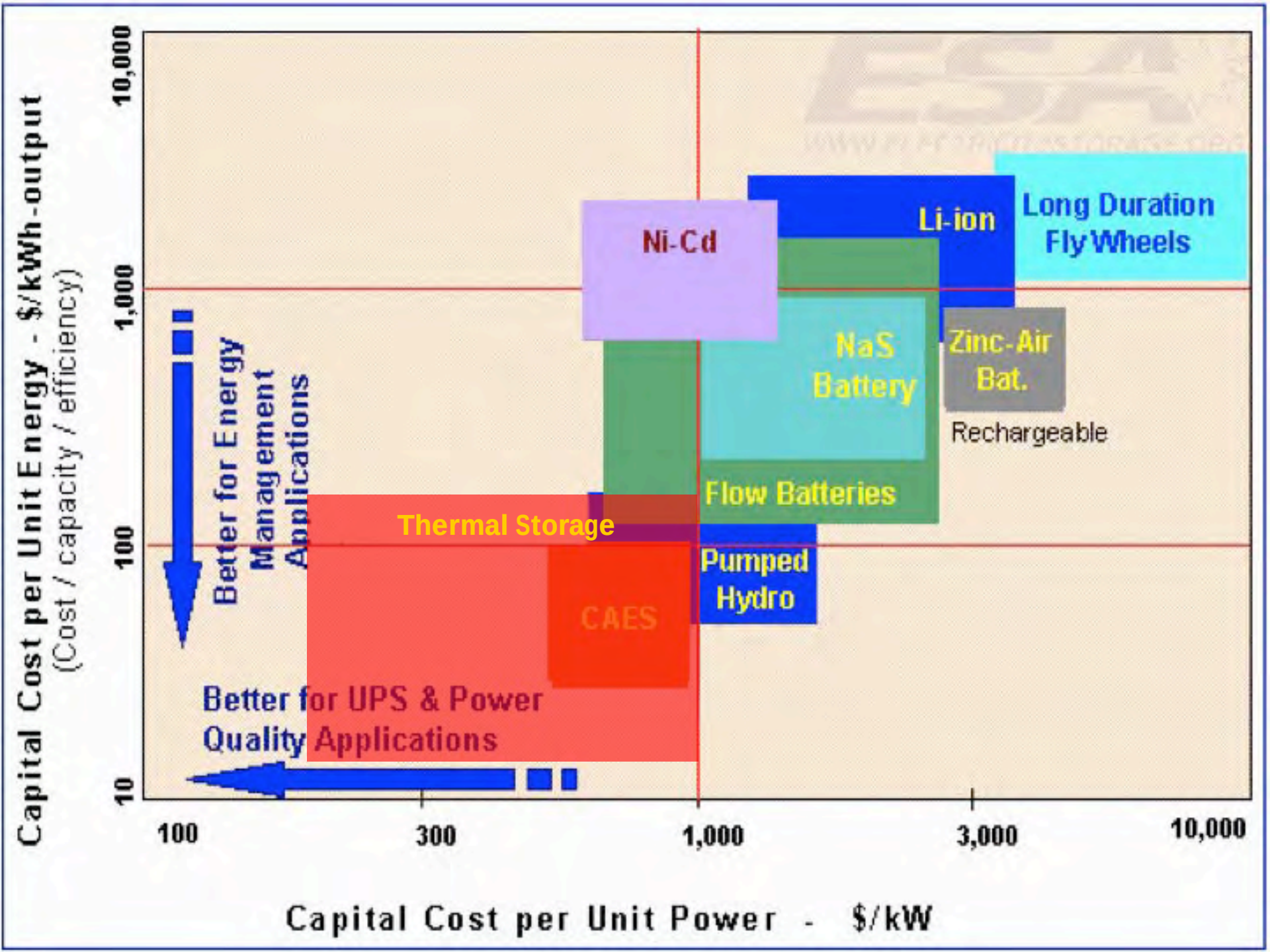
"In West Texas electricity prices dropped to zero 11% of the time in the 12 months through May 2009, says Bernstein Research analyst Hugh Wynne." (Forbes.com)



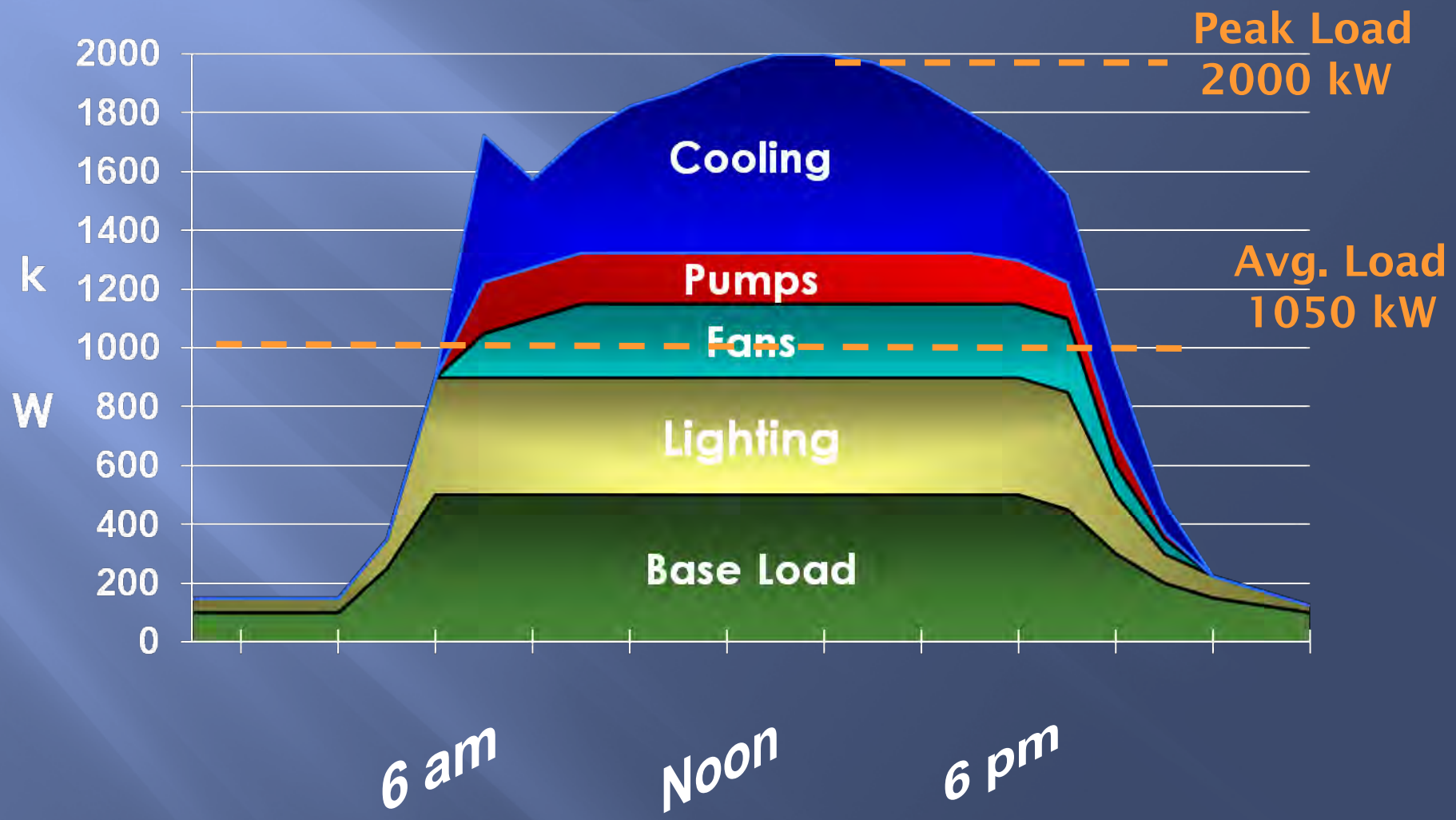
Storage Bolsters Variable Wind Resourses




Discharge Time at Rated Power
Hours
Minutes
Seconds
Metal-Air Batteries
Flow Batteries
ZnBr
VRB
PSB
Pumped Hydro
CAES
Long Duration Fly Wheels
High Energy Super Capacitors
NaS Battery
Thermal Storage
Lead-Acid Batteries
Ni-Cd
Li-ion
Other Adv. Batteries
Energy Management
Bridging Power
Power Quality & UPS
High Power Fly Wheels
High Power Supercaps
SMES
1 kW
10 kW
100 kW
1 MW
10 MW
100 MW
1 GW
System Power Ratings

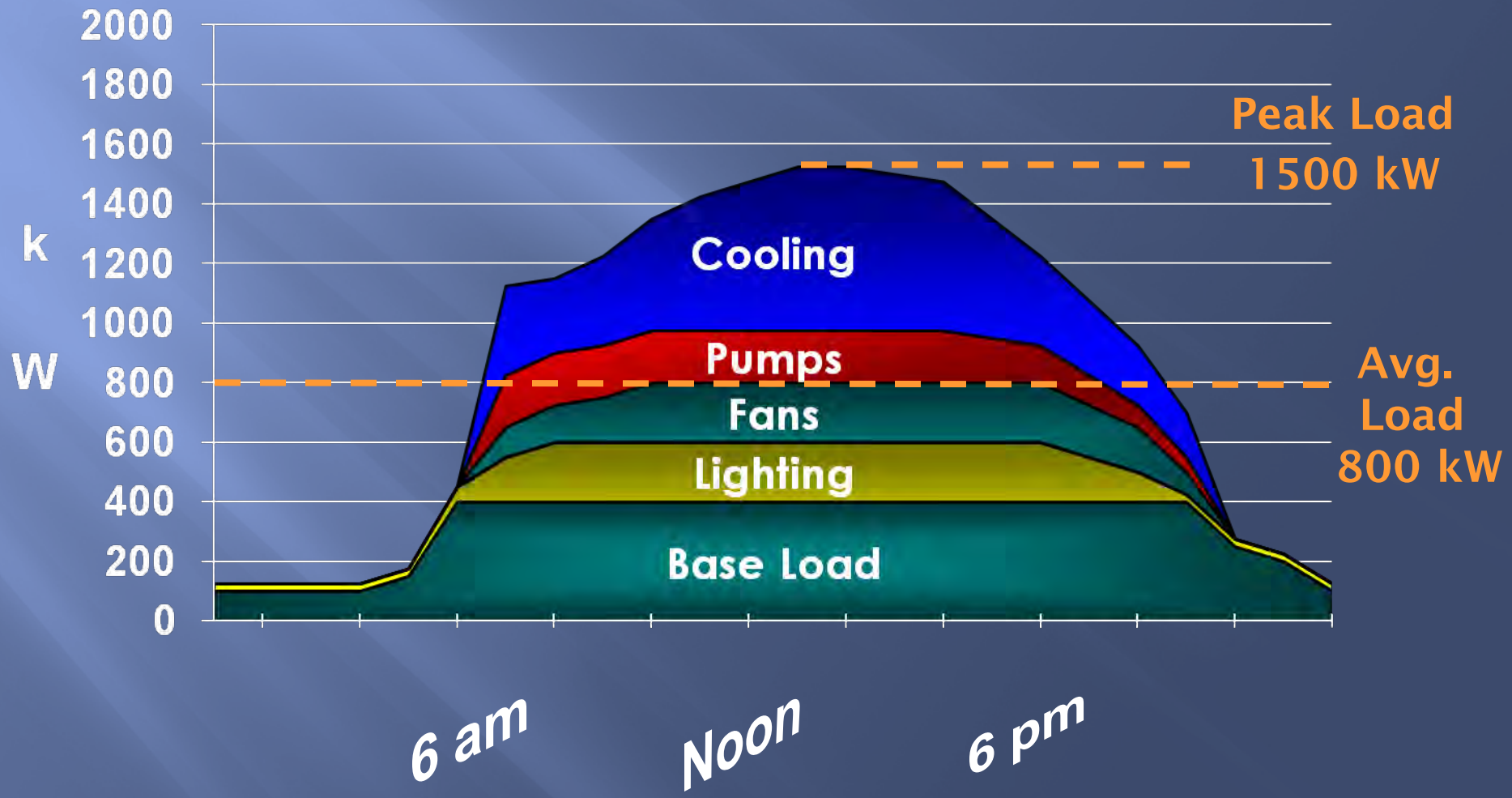

Capital Cost per Unit Energy - $/kWh-output
(Cost / capacity / efficiency)
10,000
1,000
100
10
Better for Energy Management Applications
Better for UPS & Power Quality Applications
Ni-Cd
Li-ion
Long Duration Fly Wheels
NaS Battery
Zinc-Air Bat.
Rechargeable
Flow Batteries
Thermal Storage
Pumped Hydro
CAES
100
300
1,000
3,000
10,000
Capital Cost per Unit Power - $/kW

