U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Thermal Energy Storage Webinar Series

Ice Thermal Energy Storage

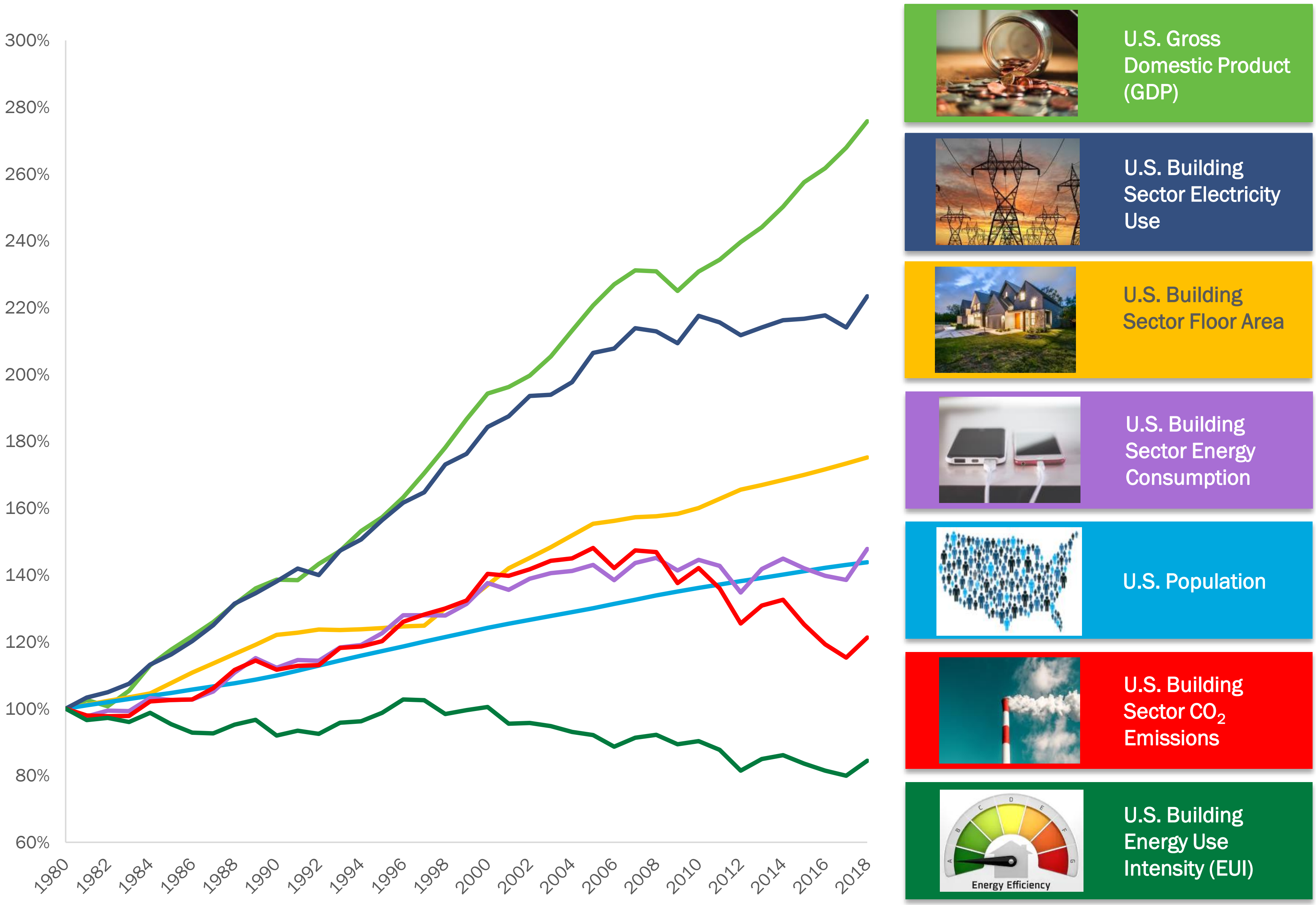
Building Technologies Office
https://www.energy.gov/eere/buildings/building-technologies-office
David Nemtzow, Karma Sawyer, Sven Mumme, Nelson James

January 16, 2020

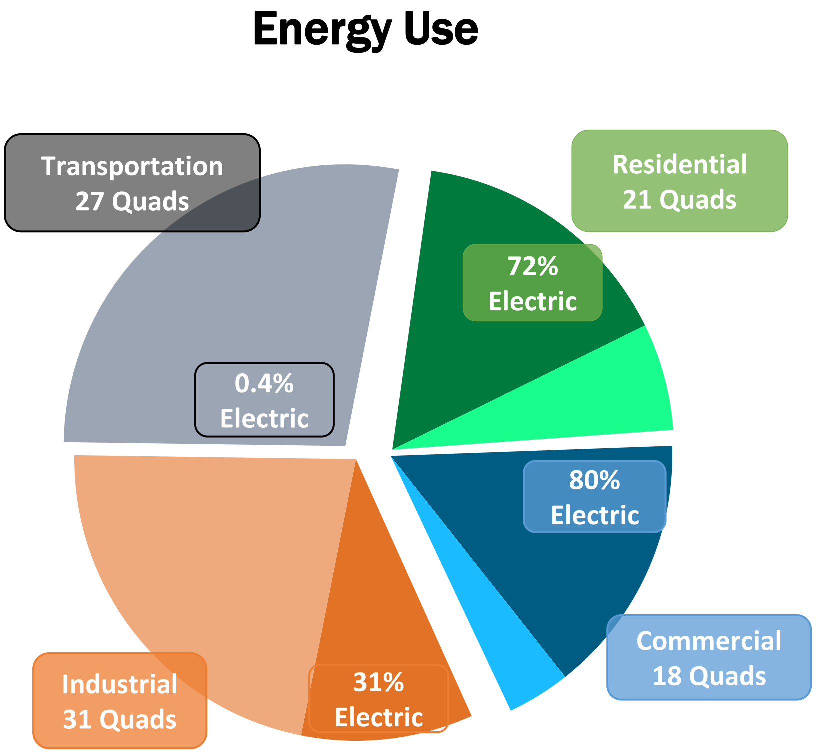
This Webinar is being recorded.

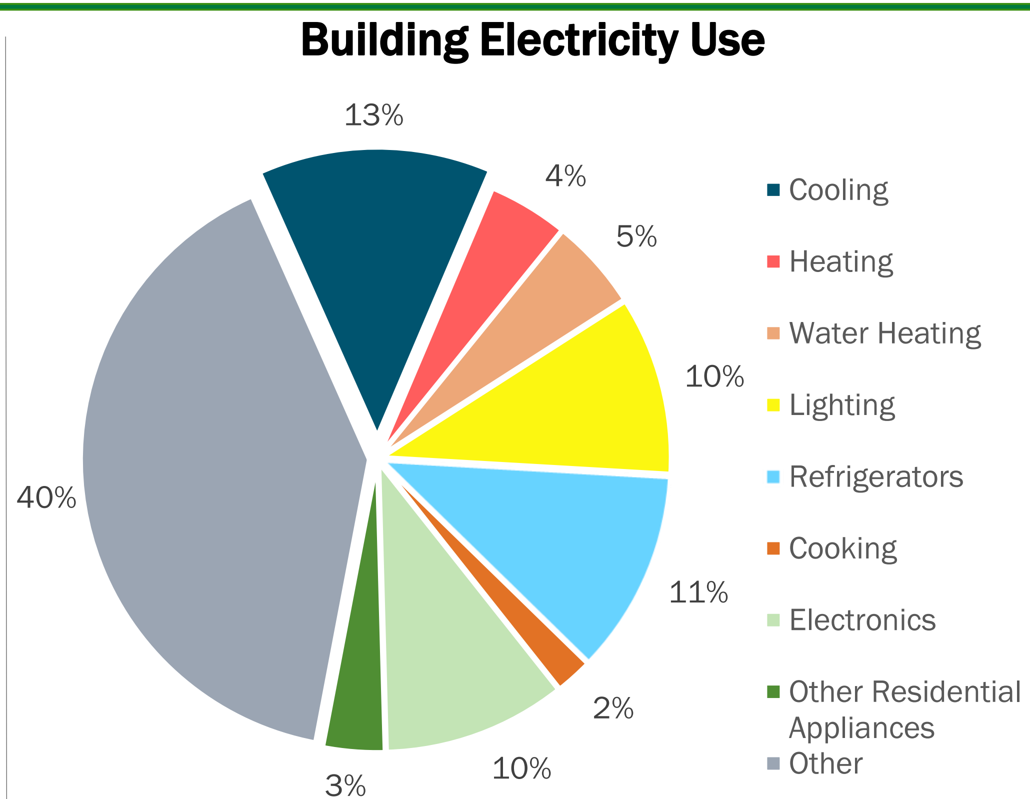
If you do not wish to participate, please exit now.

Key National Economic and Building Sector Trends: 1980 – 2018



Energy use in the U.S. building sector





Buildings Energy Use: 40% of U.S. total

Buildings Electricity Consumption: 75% of U.S. total

Buildings Peak Electricity Demand: as much as 80% of regional total

Buildings CO_2 Emissions: 36% of U.S. total

U.S. Building Energy Bill: $415 billion per year

BTO's Approach

R&D (Emerging Technologies Program)
Pre-competitive, early-stage investment in next-gen technology

Integration (Commercial and Residential Programs)
Technology validation, field & lab testing, decision tools, market integration

Codes & Standards Programs
Codes & standards development and technical analysis, standards promulgation

We lead R&D on technologies that make our homes and buildings more affordable and comfortable, and make America more sustainable, secure, and prosperous.