ASHRAE 90.1 Base Building Non-Storage Electrical Profile



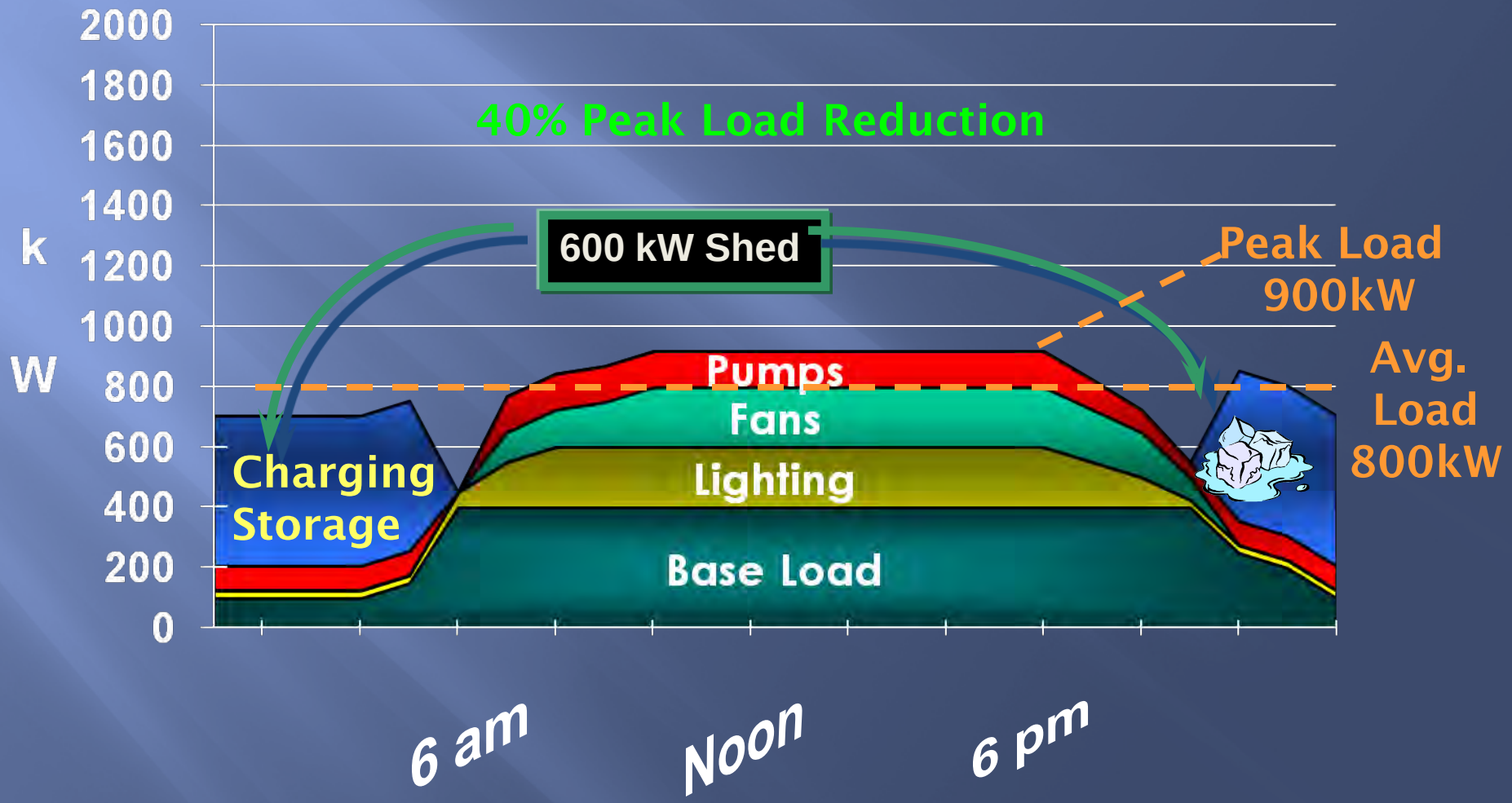
Total kWh = 28,000/day (Load Factor = 53%)

30% Better Than ASHRAE 90.1 Non-Storage Electrical Profile



Total kWh = 19,200/day (Load Factor = 53%)

30% Better Than ASHRAE 90.1 with Thermal Energy Storage



Total kWh = 19,200/day (Load Factor = 88%)

Power continues to be less expensive at Night because of Generation Load Factor

4 Buildings x 1 Megawatt

= 4 Megawatts

8,000 MW-h Sold

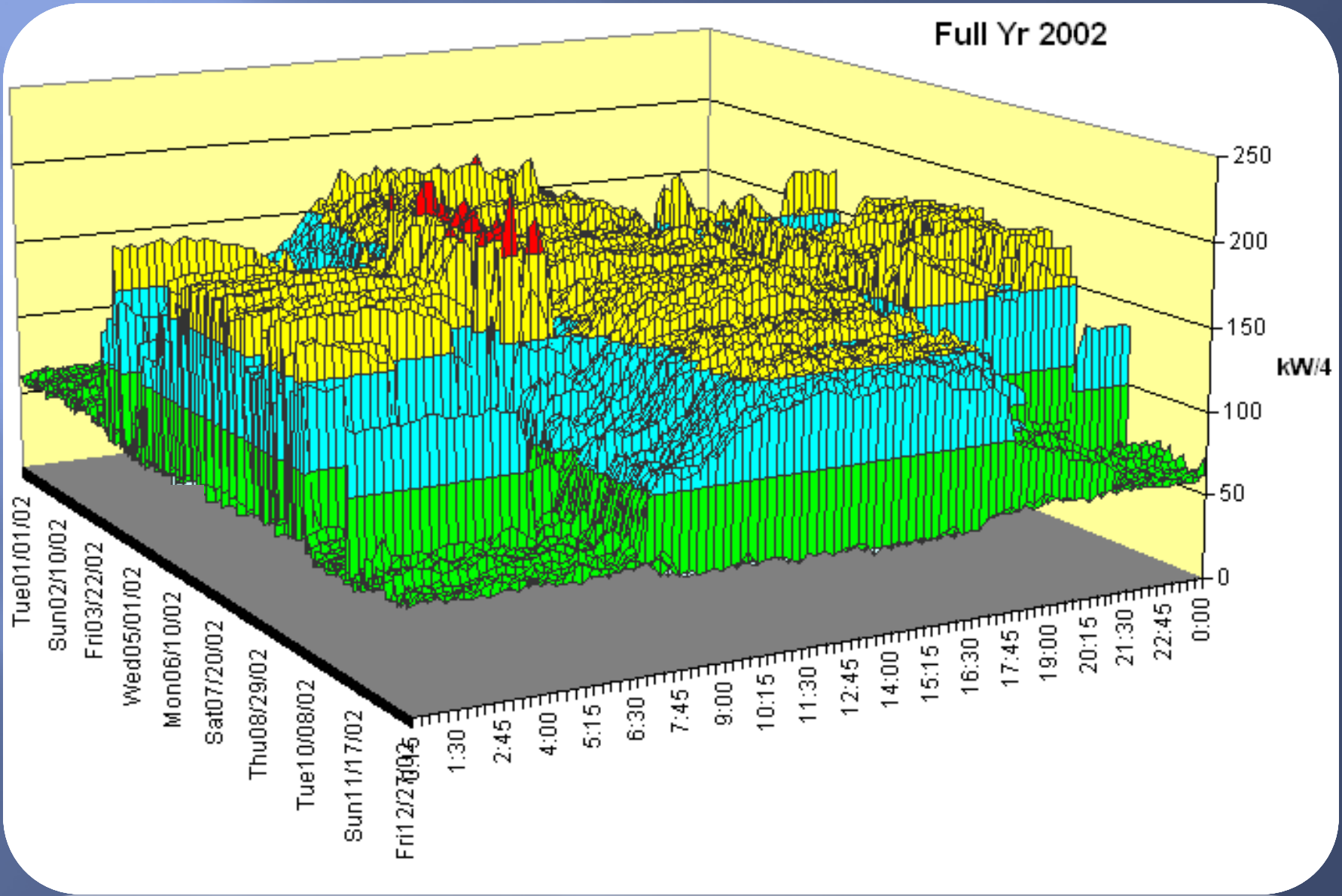
5 Buildings with TES @ 0.8 MW

= 4 Megawatts

10,000 MW-h Sold!

The same generator produces 25% more sellable MW-h

3D Electric Profile, Full Year

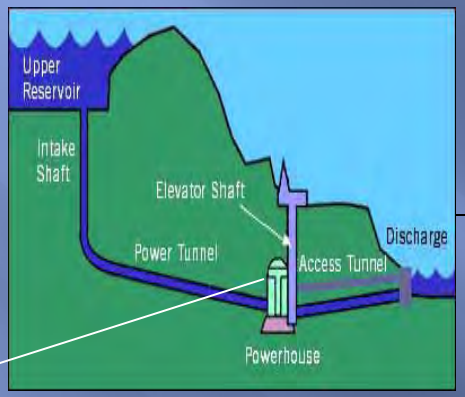


Understanding End-to-End Cycle Efficiency
Grid Storage vs. Building Energy Storage

Grid Storage

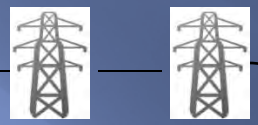
1.45kWh to create
1 ton-hr of Cooling

Pumped Hydro - 70%

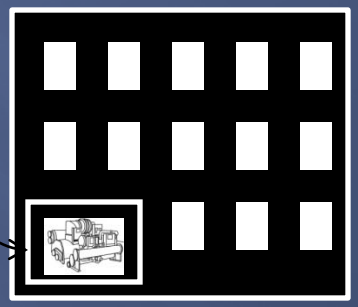


On Peak - Daytime

Transmission 95%
Distribution 93%



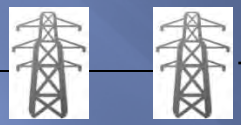
0.9 kW/ton



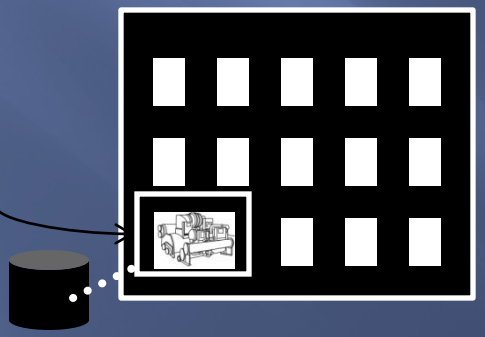
1 ton-hr of Cooling
13,000 Btu's
Source Energy*

Off Peak - Nighttime

Transmission 97%
Distribution 96%



1.0 kW/ton



1 ton-hr of Cooling
9,650 Btu's
Source Energy*

Building Storage

1.07kWh to create
1 ton-hr of Cooling

* Fossil Fuel Power Plant Eff.= 38%

Economical, Social and Environmental Benefits of Energy Storage are real.

Page 293

- **PV on Green Buildings make a Building's Load Factors worse!**

Building Type	Climate	Scenario	DDMLF (fraction)	YLF (fraction)
Prim. School	2B	90.1-1999	0.34	0.25
Prim. School	2B	90.1-2004	0.35	0.26
Prim. School	2B	90.1-2007	0.36	0.27
Prim. School	2B	Std 189P	0.36	0.28
Prim. School	2B	Std 189P - 25% PV	0.19	0.17
Prim. School	3A	90.1-1999	0.31	0.25
Prim. School	3A	90.1-2004	0.31	0.25
Prim. School	3A	90.1-2007	0.32	0.27
Prim. School	3A	Std 189P	0.34	0.29
Prim. School	3A	Std 189P - 25% PV	0.11	0.18

Thermal Energy Storage For Off-Peak Cooling

What is Thermal Energy Storage ?

How does it work?

Two Basic Systems

- Water
- Ice

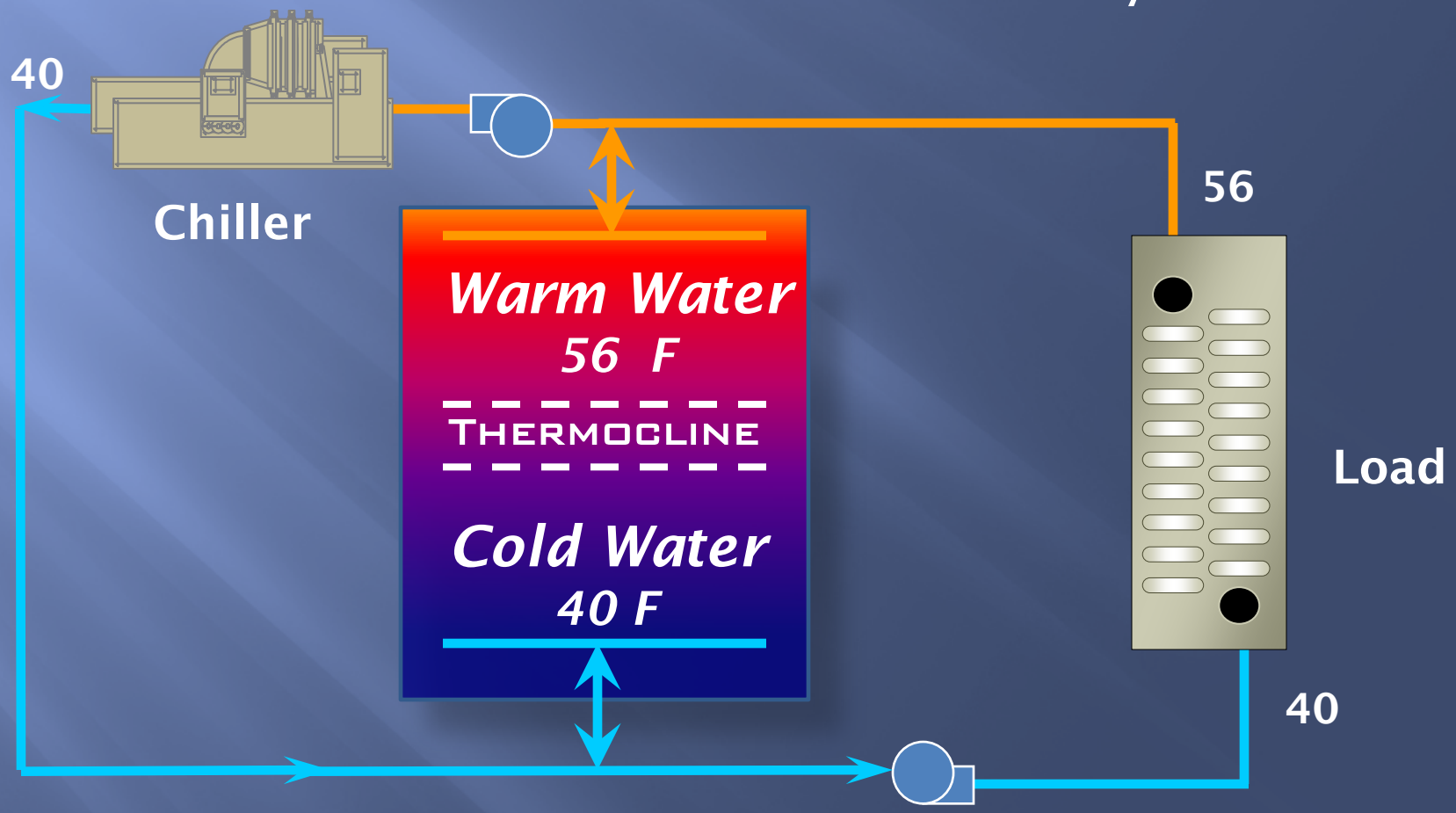
Water Storage

So what is "Different"?

Storage Tank

Keeping System delta T is a must

Not a Closed System

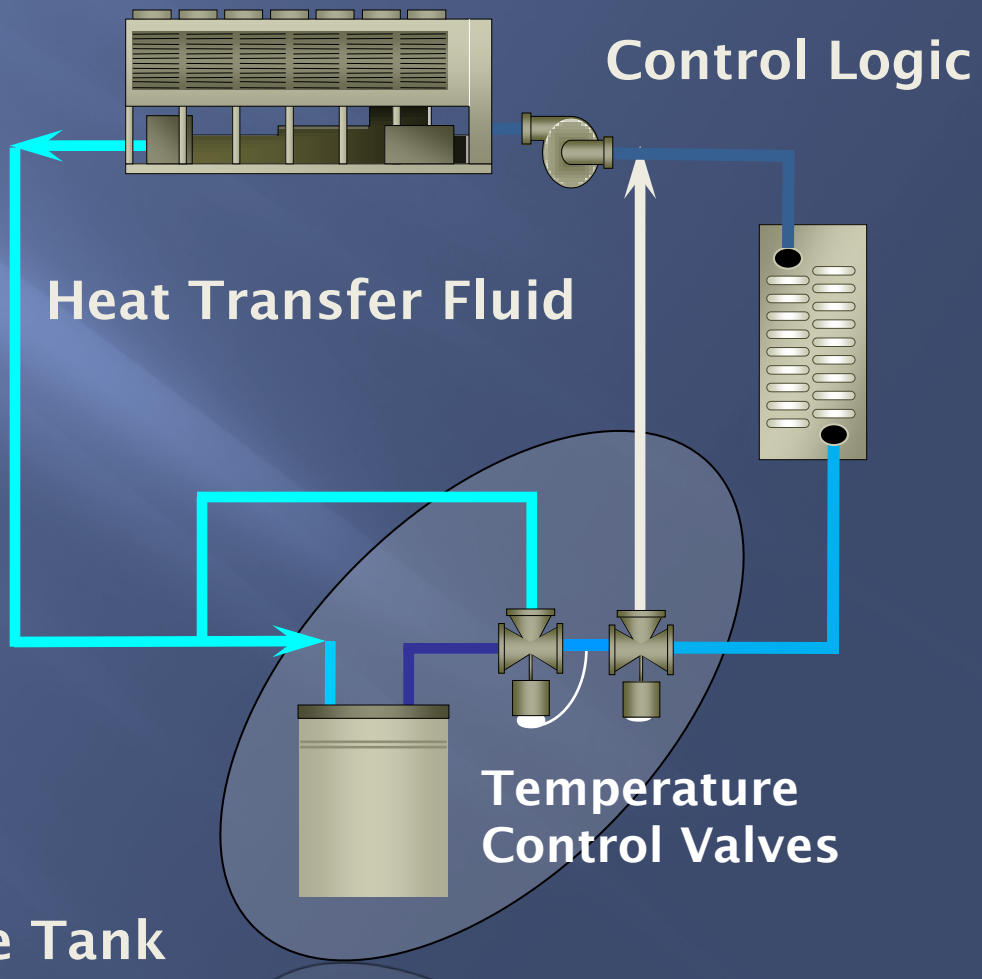


Partial Ice Storage System

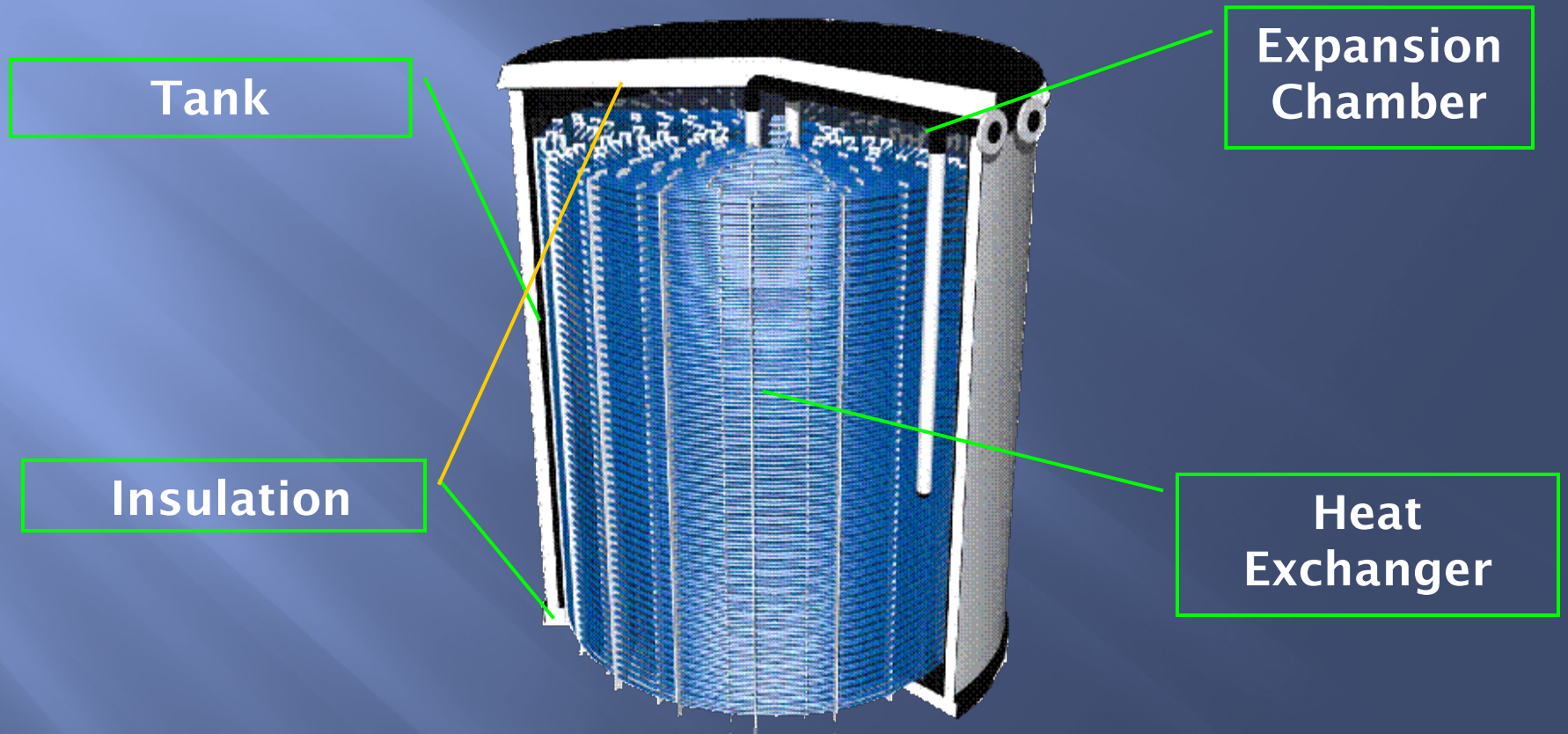
Chiller Based System

Closed System

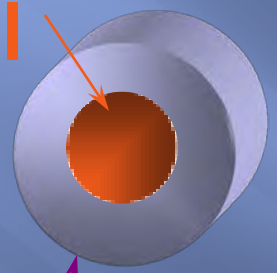
So What is Different?

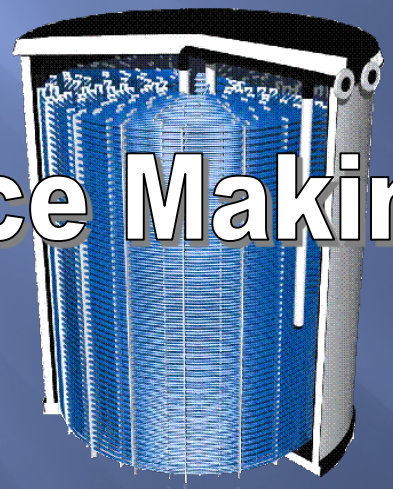


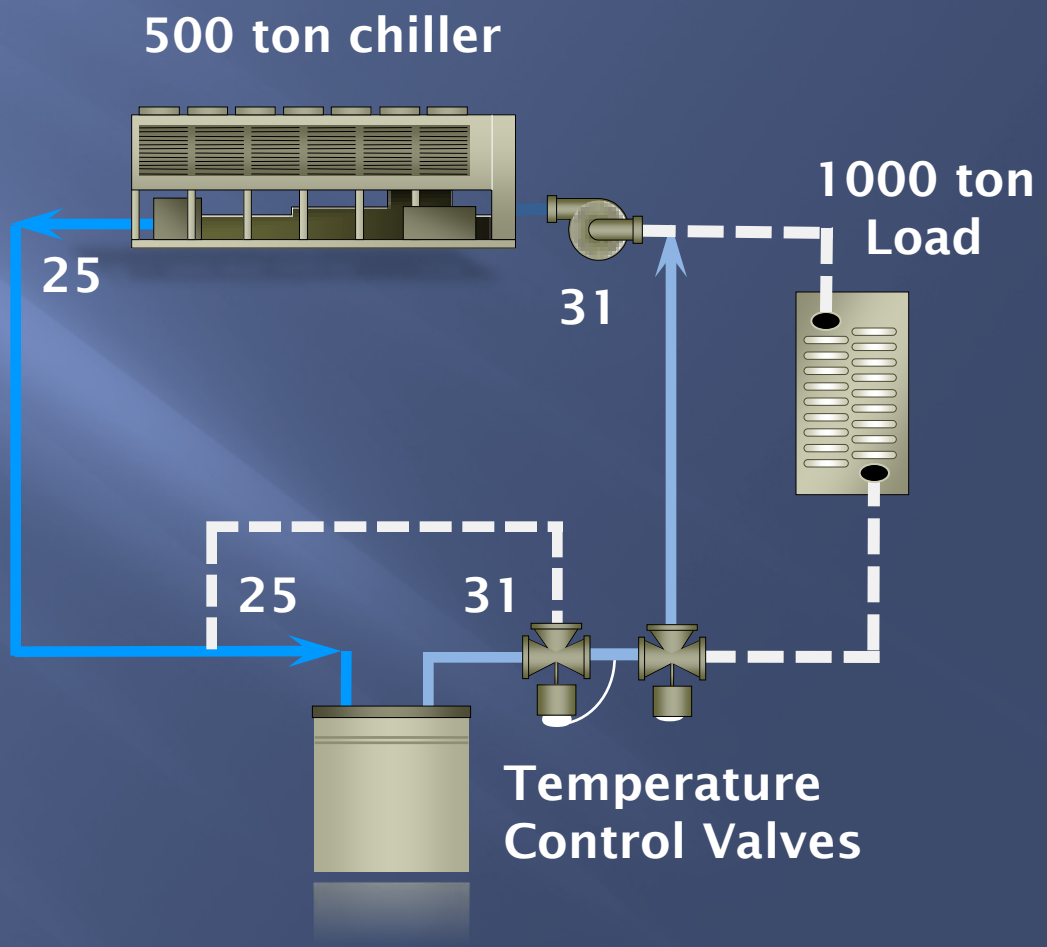
Thermal Storage Tank
Ice-on-Coil Internal Melt