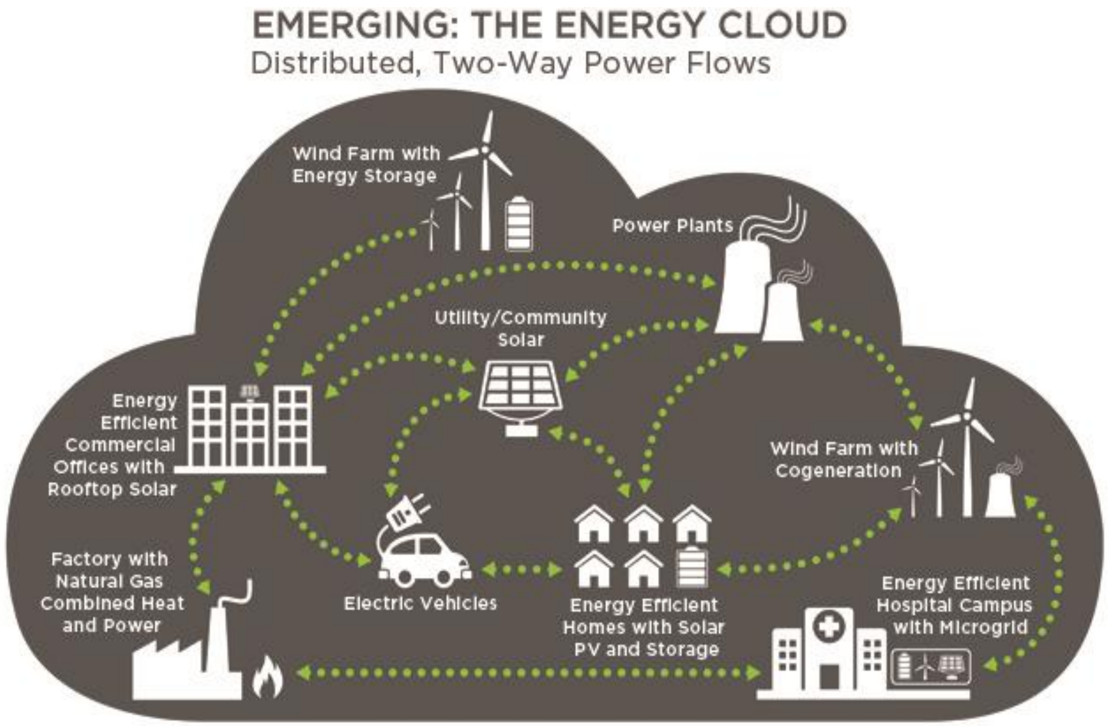
Our investments strengthen America's $68 billion building energy efficiency marketplace.

Without a catalyst like BTO, the housing industry would take 10 to 25 years to adopt new technologies and techniques.

FY20 Budget: $285M

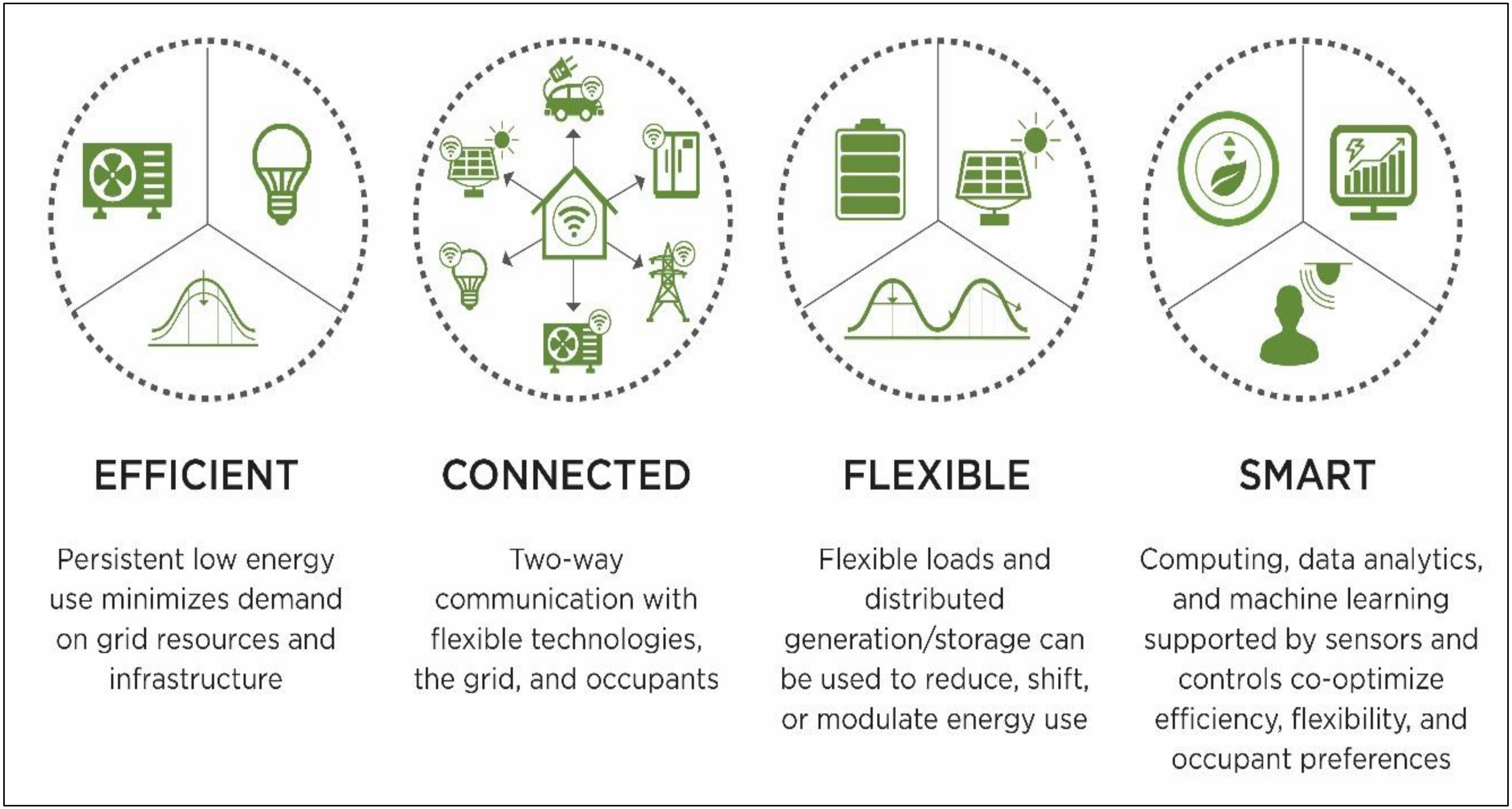
Source: AEE Advanced Energy Now 2017 Market Report, Wolfe, Raymond M. (2016). Business Research and Development and Innovation: 2013 Detailed Statistical Tables.

Moving toward the grid of the future



(Source: Navigant)

Characteristics of Grid-interactive Efficient Bldgs.



www.energy.gov/eere/buildings/GEB

Energy Storage Grand Challenge

Vision: By 2030, the U.S. will be the world leader in energy storage utilization and exports, with a secure domestic manufacturing supply chain independent of foreign sources of critical materials.

Area 1: Near-Term Acceleration

- Enhance the diversity of storage and enabling technologies to meet aggressive cost reductions and performance improvements.

Area 2: Long-Term Leadership

- Strengthen the R&D ecosystem to maintain and grow US storage leadership through constant innovation.

Energy Storage Grand Challenge

ESGC sets the following goals for the U.S. to reach by 2030:

- **Technology Development:** Establish ambitious, achievable performance goals, and a comprehensive R&D portfolio to achieve them
- **Technology Transfer:** Accelerate the technology pipeline from research to system design to private sector adoption through rigorous system evaluation, performance validation, siting tools, and targeted collaborations;
- **Policy and Valuation:** Develop best-in-class models, data, and analysis to inform the most effective value proposition and use cases for storage technologies;
- **Manufacturing and Supply Chain:** Design new technologies to strengthen U.S. manufacturing and recyclability, and to reduce dependence on foreign sources of critical minerals; and
- **Workforce:** Train the next generation of American workers to meet the needs of the 21st century electric grid and energy storage value chain.

www.energy.gov/energy-storage-grand-challenge/energy-storage-grand-challenge

Today’s Webinar

Marcus Bianchi
Senior Research Engineer
National Renewable Energy Laboratory

Mark MacCracken
VP, CALMAC Portfolio
TRANE Inc.

Richie Stever
Director of Operations and Maintenance
University of Maryland Medical Center’s
Downtown and Midtown Campuses

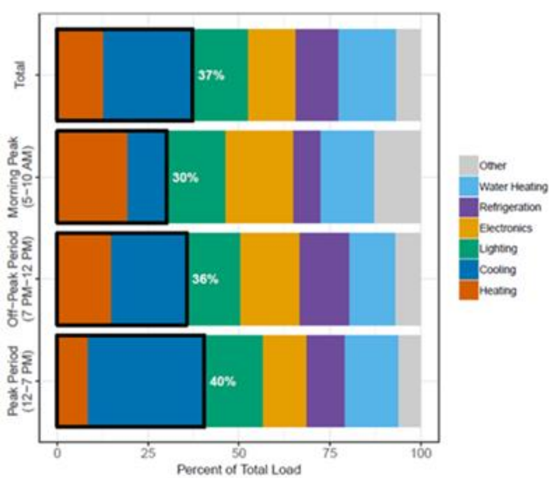
Heather Jackson
Innovation Consultant
Arizona Public Service

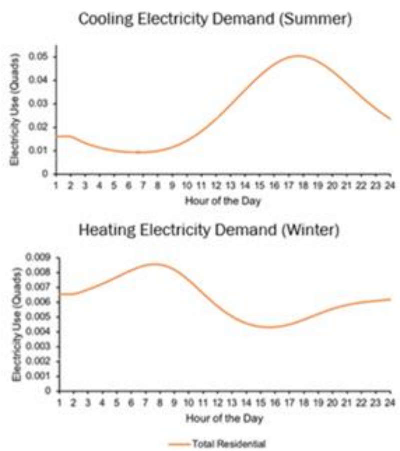
Energy Storage: Batteries and Thermal Energy

Marcus V.A. Bianchi, Ph.D., P.E.
Building and Thermal Sciences Center, NREL
January 16, 2020