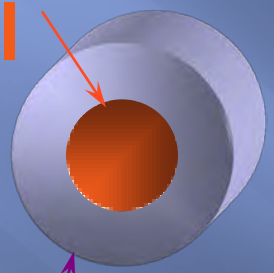
Ice on Coil Internal Melt

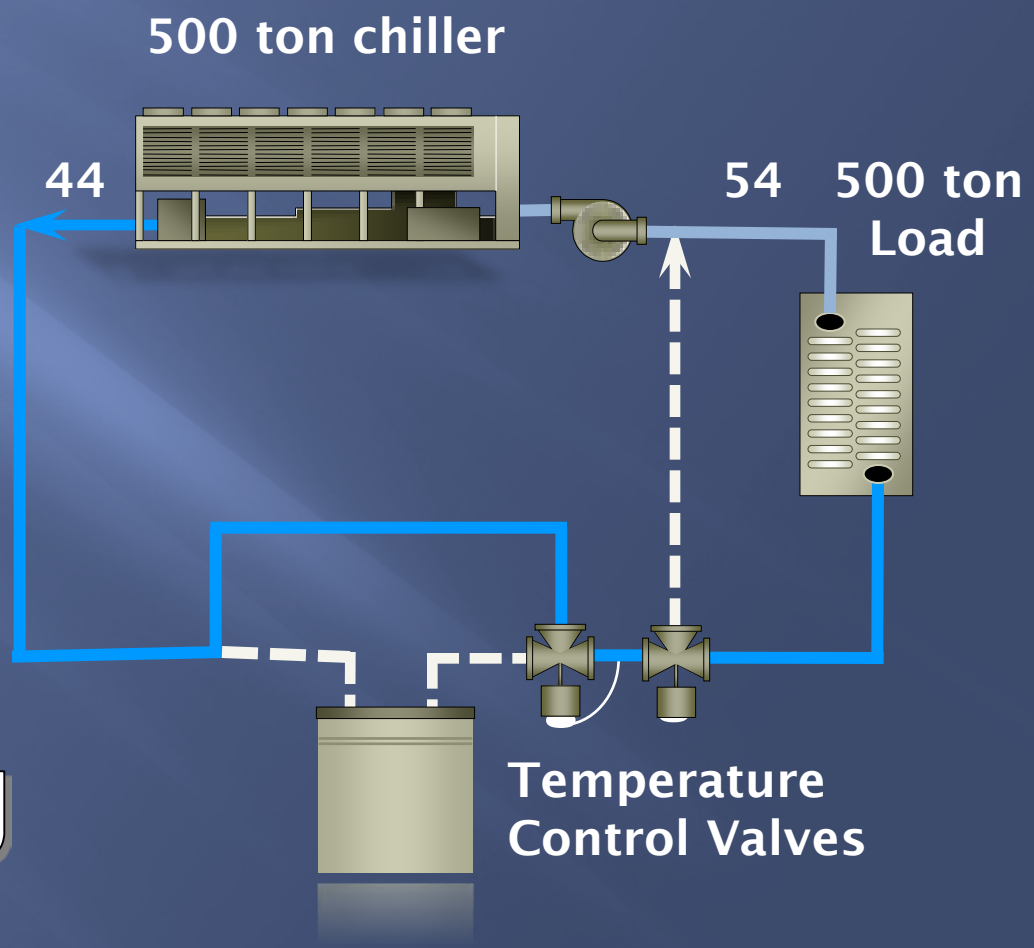


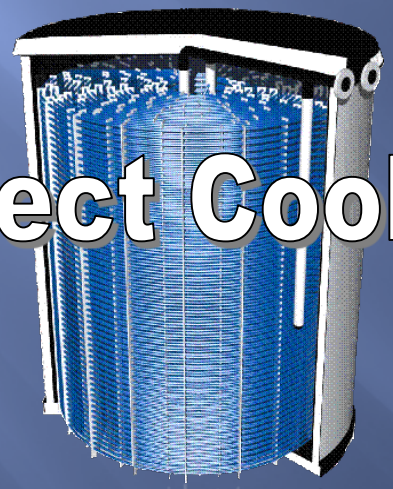




Ice on Coil Internal Melt

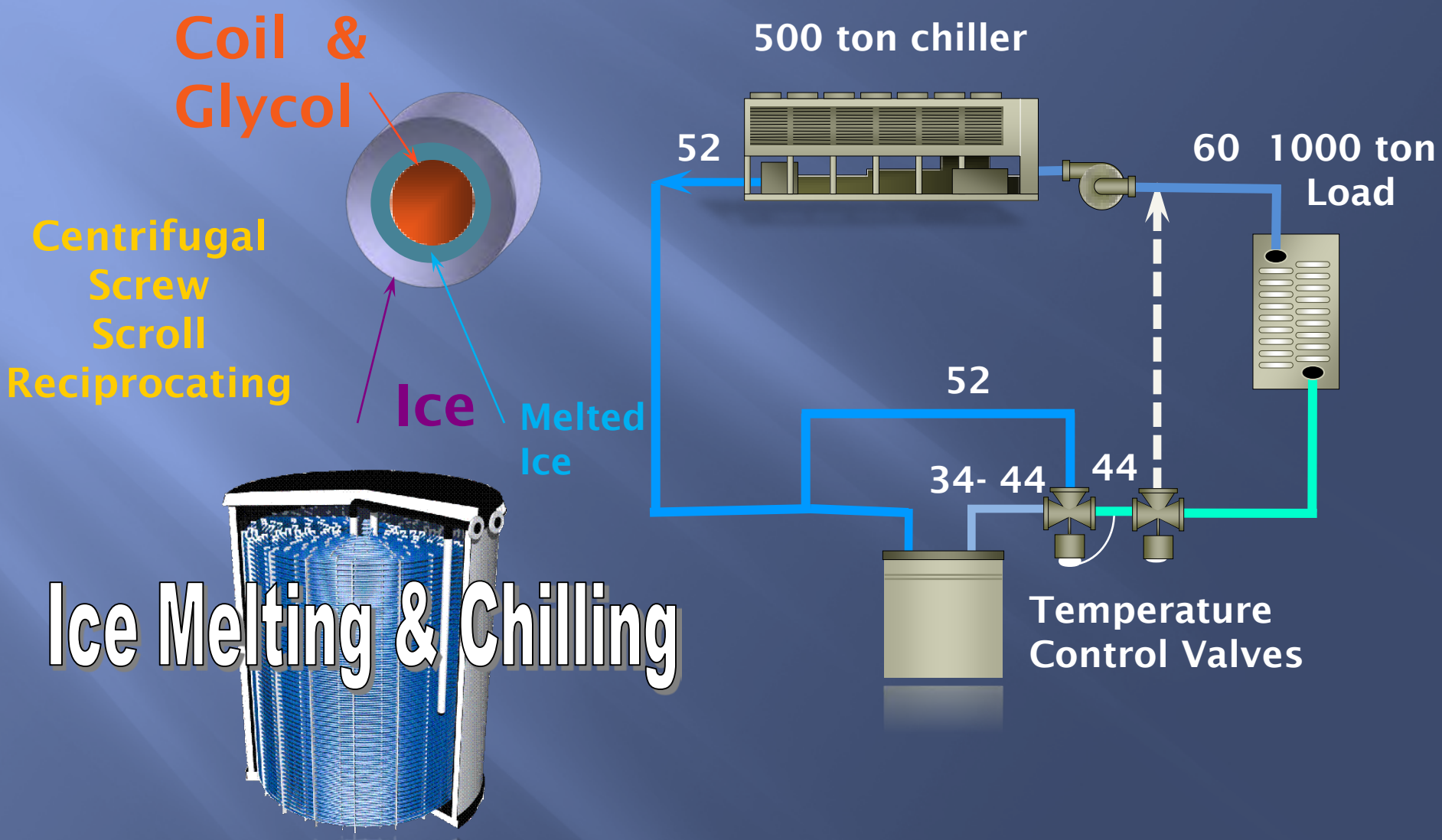






Direct Cooling

Ice on Coil Internal Melt

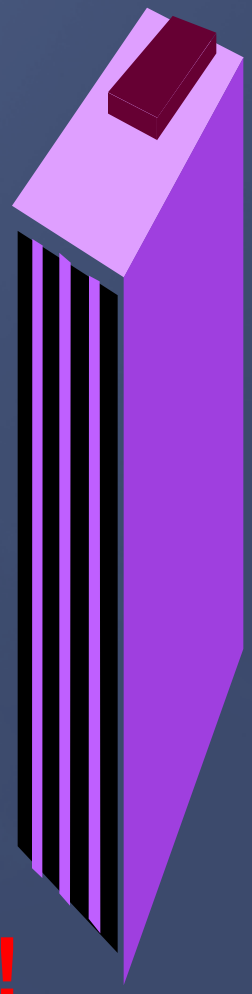


How Much Space for Energy Storage?

Full Storage: 0.70% of cooled floor space

Partial Storage: Ice provides about 33% of a cooling system reducing ice tank floor space to 0.23% of cooled floor space.

1 ton cools 500 ft^2
1 tank provides 20 tons
1 tank cools 10,000 ft^2
1 tank needs 70 ft^2 (60 ft^2)



Would need 25% of roof space on 100 story building!

Same ratio as the water heater in your house

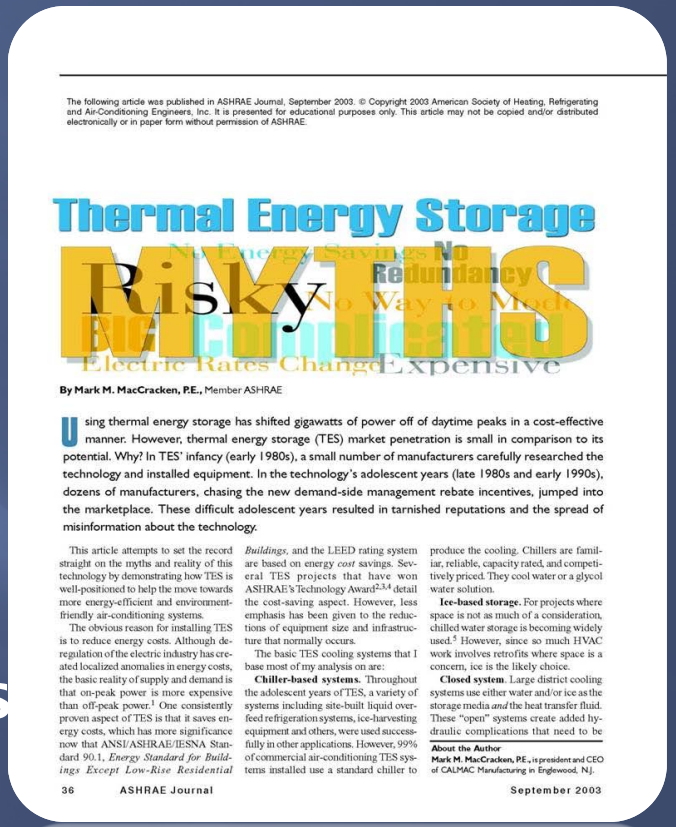
National Air and Space Museum

Washington, DC USA

4,700 Ton Hrs of Storage
On- Peak Chiller – 1122 Tons
On- Peak Ice Contribution – 729 Tons
40% On- Peak Chiller Demand Avoided

Thermal Energy Storage Myths Article
(Ashrae Journal Sept 03)

1. Uncommon
2. Too Much Space
3. Too Complicated
4. Doesn't Save Energy
5. Too Expensive
6. Lack of Redundancy (Risky)
7. Rates Will Change
8. Modeling doesn't Show Results



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Thermal Energy Storage

MYTHS

Risky

No Energy Savings

No Redundancy

No Way to Mode

No Complicated

Electric Rates Change

Expensive

By Mark M. MacCracken, P.E., Member ASHRAE

Using thermal energy storage has shifted gigawatts of power off of daytime peaks in a cost-effective manner. However, thermal energy storage (TES) market penetration is small in comparison to its potential. Why? In TES' infancy (early 1980s), a small number of manufacturers carefully researched the technology and installed equipment. In the technology's adolescent years (late 1980s and early 1990s), dozens of manufacturers, chasing the new demand-side management rebate incentives, jumped into the marketplace. These difficult adolescent years resulted in tarnished reputations and the spread of misinformation about the technology.

This article attempts to set the record straight on the myths and reality of this technology by demonstrating how TES is well-positioned to help the move towards more energy-efficient and environment-friendly air-conditioning systems.

The obvious reason for installing TES is to reduce energy costs. Although deregulation of the electric industry has created localized anomalies in energy costs, the basic reality of supply and demand is that on-peak power is more expensive than off-peak power.[1] One consistently proven aspect of TES is that it saves energy costs, which has more significance now that ANSI/ASHRAE/IESNA Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, and the LEED rating system are based on energy *cost* savings. Several TES projects that have won ASHRAE's Technology Award[2,3,4] detail the cost-saving aspect. However, less emphasis has been given to the reductions of equipment size and infrastructure that normally occurs.

The basic TES cooling systems that I base most of my analysis on are:

Chiller-based systems. Throughout the adolescent years of TES, a variety of systems including site-built liquid overfeed refrigeration systems, ice-harvesting equipment and others, were used successfully in other applications. However, 99% of commercial air-conditioning TES systems installed use a standard chiller to produce the cooling. Chillers are familiar, reliable, capacity rated, and competitively priced. They cool water or a glycol water solution.

Ice-based storage. For projects where space is not as much of a consideration, chilled water storage is becoming widely used.[5] However, since so much HVAC work involves retrofits where space is a concern, ice is the likely choice.

Closed system. Large district cooling systems use either water and/or ice as the storage media *and* the heat transfer fluid. These "open" systems create added hydraulic complications that need to be

About the Author

Mark M. MacCracken, P.E., is president and CEO of CALMAC Manufacturing in Englewood, NJ.

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Reality

TES is a Proven Technology that saves Money and Energy

Thermal Energy Storage For Off-Peak Cooling

What is it?

How does it work?

Why is it Green?

How do you measure "Green"?

One Metric is….