Thermal Energy Storage for Buildings

Electrical Consumption for Homes





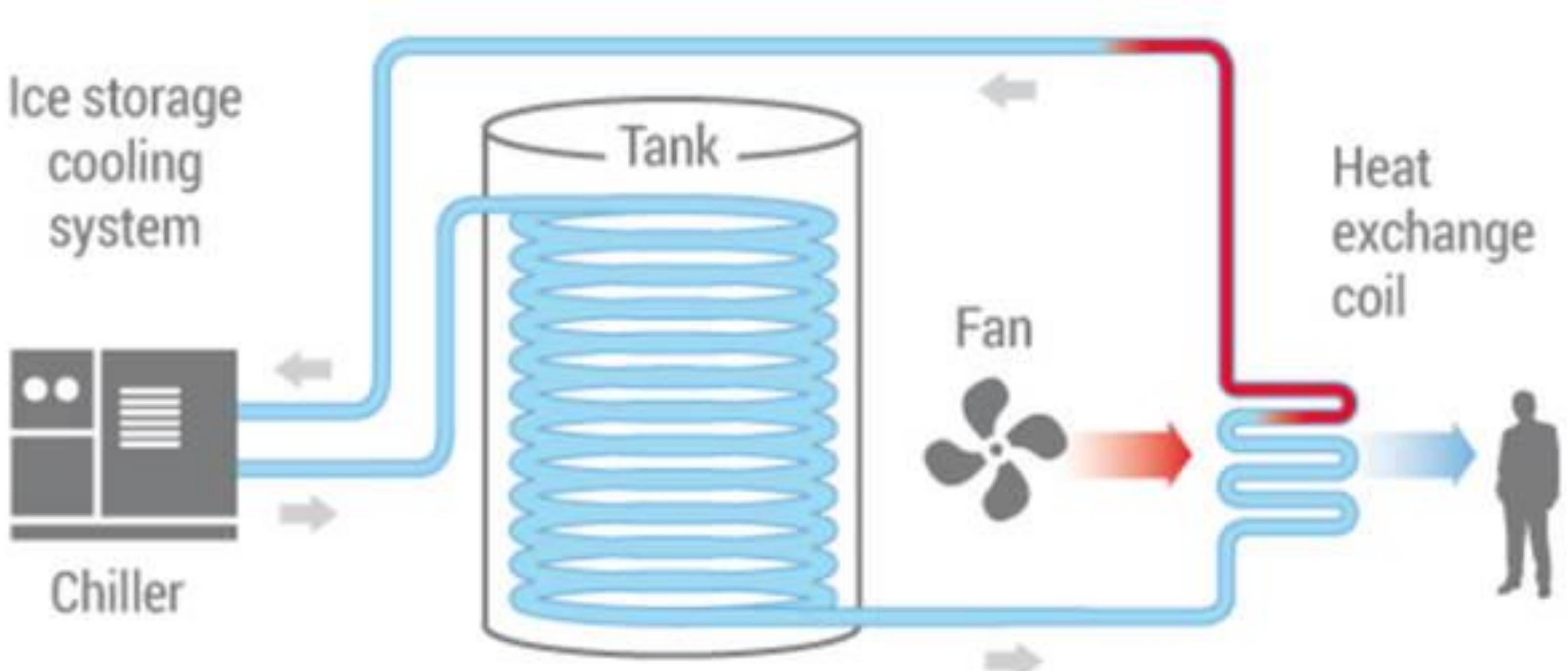
Thermal End-Uses Dominate Building Energy Consumption

- HVAC and refrigeration
  - Major drivers of peak demand
  - Easiest electrical load to shift
- Thermal storage has benefits
  - Higher roundtrip efficiency than batteries for HVAC
  - Batteries are charged with higher value energy
  - Capital cost could be far lower
  - Lifetime could be far greater

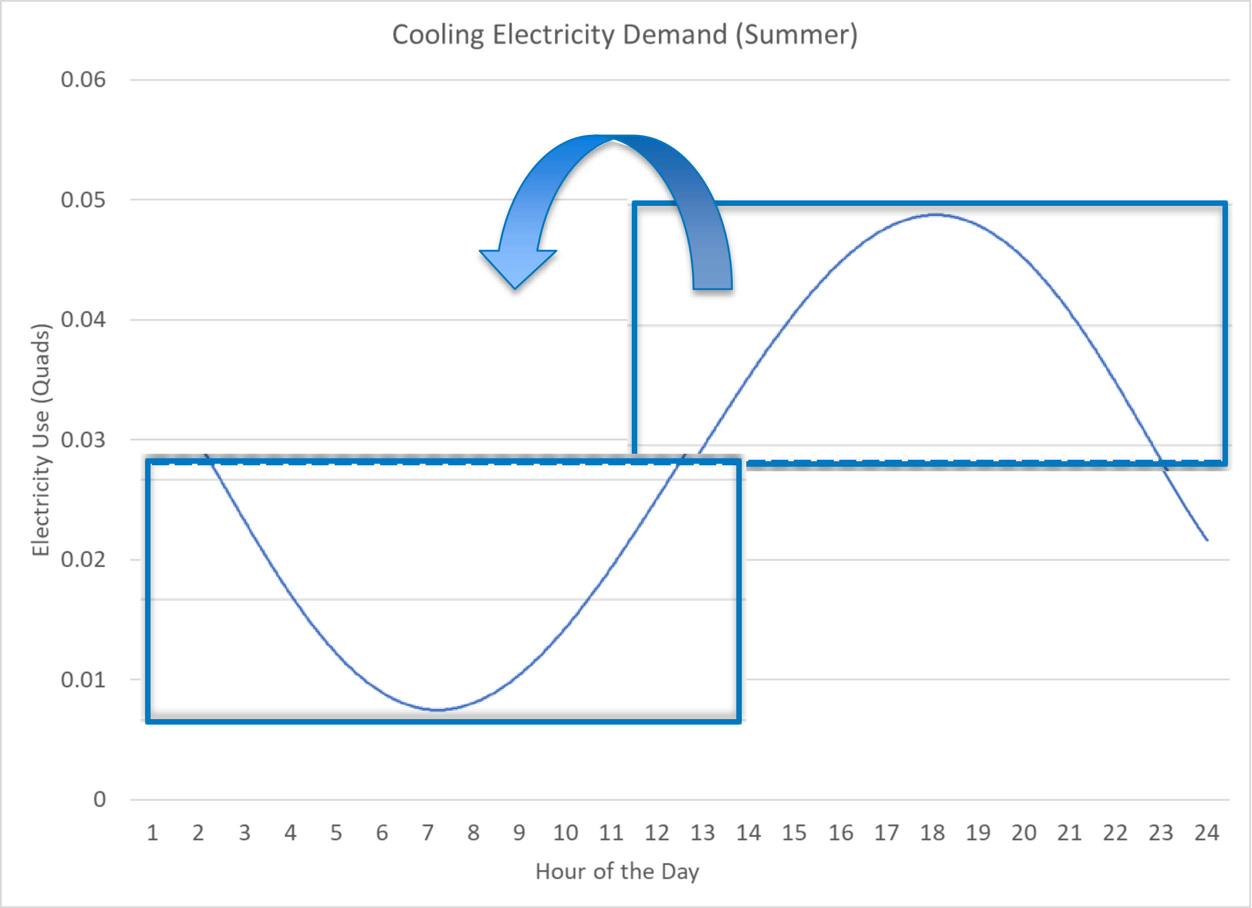
Thermal Energy Storage Examples

- Sensible
  - Adobe
  - Hot or chilled water
  - Underground systems (borehole, aquifer, cavern)
- Latent
  - Phase change materials (ice, paraffin)
- Chemical
  - Sorption of water

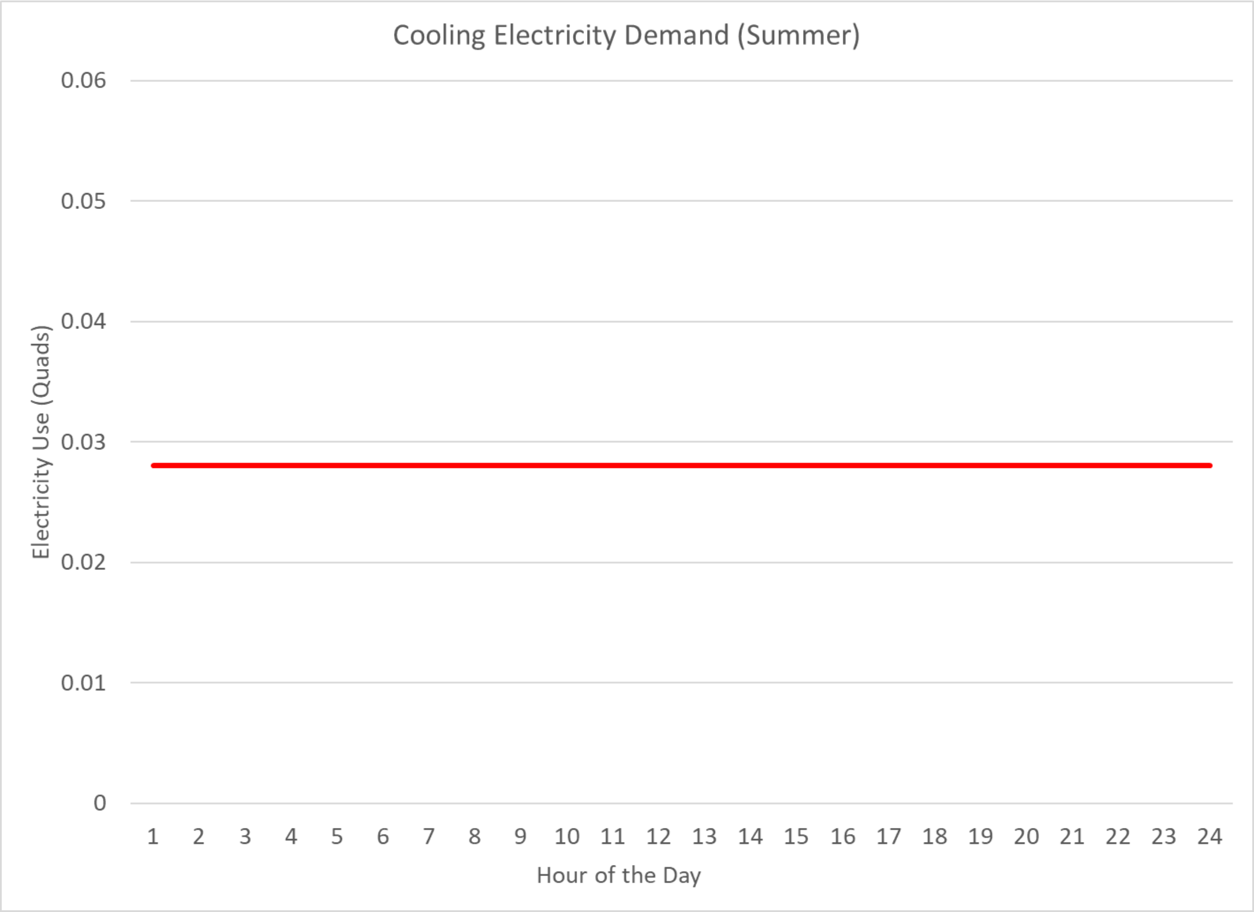
Example of Ice Storage System



Peak Shifting during Cooling



Peak Shifting during Cooling



Thank You

Marcus.Bianchi@nrel.gov

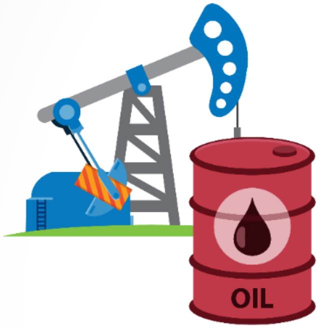
NREL

Transforming ENERGY

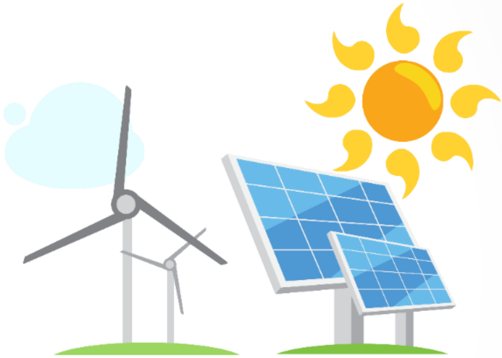
Thermal Energy Storage: The Need, the Successes the Challenges and the Opportunities

Mark MacCracken, PE, Pte, LEED Fellow
President of CALMAC, a portfolio of Trane
mm@calmac.com

CALMAC is a portfolio of Trane



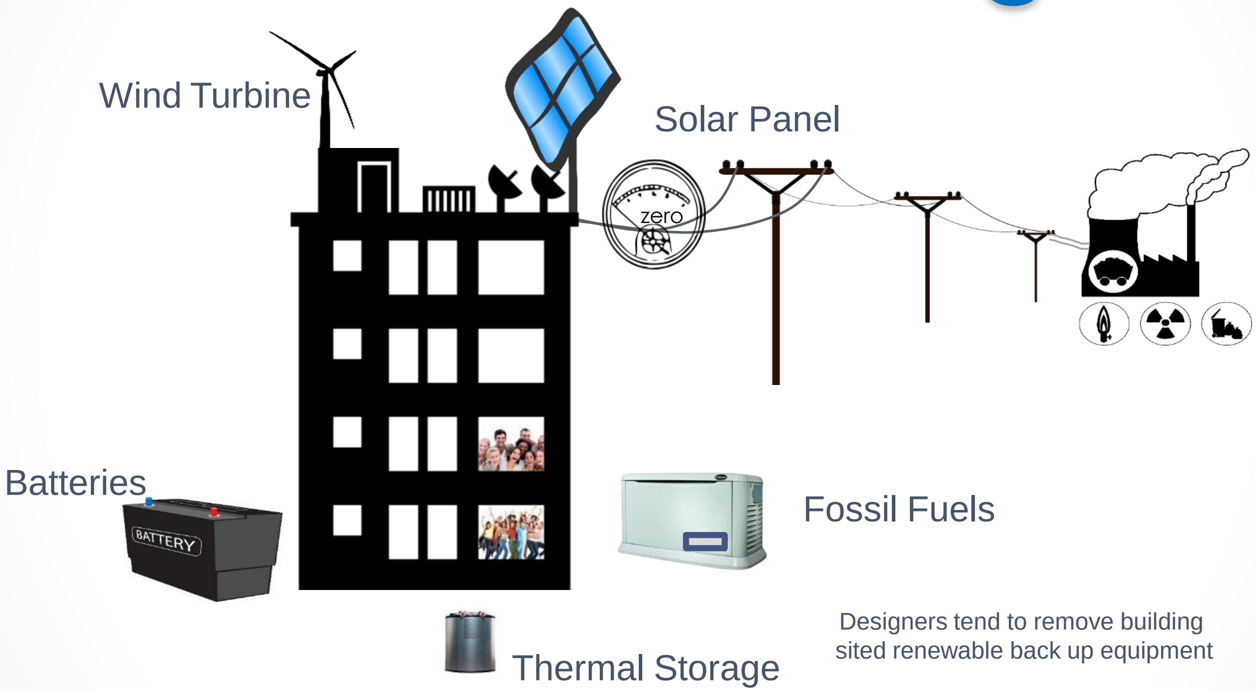
Stored Energy



Energy

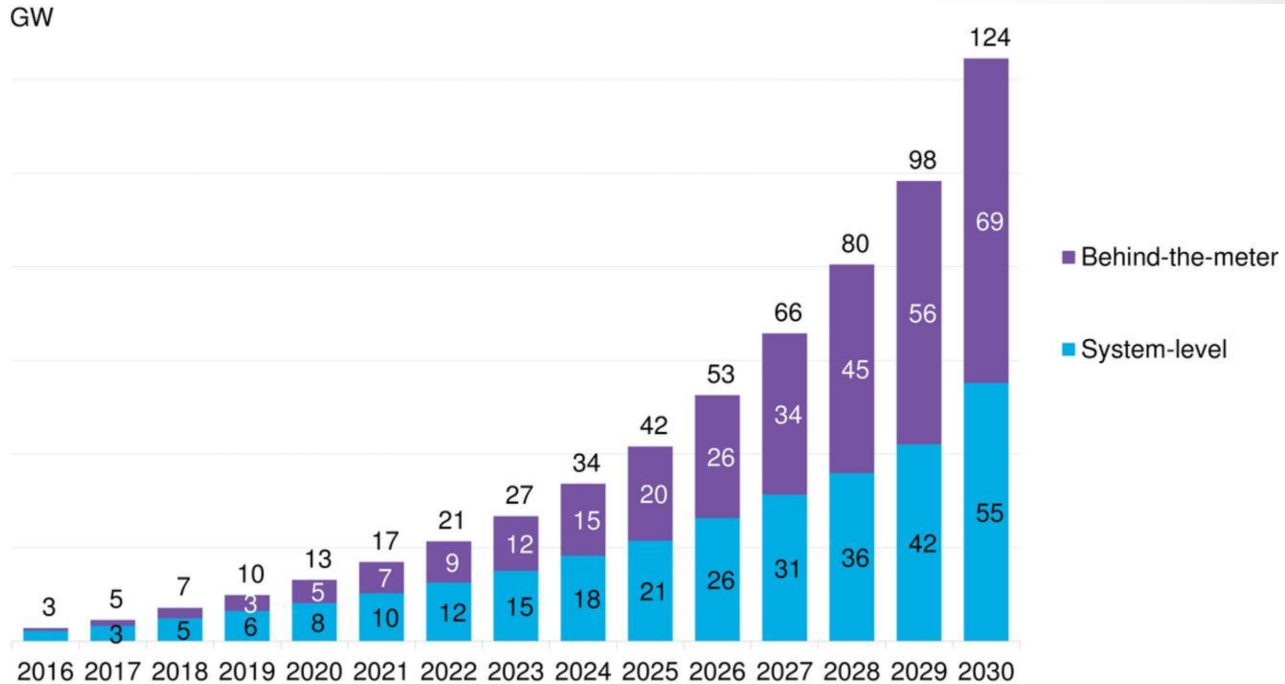
Where is the storage?

Net Zero Grid Building:



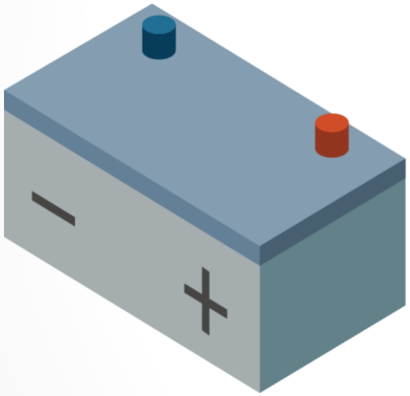
Buildings becoming part of the storage and distribution system

BNEF projections of storage deployment over the next decade



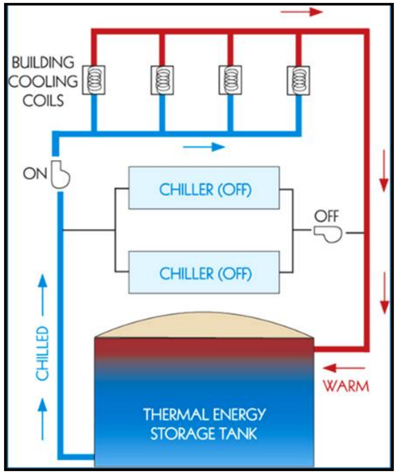
Building Side (of meter) Energy Storage Technologies