LEED™ Green Building Rating System

U.S. GREEN BUILDING COUNCIL

LEED™

LEADERSHIP IN ENERGY & ENVIRONMENTAL DESIGN

LEED™ Credits V3 NC

Certified 40-49 points
Silver 50-59 points
Gold 60-79 points
Platinum 80 points and above

Sustainable Sites:	**26 points**
Water Efficiency:	**10 points**
Energy* & Atmosphere:	**35 points**
Materials & Resources:	**14 points**
Indoor Environment Quality:	**15 points**
Base Points Possible	**100 points**

Innovation & Design:	**6 points**
Regional Priority	**4 points**

***19 Energy Credits are based on ASHRAE 90.1 which is based on Energy COST Reduction**

William & Flora Hewlett Foundation
LEED™ Gold
35% Energy Cost Reduction (5points)

www.usgbc.org

Project Overview

Corporate Headquarters That went LEED

Bank of America Tower
LEED Platinum

SAP America
LEED Platinum

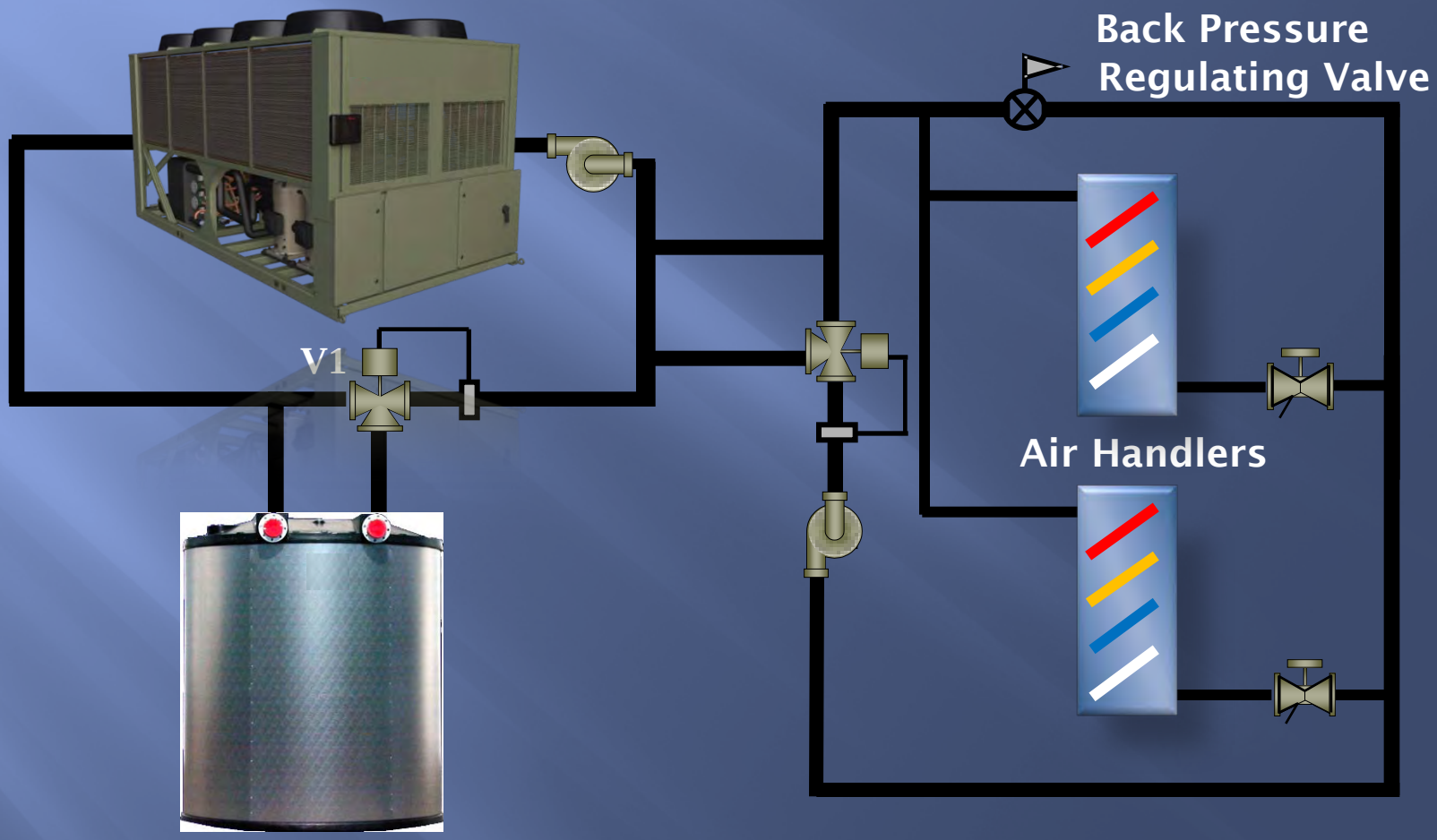
JC Penney
LEED Gold

Owens-Illinois
LEED Gold

Hewlett Foundation
LEED Gold

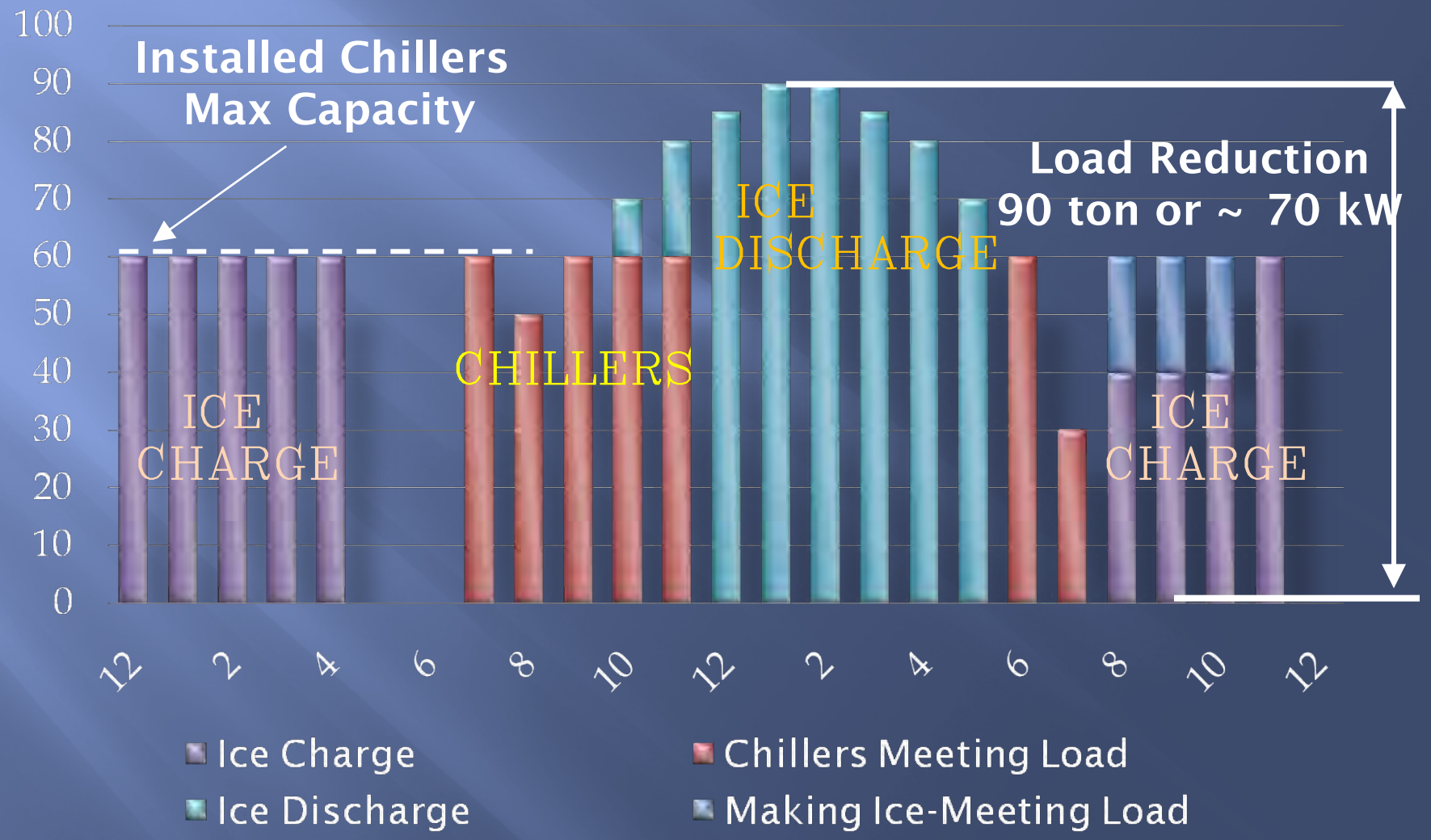
Goldman Sachs
LEED Gold

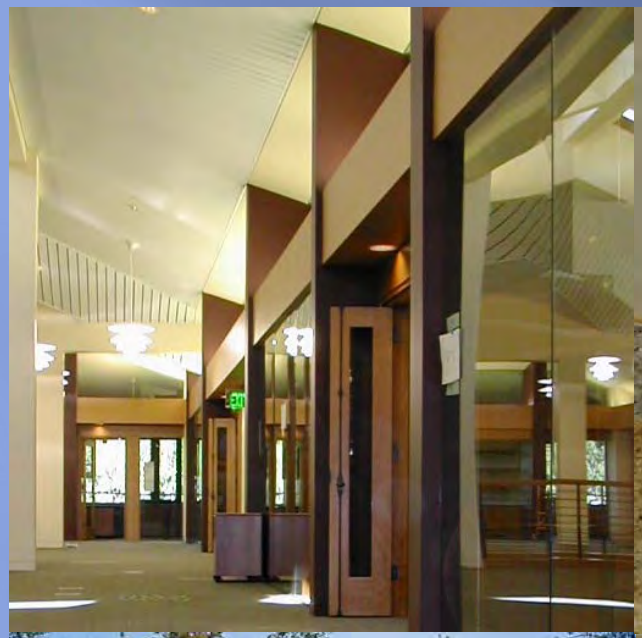
Basic Schematic



Design Day Off-Peak Cooling System

Storage System - 80 ton Chiller & 1,100 ton- hr Storage





Teamwork

- Owner
  The Hewlett Foundation
- Owner's Representative
  Bennington/Conover & Associates
- Shell Architect
  B.H. Bocook Architects
- Interior Architecture and Design
  Hawley Peterson & Snyder Architects
- Landscape Architect
  The Office of Cheryl Barton
- Contractor
  Vance Brown, Inc.
- Environmental Building Consultant
  Simon & Associates

Real Reasons Energy Storage is Green:

1. It is much more Energy Efficient to create and deliver a kWh of Electricity at night than during the hot of the day.
   - Research from the California Energy Commission on 2 Cal. Utilities Reports 8 to 34% savings in raw fuel when comparing On and Off Peak Operation!
   - Heat Rates for Base Load Plants ~7,800 Btu/kWh vs.
     Peaking Plants ~9,400 to 14,000 Btu/kWh

2. The last power plants to come on during peak hours are normally the dirtiest per kW
   - Ashok Gupta (Director of Energy, NRDC) in NY Times article "Peak Shifting results in lower emissions because some of the plants used to meet demand peaks are among the dirtiest in the city"
   - New CA Report by Greg Kats ***The Costs and Financial Benefits of Green Buildings*** states Peak power in CA is twice as dirty as Off Peak Power.

Thermal Energy Storage For Off-Peak Cooling

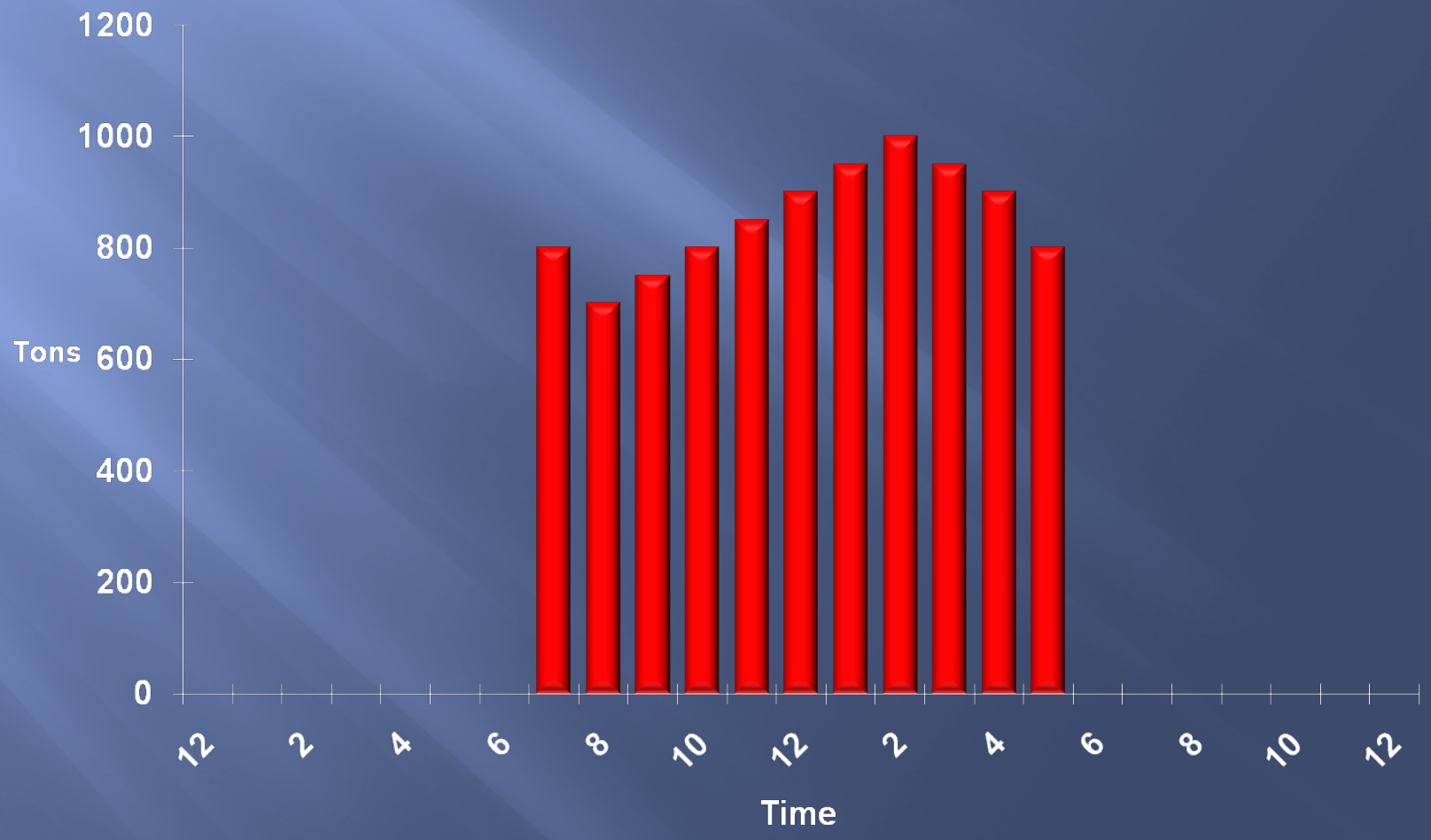
- What is it?
- How does it work?
- Why is it Green?
- Other "Green" Advantages

Other "Green" Issues

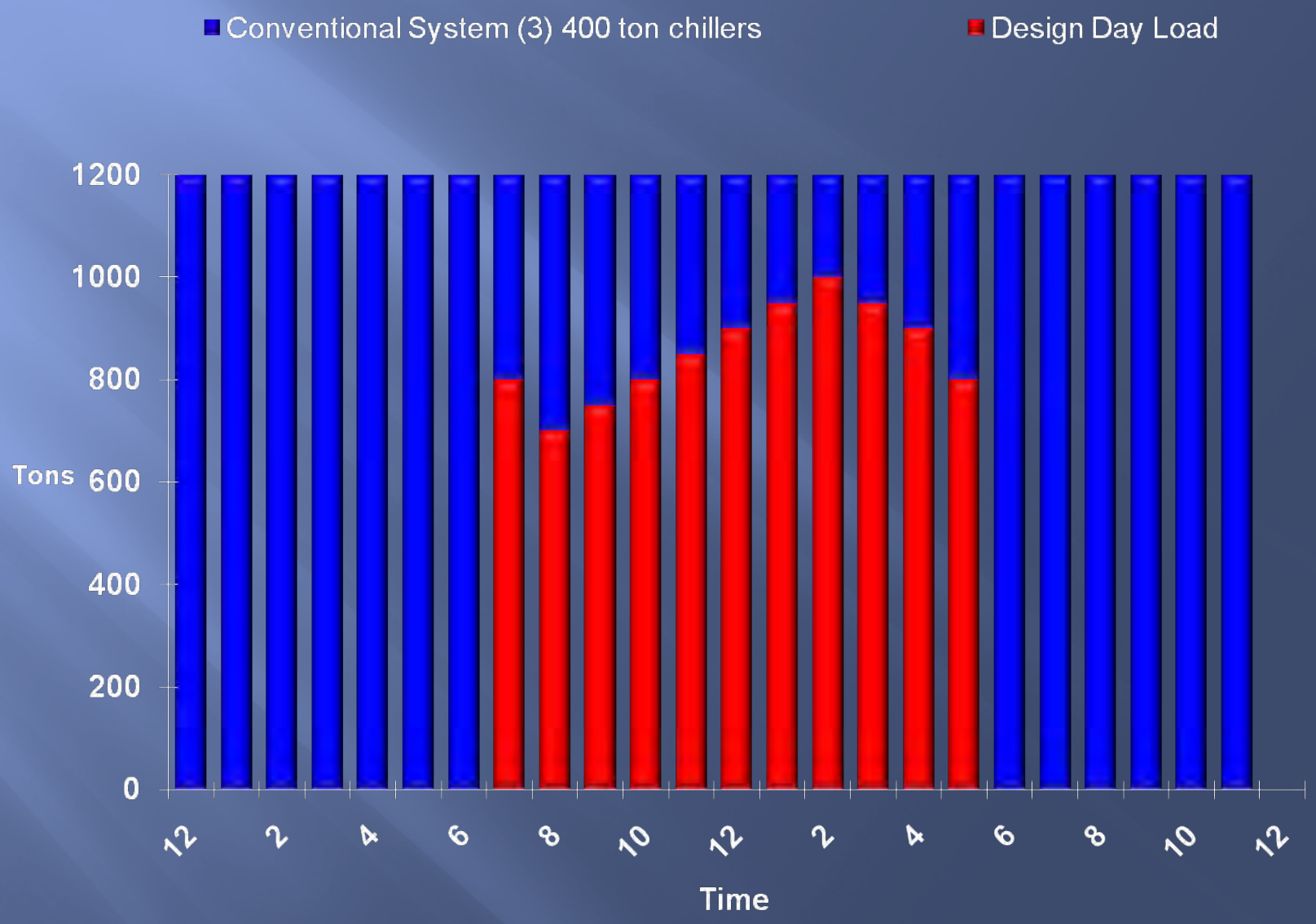
1. Safety Factors/Redundancy (Over-sizing)
   - Well documented that over-sizing chiller plants creates less efficient real world operation.
   - Engineers have to protect their license