Battery



Thermal Energy Storage

(TES) Hot, Cold or Ice, Active or Passive



Basic Thermal Storage

Thermal Storage

How many lbs. of ice do you need for each person for a party? **~1 lbs.**

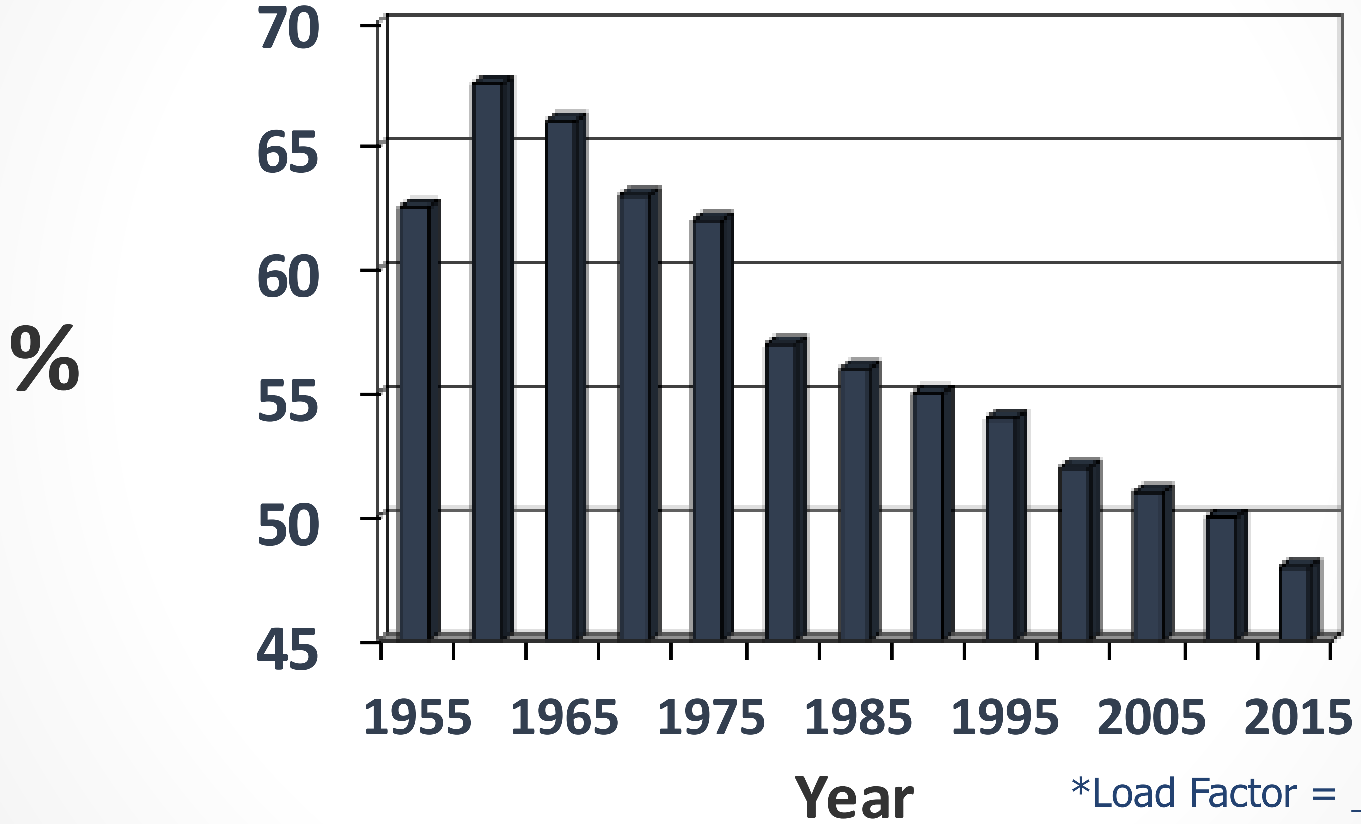
How many lbs. of ice do you need each day to cool each person in a typical office building?

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

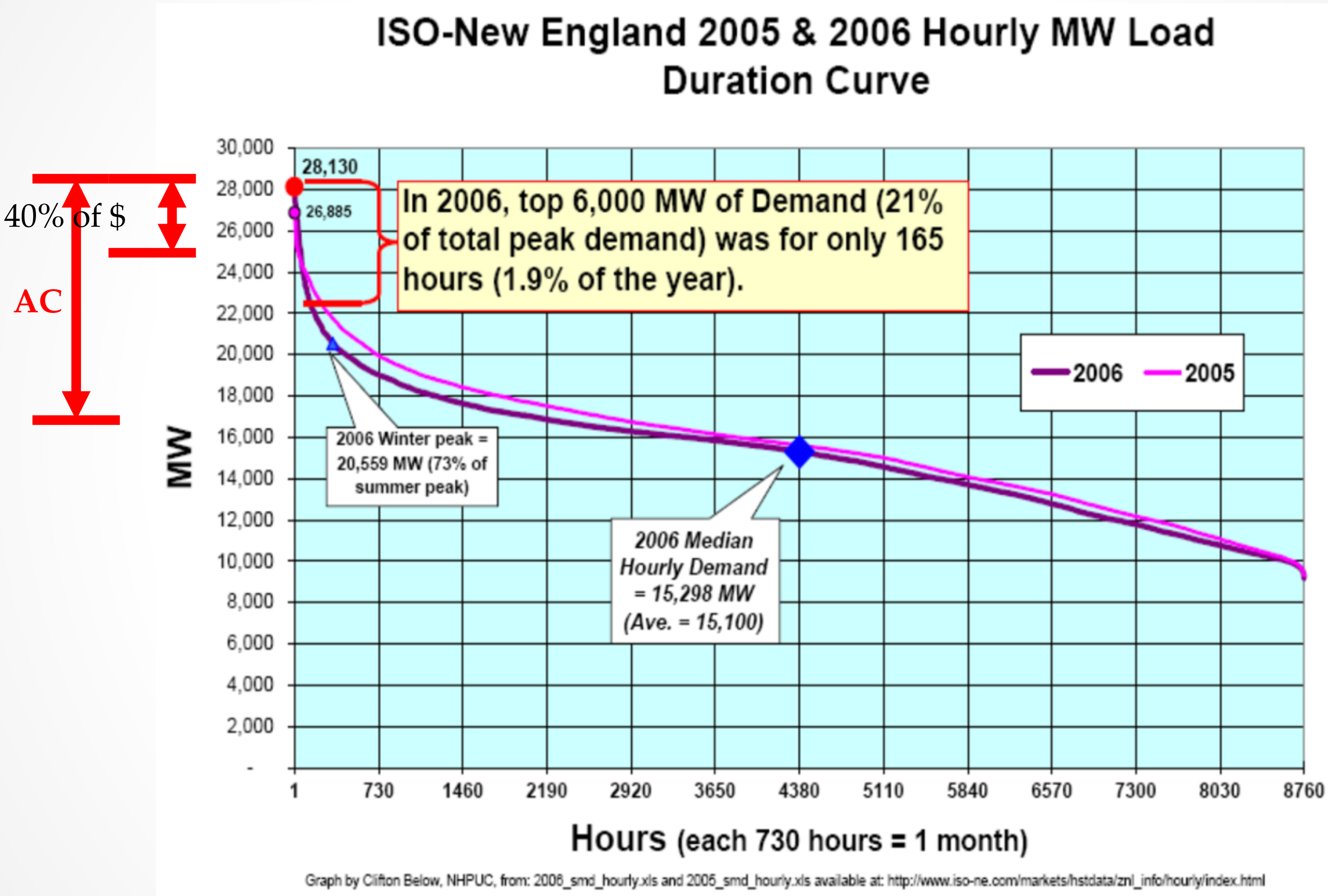
Engineer **300 ft^2/ton** **400 ft^2/ton** **500 ft^2/ton**

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



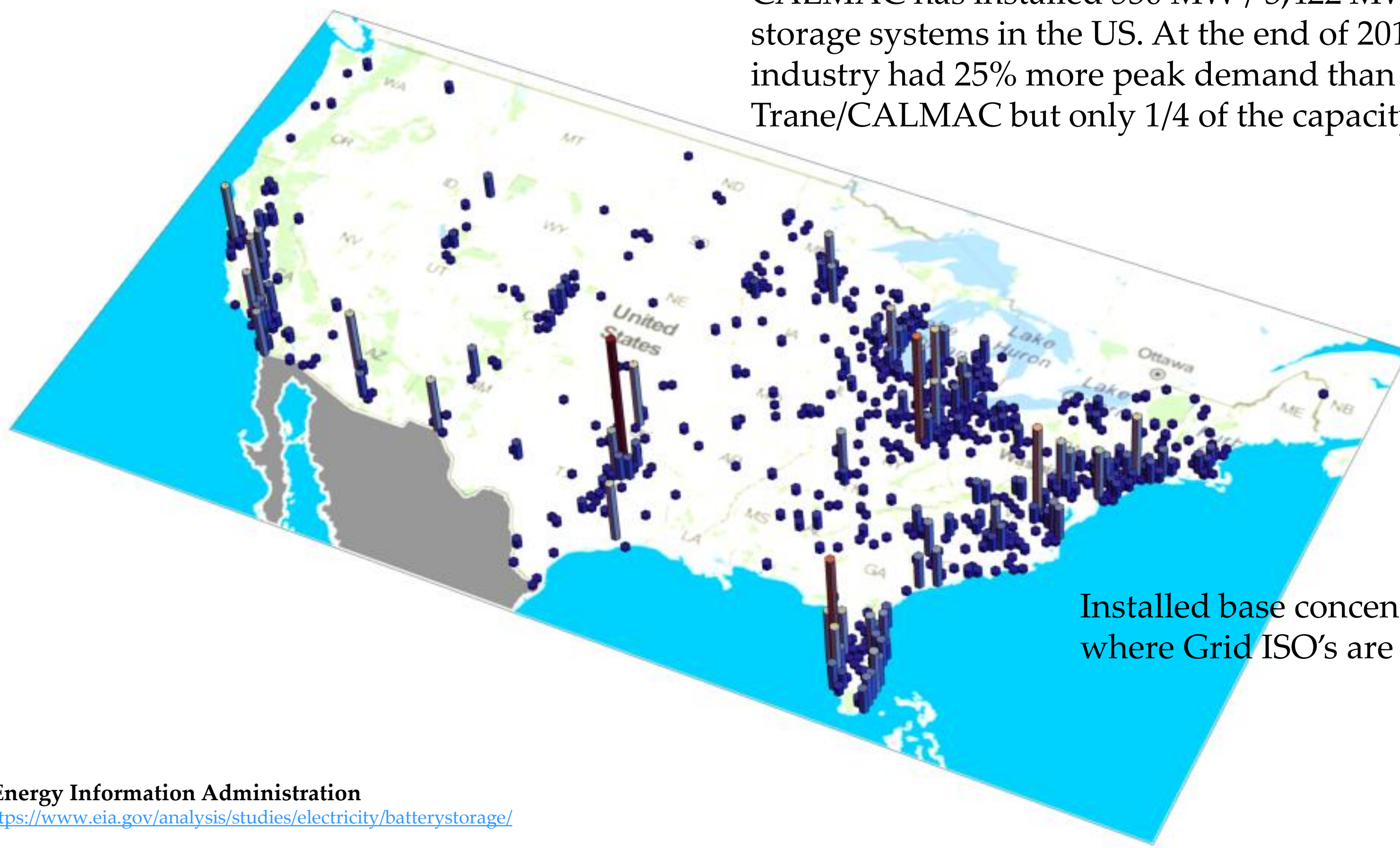
*Load Factor = $\frac{\text{Avg. Load}}{\text{Peak Load}}$


ISO-New England 2005 & 2006 Hourly MW Load Duration Curve
40% of $
AC
28,130
26,885
In 2006, top 6,000 MW of Demand (21% of total peak demand) was for only 165 hours (1.9% of the year).
2006
2005
2006 Winter peak = 20,559 MW (73% of summer peak)
2006 Median Hourly Demand = 15,298 MW (Ave. = 15,100)
MW
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
1
730
1460
2190
2920
3650
4380
5110
5840
6570
7300
8030
8760
Hours (each 730 hours = 1 month)
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

NEW YORK CITY ICE STORAGE INSTALLATIONS ~ 120 MW-HR

CALMAC US Projects Histogram 3D

CALMAC has installed 530 MW / 3,422 MWH of TES storage systems in the US. At the end of 2017, the battery industry had 25% more peak demand than Trane/CALMAC but only 1/4 of the capacity *



Installed base concentrated where Grid ISO's are active!

***Energy Information Administration**
https://www.eia.gov/analysis/studies/electricity/batterystorage/

Why not more TES?

- Fossil Fuels come with Free Storage
- Lack of awareness of Electrical costs, 50% less at night
- Perceived more "risk" in the design phase (more effort) because "Modeling" is difficult.
- Only for cooling season:

"Electrification" of Buildings will enable Thermal Energy Storage to add value 12 months of the year

Electricity is 50% Less Expensive at Night

Consumers Energy (Mich.) General Primary rate

Energy (usage):

Day: ~~$0.085/kWh~~ $0.170/kWh

Night: ~~$0.085/kWh~~ $0.085/kWh

Demand: ~~$14.00/kW~~/Month

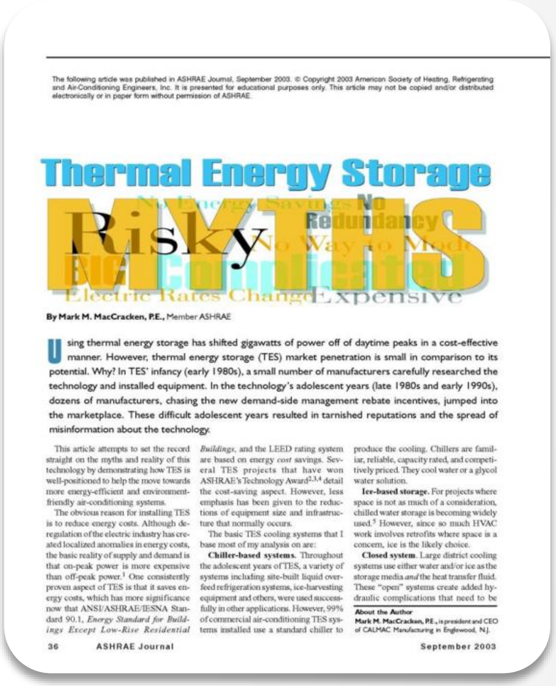
Jefferson Community College- Watertown, NY

Thermal Energy Storage Myths Article

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

Reality:

TES is a Proven Technology that saves Money and Energy



Thermal Energy Storage MYTHS

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, N.J.

Electrification = Big Heat Pumps

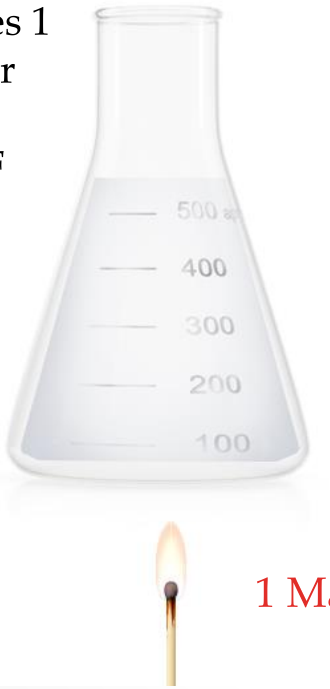
- Chillers are Big Heat Pumps, but only pump the energy in one direction (not reversible)
- Water Cooled Chillers = Water to Water Heat Pumps

Thermal Batteries

- You know these as "Ice Storage Tanks"
- They are actually Thermal Batteries
  - **When you take energy out, the water turns to ice**
  - **When you put energy in, the ice melts**

Water's Phase Change (Btus)

1 match takes 1 lb. of water from 32F to 33F



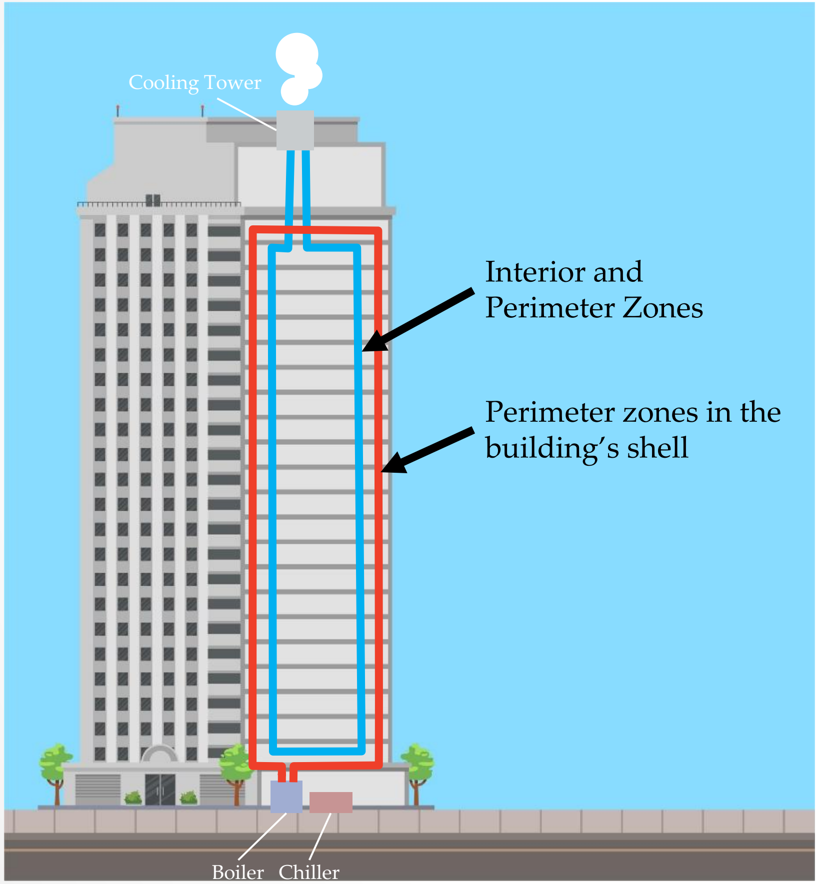
1 Match

144 Matches

144 matches takes 1 lb. of water from 32F Ice to 32F water

Changing Water's Phase (solid to liquid) stores tremendous amounts of thermal energy

Winter Simultaneous Heating & Cooling



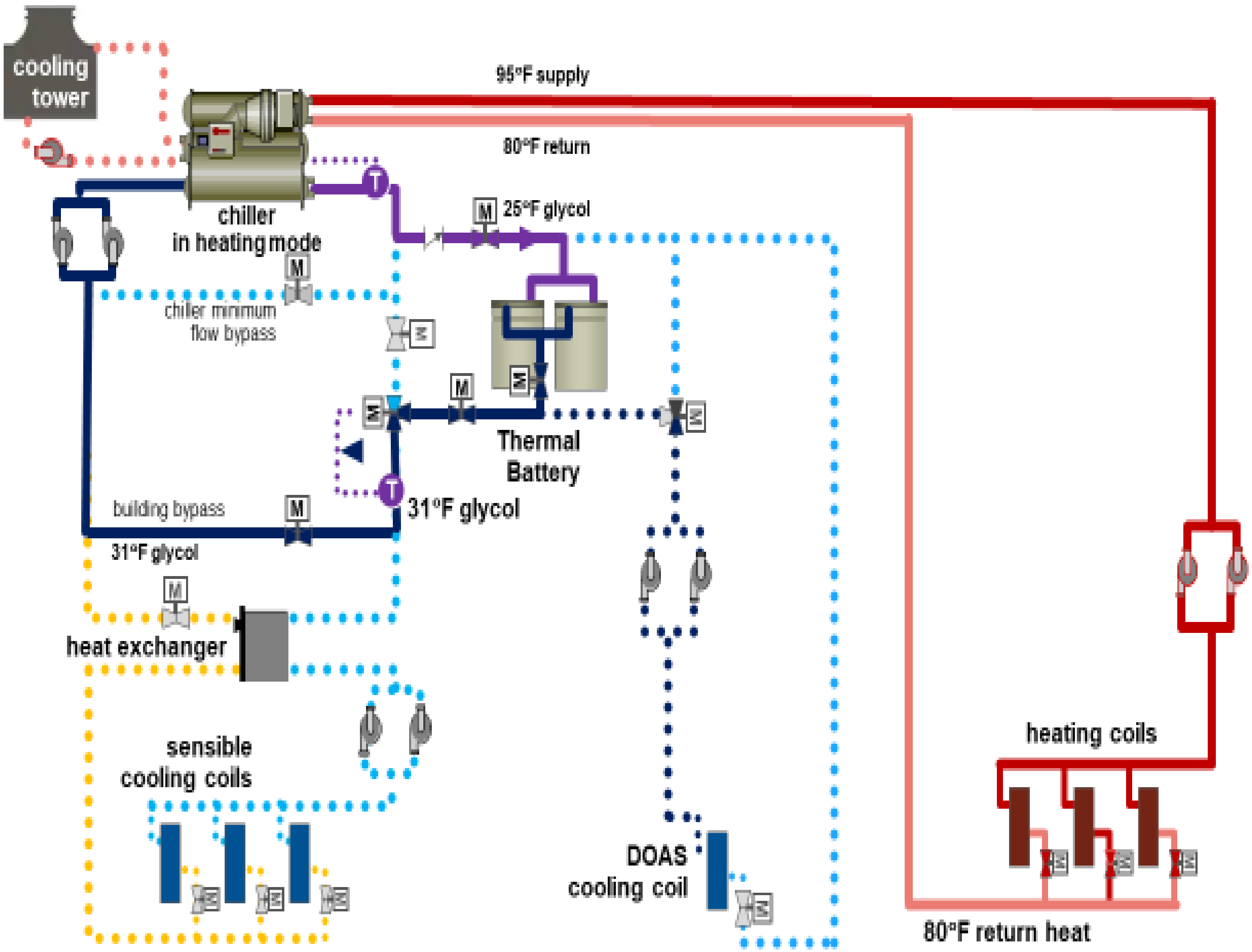
During the winter months, most large New York City buildings simultaneously heat and cool.