- Storage is the Natural solution

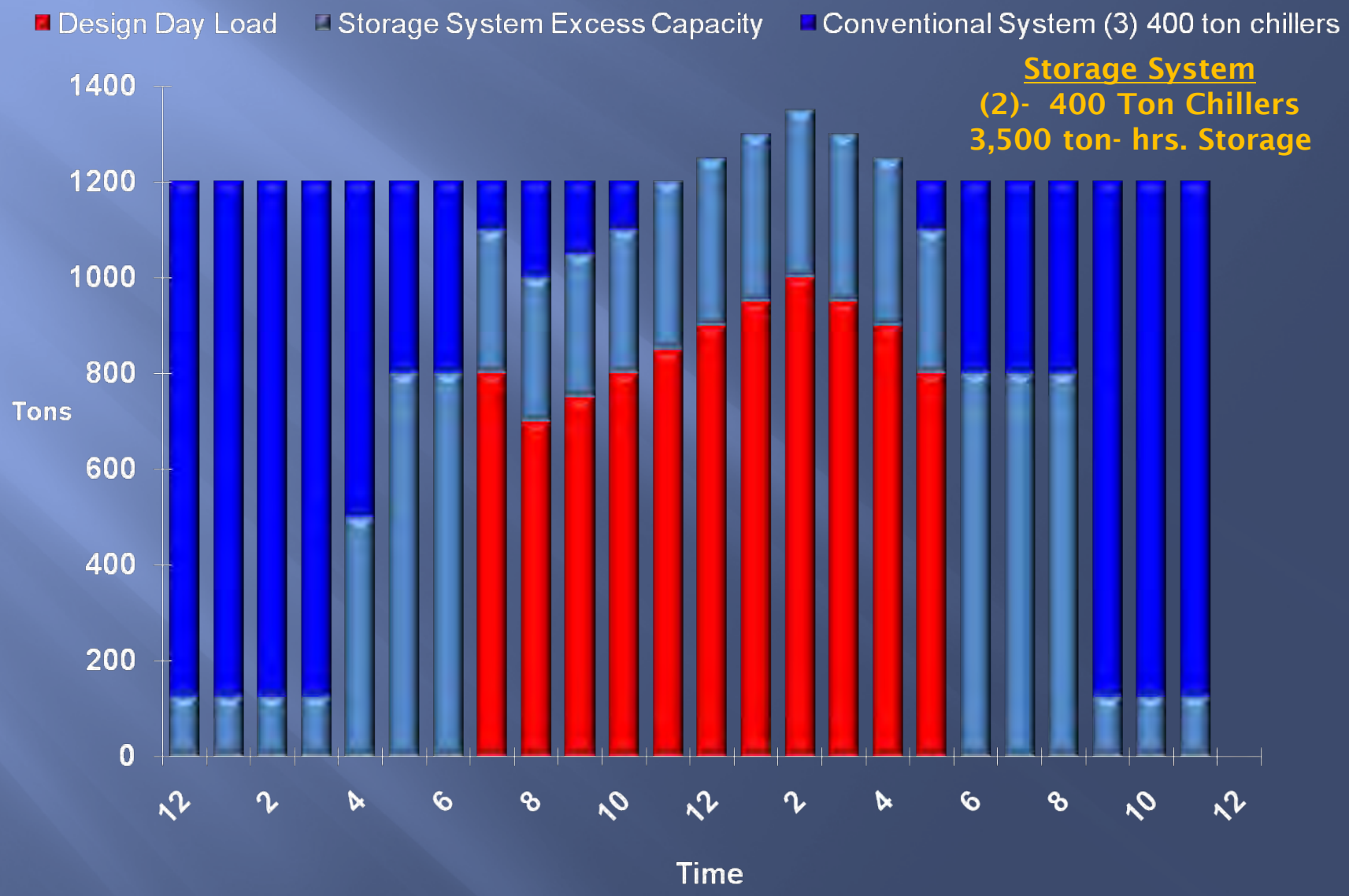
Design Day



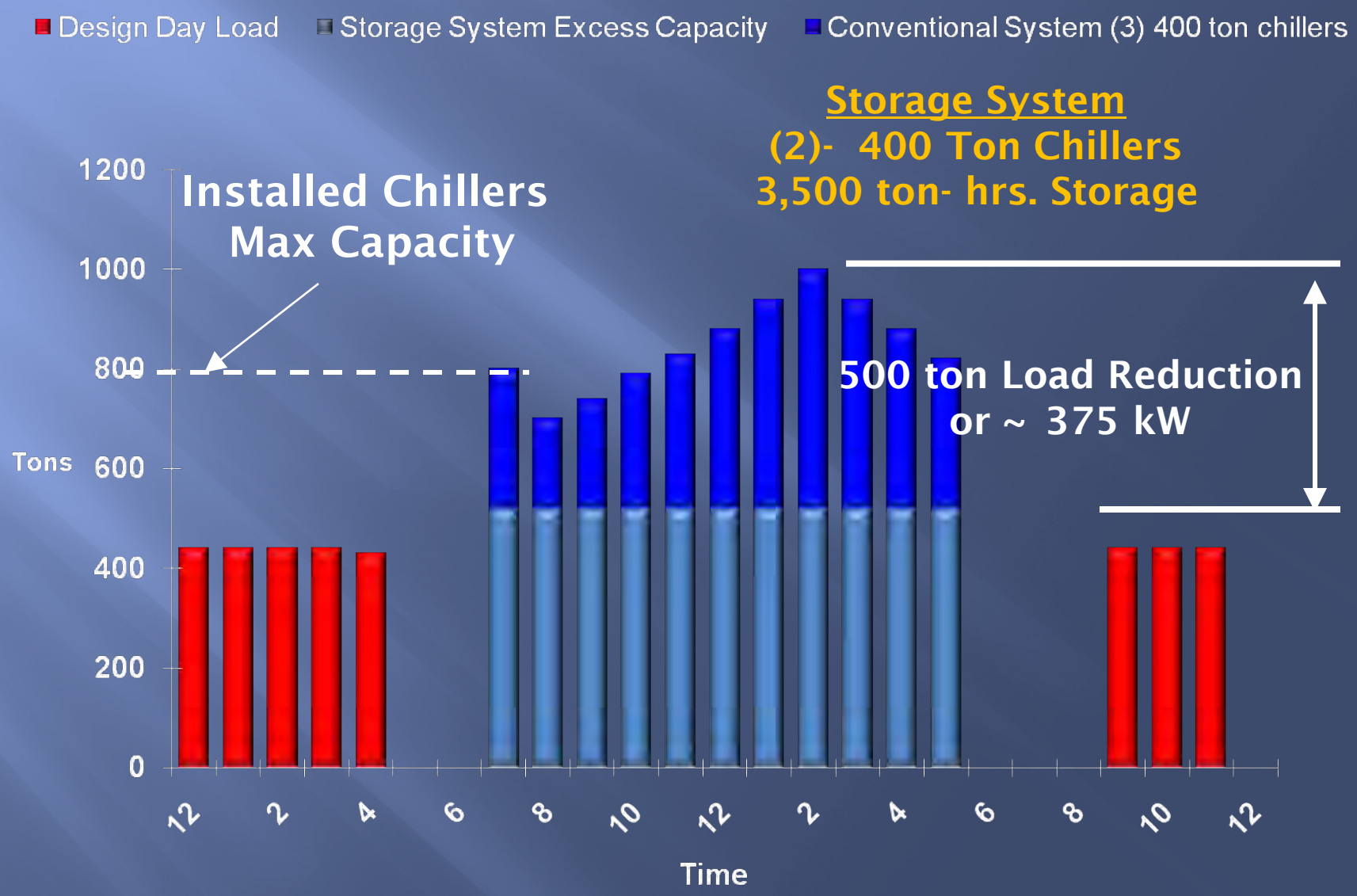
Excess Capacity on Design Day



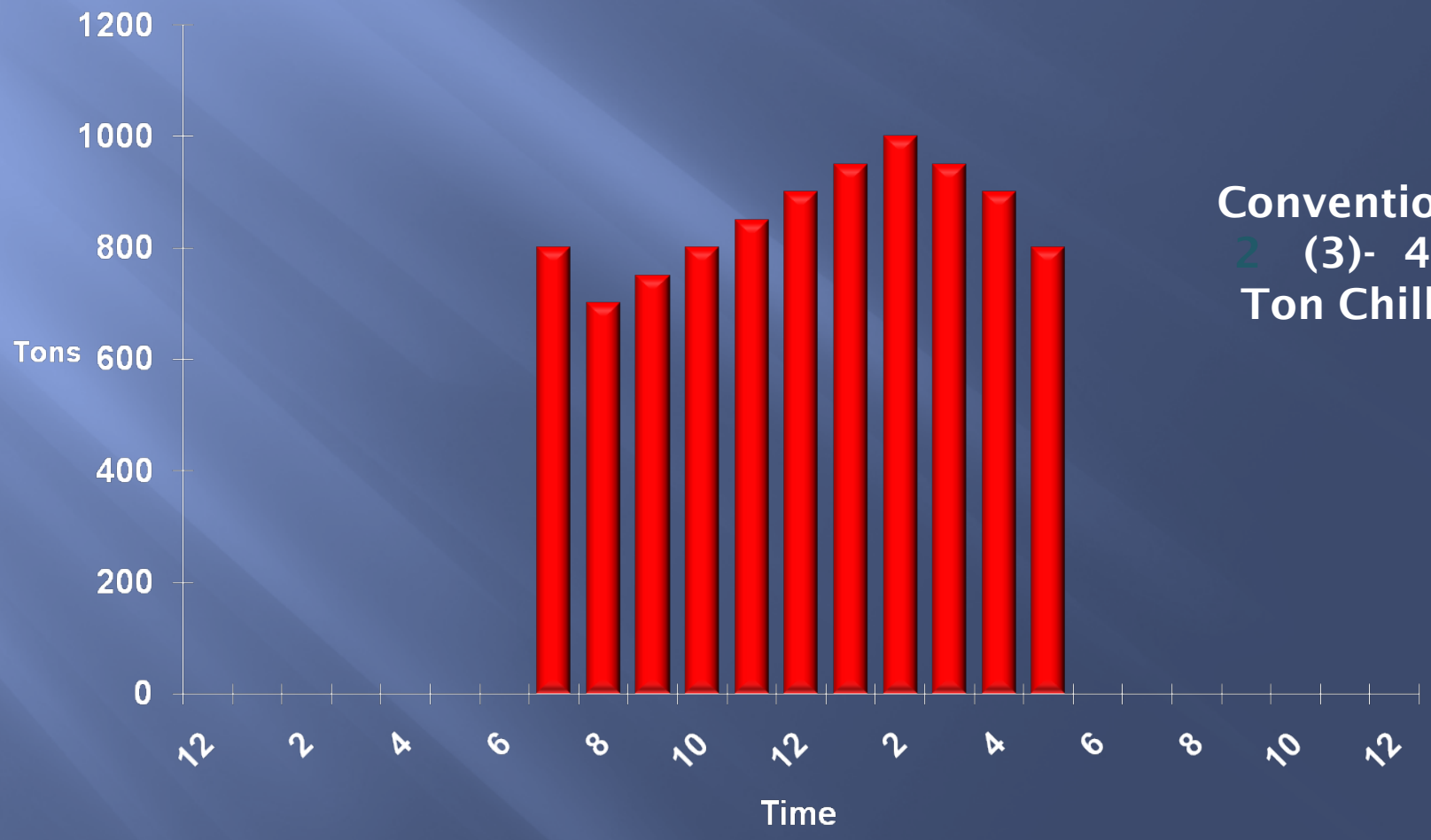
Excess Capacity on Design Day



Design Day Operation

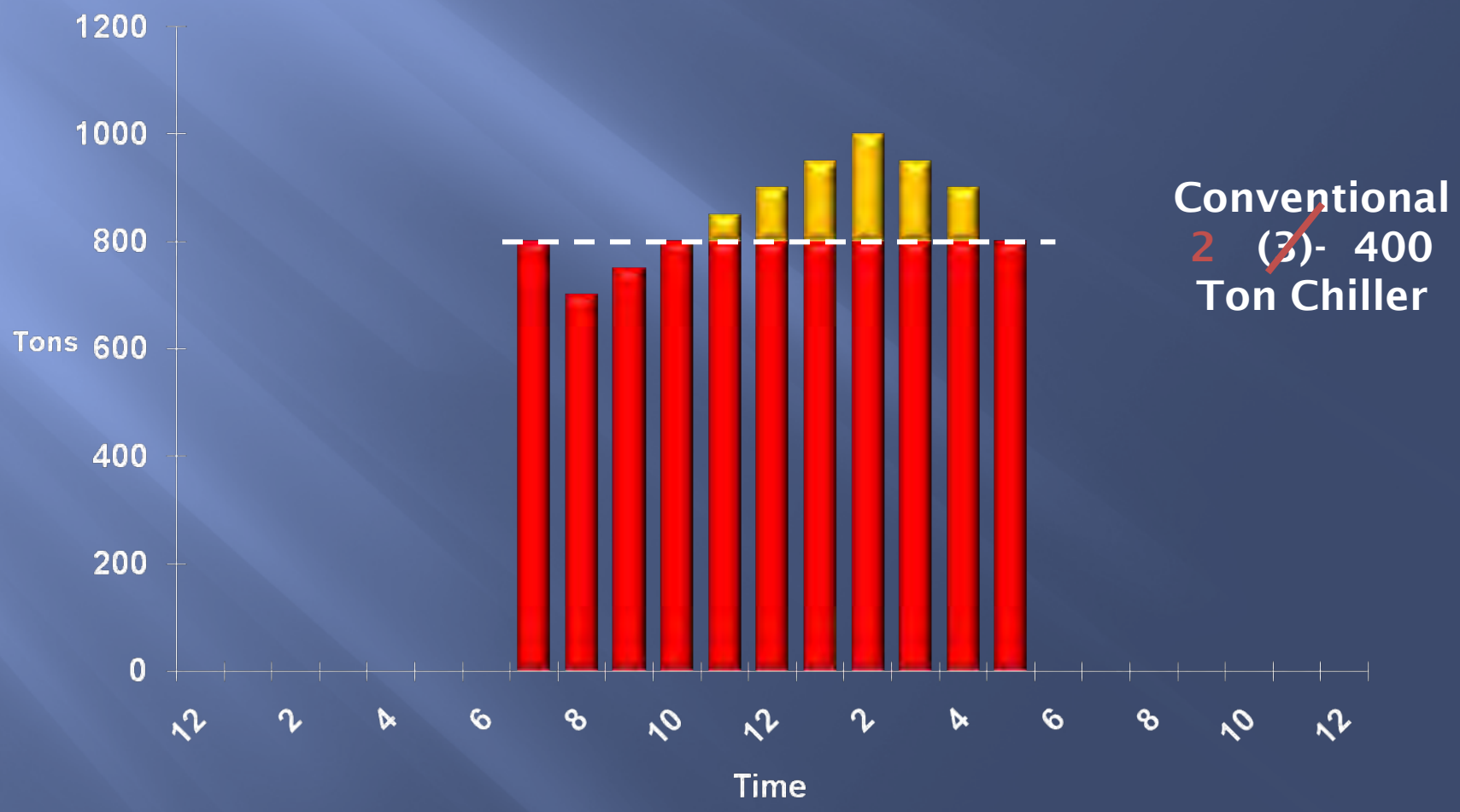


Design Day

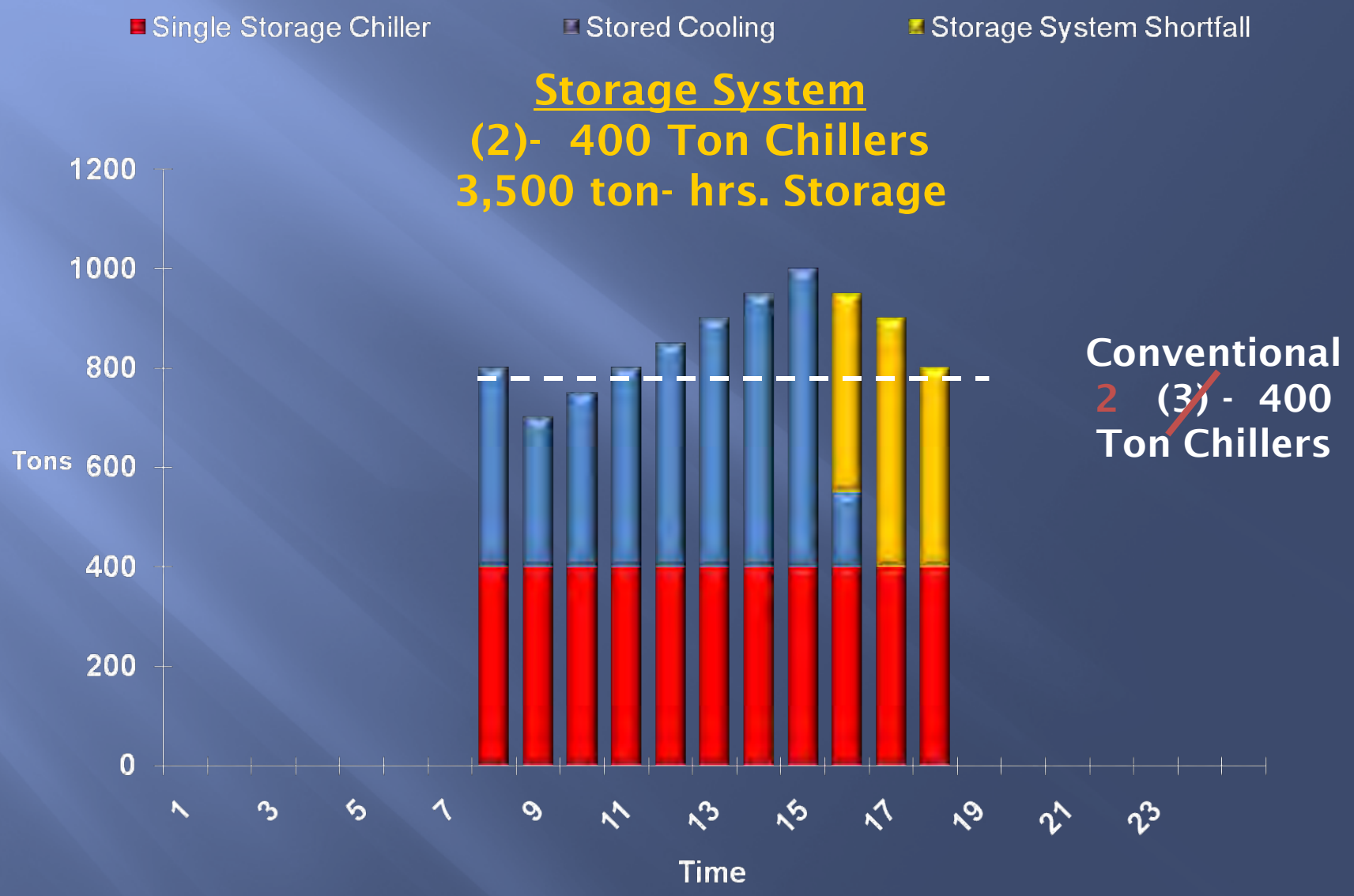


Conventional
2 (3)- 400
Ton Chiller

Design Day with Chiller Failure



Design Day with Chiller Failure



Costs of Storage

Standard Chiller Plant Installed?

$1000/ton , $1300/ton, $1600/ton, $1800/ton

Storage Costs installed ~ $100 to $180 per ton-hr

Depending on location, application and design

For each 1 ton of chiller you reduce you need about 8 to 10 ton-hrs of storage.

Costs are about the same

Daytime

$ 3.99/ gallon

Nighttime

$ .99 / gallon

When Would you Fill-up?

Austin Energy EO 6 Rate

Energy:

Day:	$0.054/kWh	$0.140/kWh
Night:	$0.054/kWh	$0.054/kWh

Demand: $14.00/kW/Month (4 Summer months)

How big an effect is the Demand Charge??

62% less costly at night

PG&E E-20 Rate

Energy:

Day:	$0.13/kWh	$0.30/kWh
Night:	$0.07/kWh	$0.07/kWh

Demand: $28.00/kW/Month 4 Summer months)

How big an effect is the Demand Charge??

76% less costly at night

Demand Charge Effect…..
Do the Math (Back of the Envelope)

Conventional Chiller System

Demand Cost /month

1000 tons x 0.8 kW/ton = 800kW

800 kW x $28.00 = $22,400/month

Energy Usage for Chiller for Month

1000 tons x 10 Hrs x 75% x 0.8 kW/ton x 22 days/month

=

132,000 kWh

Approximate Cost for Demand / kWh

$22,400/132,000 kWh/month = $0.172/kWh

Therefore Daytime Energy = $0.13 + $0.172= $0.30

Cost per Ton hr……. Conventional vs. Storage

Conventional

1 ton x 0.8 kW/ton x $0.30 = $0.24/ton-hr

Storage System

1 ton x 0.9 kW/ton x $0.07 = $0.063/ton-hr

~ 75% reduction in cost of creating cooling

Stable Electric Rates

Edison Electric Institute stated that the only form of Energy that has stayed the same cost or gone down in last 30 to 40 years has been

Off- Peak Electricity

Thermal Energy Storage and Sustainable Buildings

Topics:

LEED
Why Green
Safety Factory
Redundancy
Back- up Generation

BUILDING FOR THE FUTURE

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Thermal Energy Storage In Sustainable Buildings

By Mark MacCracken, P.E., Member ASHRAE

This article demonstrates why designing a building with stored cooling is a beneficial approach and how oversizing the chiller plant for safety factor does not make sense. This article discusses what makes thermal energy storage (TES) a green technology, TES and safety factor, and benefits from incorporating storage.

LEED™ Rating System

One system for rating the "greenness" of buildings is the U.S. Green Building Council's (USGBC) LEED rating system. Based on this unit of measure, TES is considered green. The ratings are based on a point system (10 points are for energy savings).

LEED points are based on ANSI/ASHRAE/IESNA Standard 90.1-1999, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, which is based on energy *cost* savings, not energy savings. Cost is the only common denominator for all the different energy-efficient possibilities, as well as the common metric that usually drives a building owner's decisions. To receive LEED points, the building must surpass Standard 90.1-1999 by more than a certain percentage for a certain amount of points (20% = 2 points, 30% = 4 points up to 60% = 10 points).

TES and LEED

The reason TES is a green technology in the LEED system is that, in most locations, electricity at night costs less than half as much as during the day.[1] As demonstrated in thousands of installations, major energy cost savings are realized by using inexpensive power at night to create and store cooling, and using storage to cool the building during the next day. These savings provide LEED points, which was demonstrated in California's first LEED 2.0 Gold building built by The William and Flora Hewlett Foundation in the City of Menlo Park.

The building had a total of 43 points (out of 69), of which five were because of the 35% energy cost reduction. This project took advantage of four major cost/energy-saving techniques including external shading, natural lighting, natural ventilation and off-peak cooling (OPC) using ice-based thermal storage. Three of the four are reducing the amount of mechanical cooling, and the OPC system shifts most of what mechanical cooling is required to the inexpensive off-peak period.

Real Reason Thermal Storage Is Green

Many studies, most notably one by the California Energy Commission,[2] have demonstrated that, for many reasons, it takes less fuel to make an off-peak kWh. The main reasons are:

- Off-peak, base-load plants are much more energy efficient than on-peak plants, with 7,900 to 8,500 Btu/kW (8335 to 8970 kJ/kW) heat rates typical for base-load plants. The existing stock of "peaking" plants, which are comprised mainly of simple cycle combustion turbine units, are in the range of 9,000 to 12,000 Btu/kW (9495 to 12 660 kJ/kW).
- Line losses are less off-peak because that much less power is transmitted at night.
- Spinning reserve requirements are lower. (Spinning reserve essentially means power plants are forced to spin turbines at night, without generating power. So, the plants are ready to help meet the following day's peak load). Therefore, lower on-peak power requirements translate into less waste from spinning reserves.

The results of the Califonia Energy Commission's study showed that for the two major California utilities, it required

(*ASHRAE Journal* Sept 04)

Thermal Energy Storage For Off-Peak Cooling

- What is it?
- How does it work?
- Why is it Green?
- Other “Green” Advantages
- Applications/Case Studies

Durst HQ Retrofit

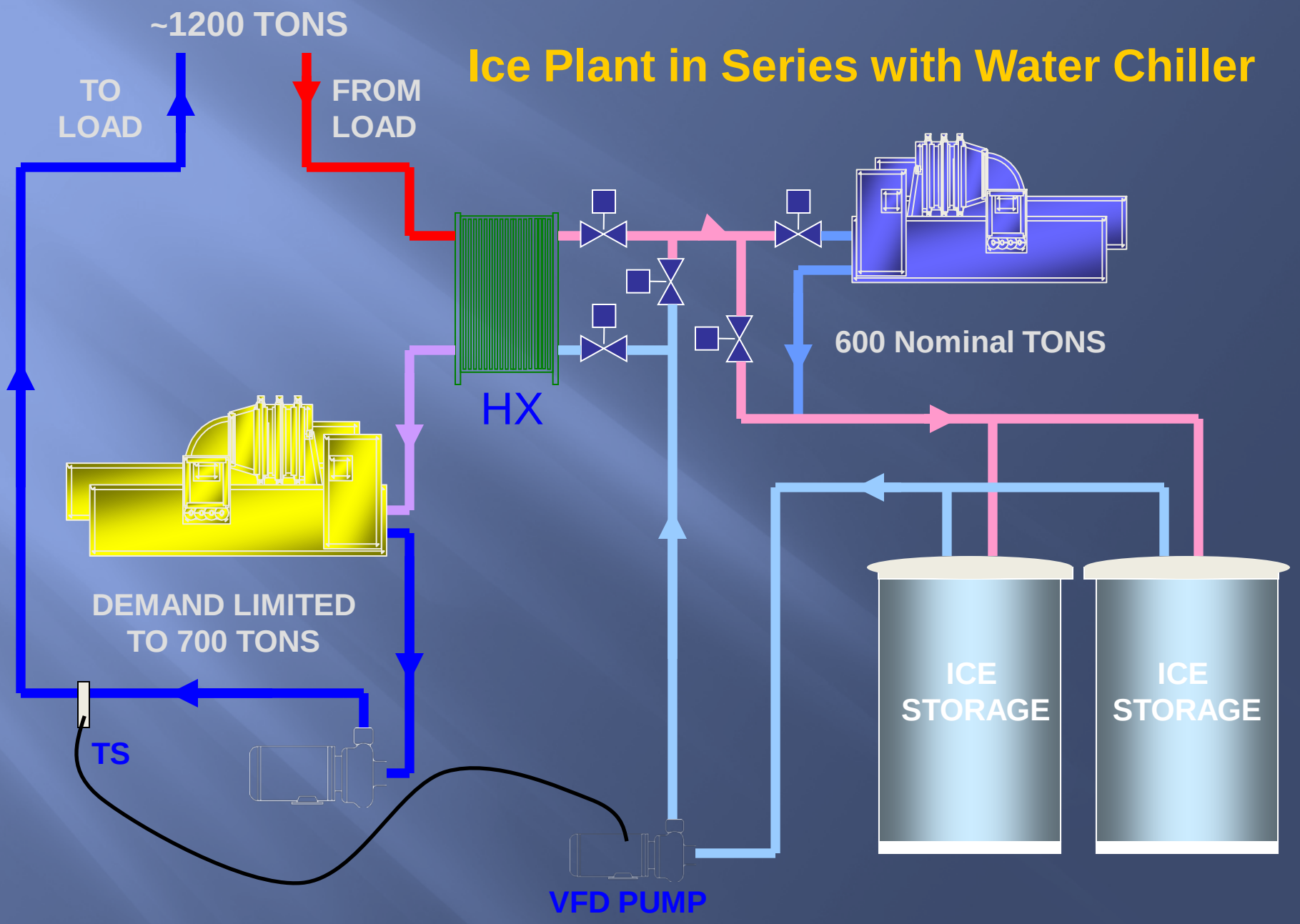
1155 Avenue of the Americas

41 Stories

3400 Ton Hours Storage

Avoids ≈ 700kW out of 3500kW Original Total

Ice Plant in Series with Water Chiller



Fossil Ridge HS – Poudre School District Ft. Collins, CO

LEED Gold
250,000 ft^2
Peak Load – 243 Tons
Actual Chiller – 125 Tons
1280 Ton Hrs Ice Storage

University of Arizona

- Campus Statistics
  - 28,300 Tons of Refrigeration
  - 12 Million Sqft.
  - 130 Buildings
  - 35 MW Peak
  - 14 MW of Gas Turbine Gen.
  - 14,000 ton-hr of Ice Storage

Main reason for Storage: Optimizing Gas Turbine Generator's Efficiency, Emissions and Heat output

Underwriters Laboratory

Schaumberg, IL

8,000 T-Hr 2.5 days to install

Costco Installations

3 in Japan

2 in Korea

2 in USA

TIAA CREF

30 Model 1220 Tanks

6,500 ton- hrs

On 28th Floor Roof

Credit Suisse

11 Madison Ave., NY, NY

30 Stories, 2.2 Million Ft^2

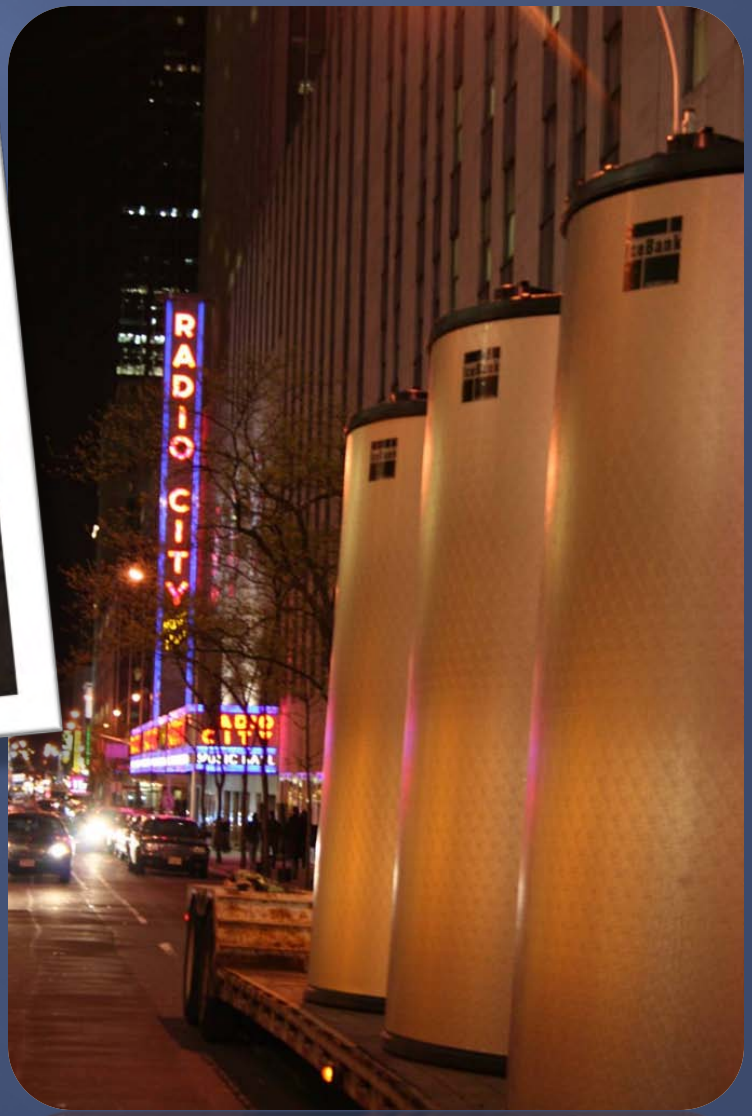
6200 Ton Hours Storage

Savings ~ $1,000,000/year
Avoids ~ 1000 kW

Main reason for Storage: Resiliency

Rockefeller Center

New York, NY



9000 ton- hrs

TIAA-CREF

NEW YORK CITY INSTALLATIONS

11 Madison Ave.
Credit Suisse

Fordham Road

AXA Equitable

Rockefeller Center

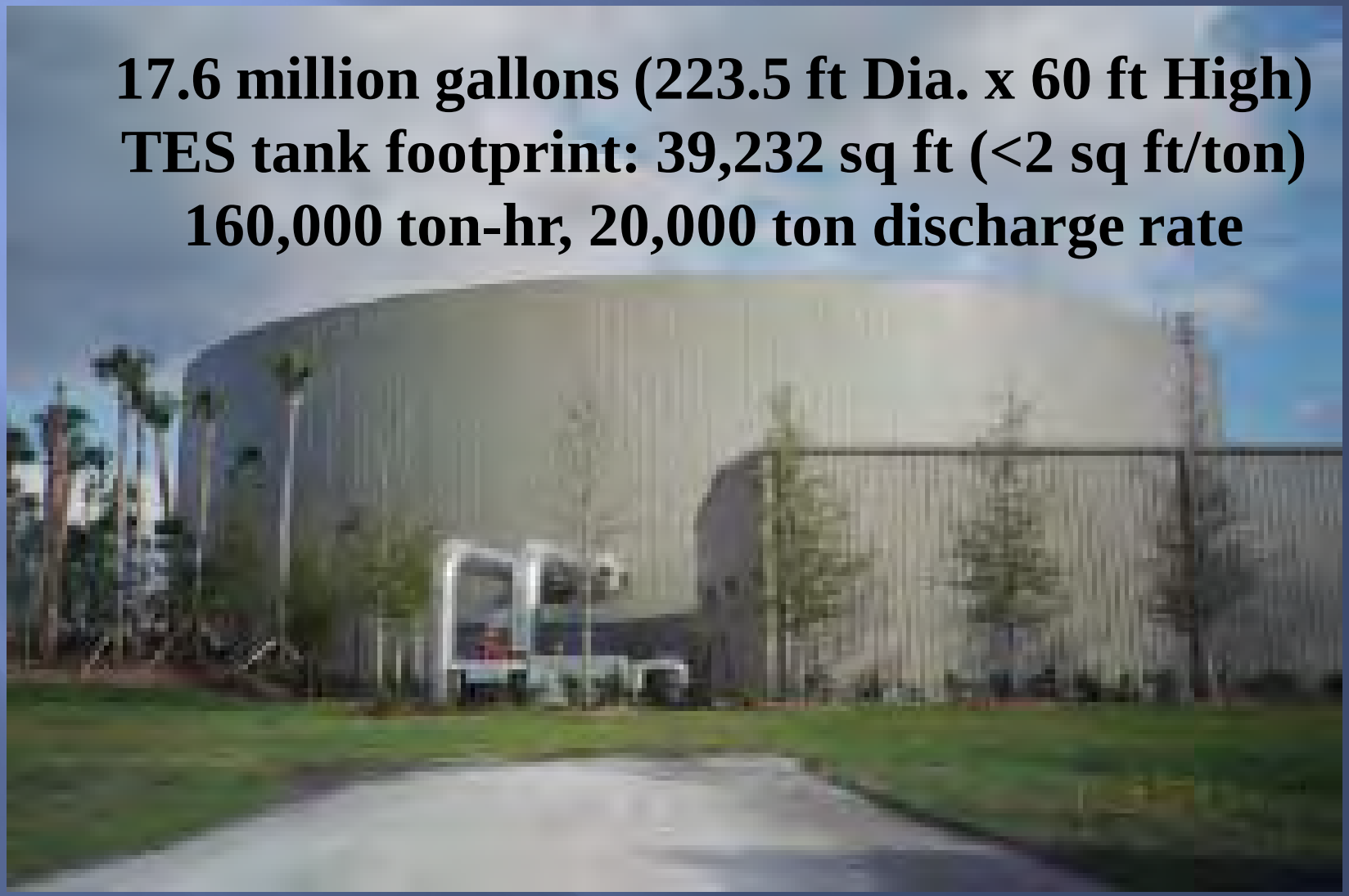
1155 Ave. of the Americas
Durst Organization

One Bryant Park
Bank of America
LEED Platinum

522 5th Ave.
Morgan Stanley

Goldman Sachs
LEED Gold

Orlando District Cooling System



There are over 7,000 installations of Energy Storage for cooling buildings in 40 countries, many installed over 25 years ago

Energy Storage Conclusions

- Renewables need Storage to be a true replacement for Fossil Fuels
- All types of Energy Storage will be needed to meet the massive needs.
- Cool Storage out performs just about all other types in every category, except possibly space.
- If Stored Energy is going to be used to meet a cooling load, it is dramatically more efficient and less expensive to store the cooling than the electrons to make it.

Mark M MacCracken
CEO of CALMAC
MM@ calmac.com