- They cool with waterside economizers
- At the same time, they heat the building with natural gas boilers or steam

Some call waterside economizers "free cooling" which is a misnomer.

This process wastes energy that the HVAC plant could efficiently use to warm the perimeter zones.

Heating with Thermal Battery and Heat Recovery Chiller



The "6-pipe" dual condenser Heat Recovery Chiller eliminates the need for a Plate and Frame Heat Exchanger in the heating loop thereby increasing efficiency and streamlining the system.

TRANE®

LET'S GO BEYOND™

Mark M. MacCracken
mm@calmac.com

CALMAC®

Ingersoll Rand

Our Values

Respect and Integrity
We Honor All People

Teamwork and Collaboration
We Are Better Together

Excellence and Innovation
We Seek To Advance

Diversity and Inclusion
We Value Each Other

Uses and Lessons of Ice Storage on the Medical Campus

Building Technologies Office Webinar

Richie Stever
Director of Operations and Maintenance
January 16, 2020

University of Maryland Medical Center

ABOUT THE MEDICAL CENTER

757 bed academic teaching hospital

31 ORs

8600 employees

2.5 million square feet

Hospital: 2,100,000sqft

Medical Office Buildings:121,000sqft

Parking Garage: 309,000sqft

$14 million on energy bills a year

500,000 gallons of water a day

HVAC/REFRIGERATION

2 – Ice Storage Tanks

13 – Cooling Towers

14 – Chillers

56 – Air Handling Units

64 – Exhaust Fans

95 – Ice Machines

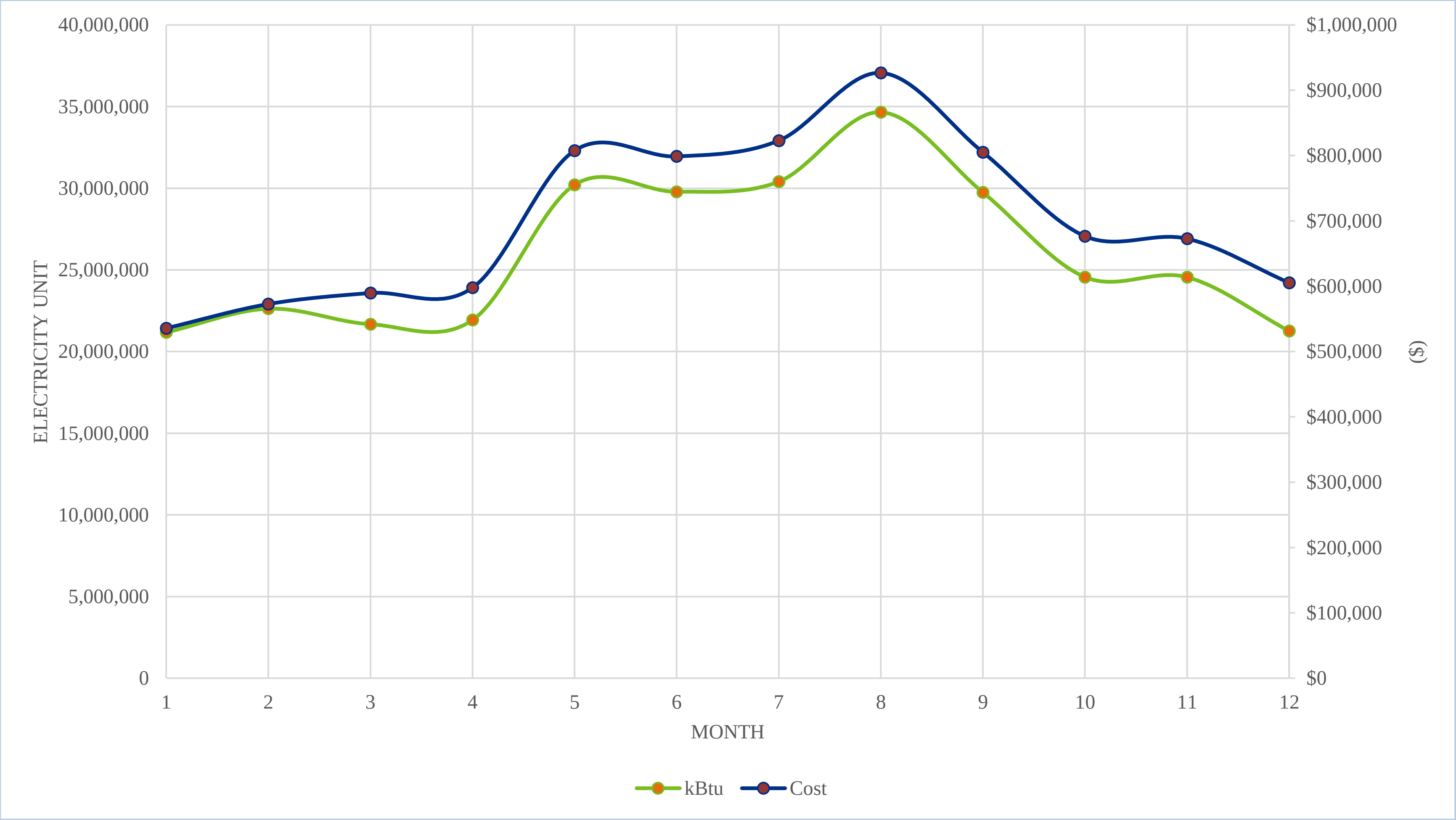
148 – Fan Coil Units

156 – Isolation/Protective Environment Rooms

521 - Refrigerators

Electrical Usage 2019

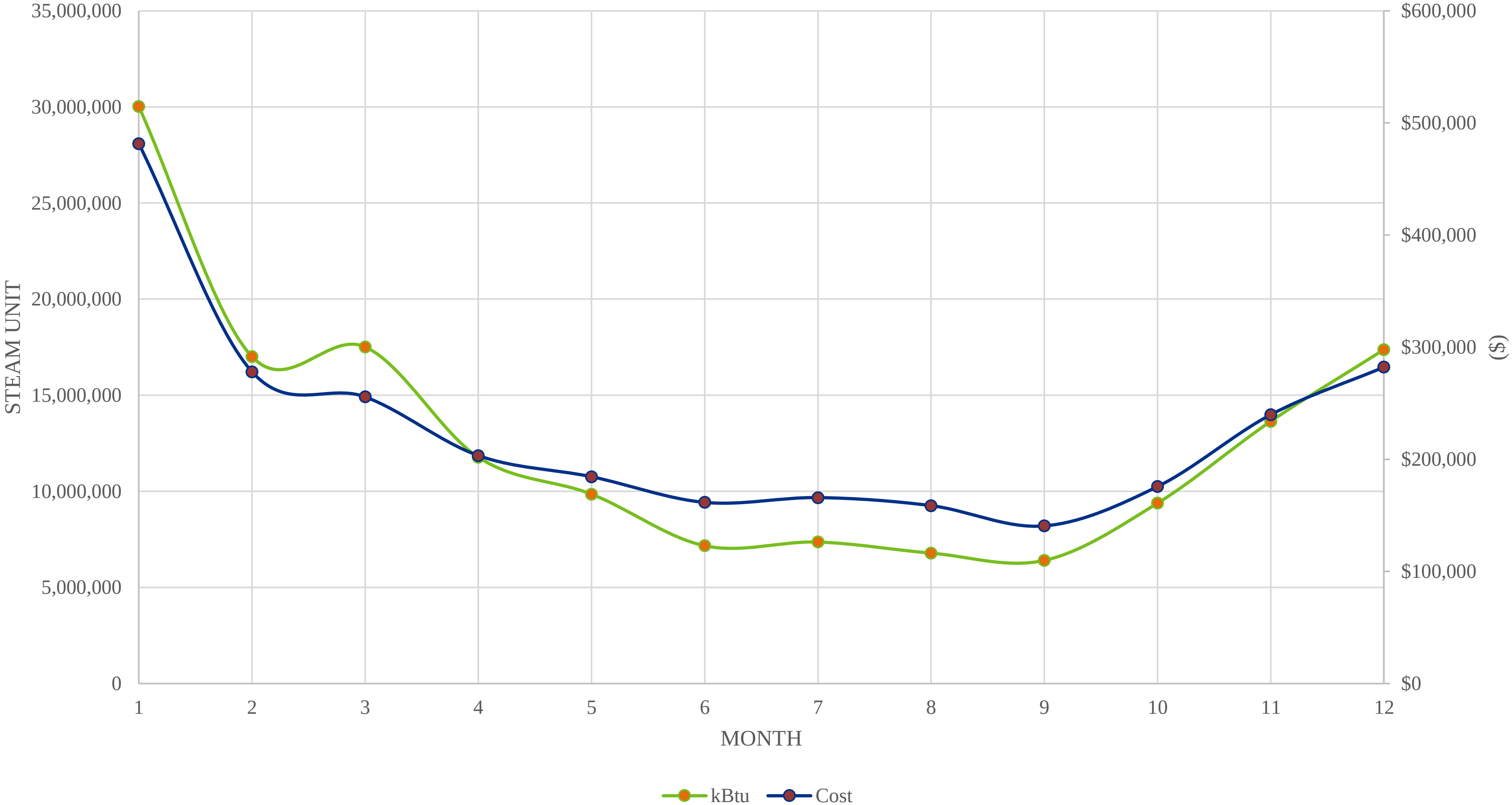
Average: $700,956/month



Our Values

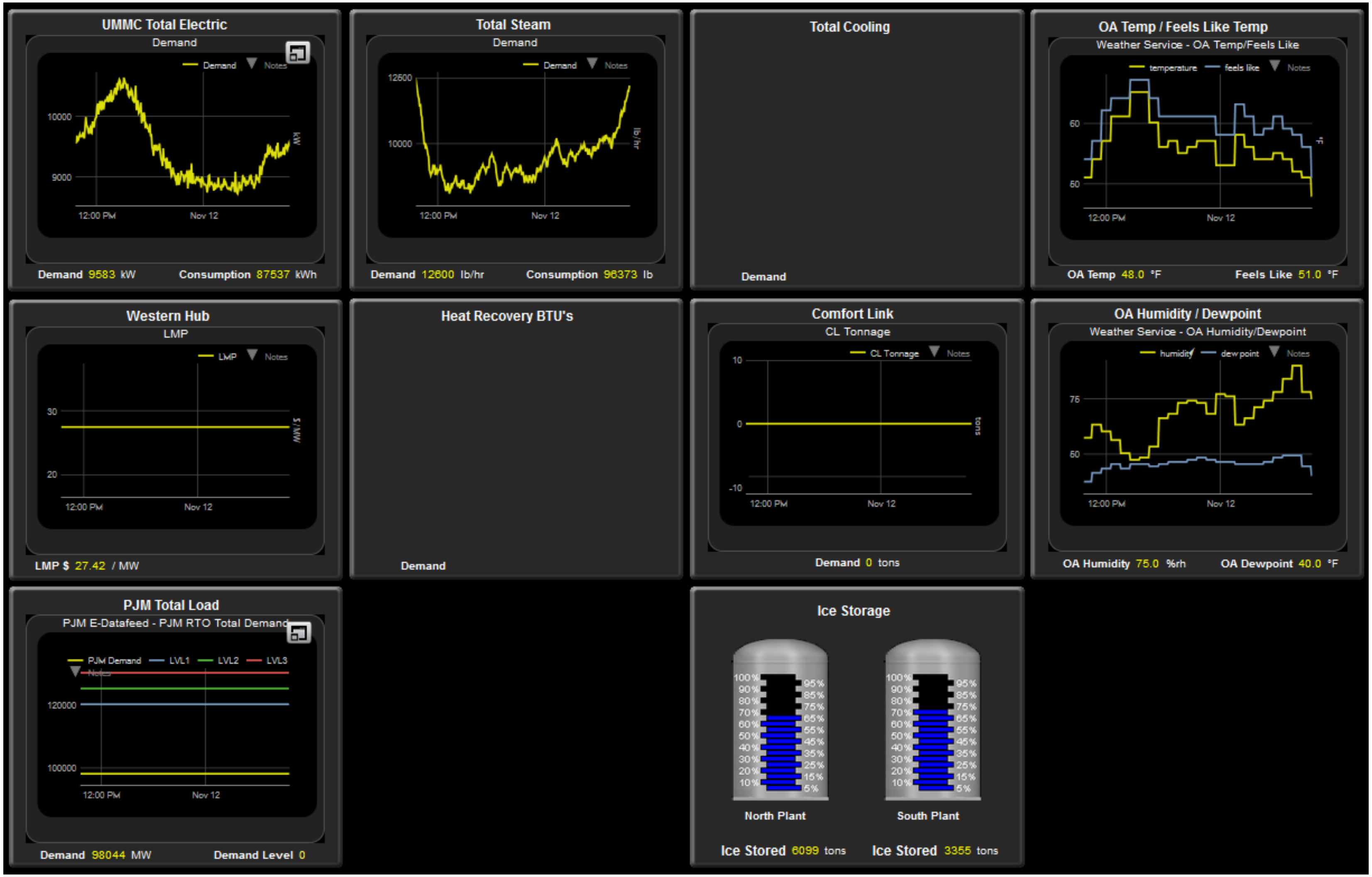
Steam Usage 2018

Average: $227,288/month



BAS MONITORING

Utility Dashboard



Our Values

Respect and Integrity | Teamwork and Collaboration | Excellence and Innovation | Diversity and Inclusion

COMPOUND HEAT RECOVERY CHILLER

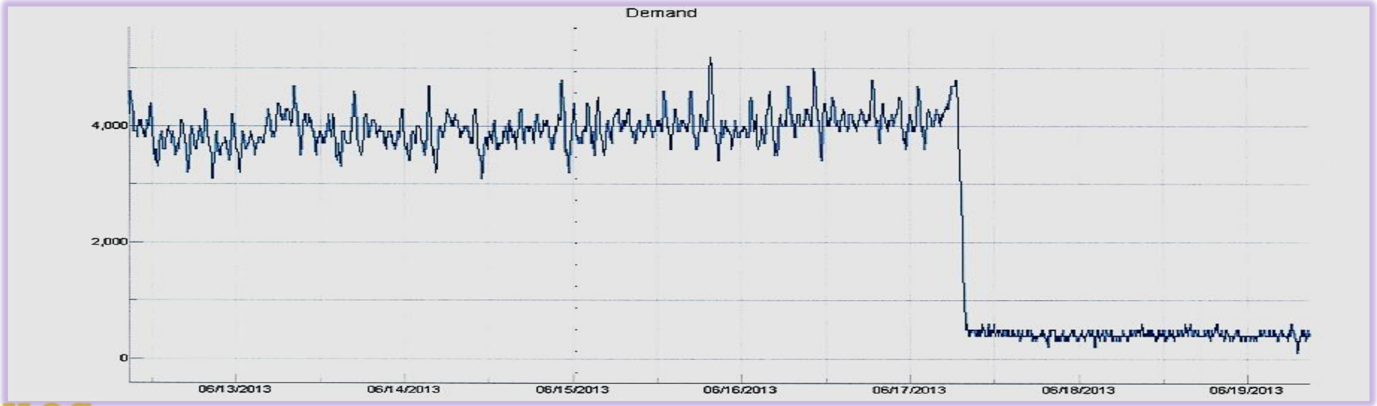
Manufacturer: York

Capacity: 500 tons

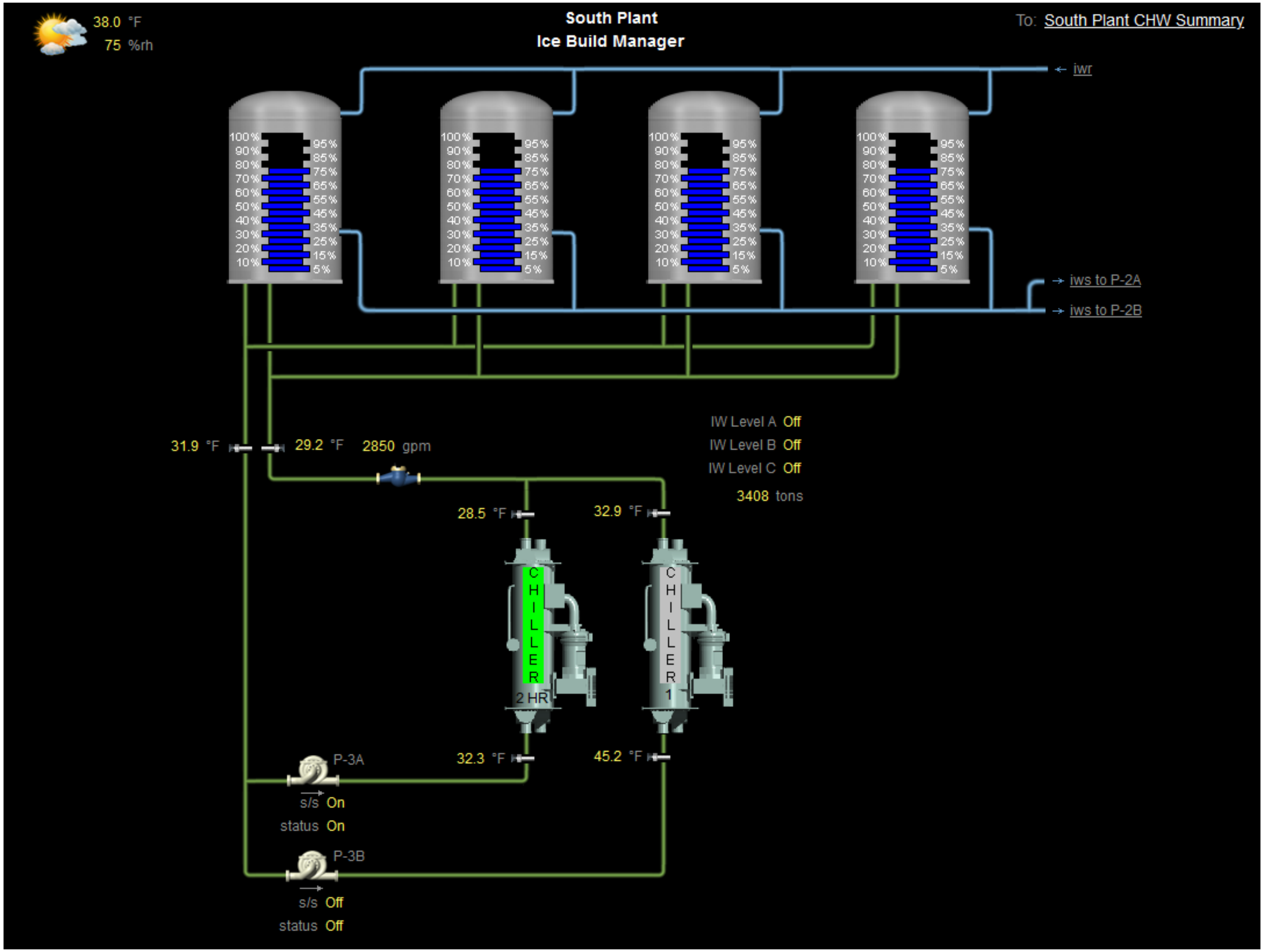
Compressor: Two Stage Centrifugal

Evaporator Water is used to Chill Glycol Temperature: 26 - 32F

Condenser Water is use for Heating Water Temperature:140F



ICE PLANT



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ICE STORAGE TANK

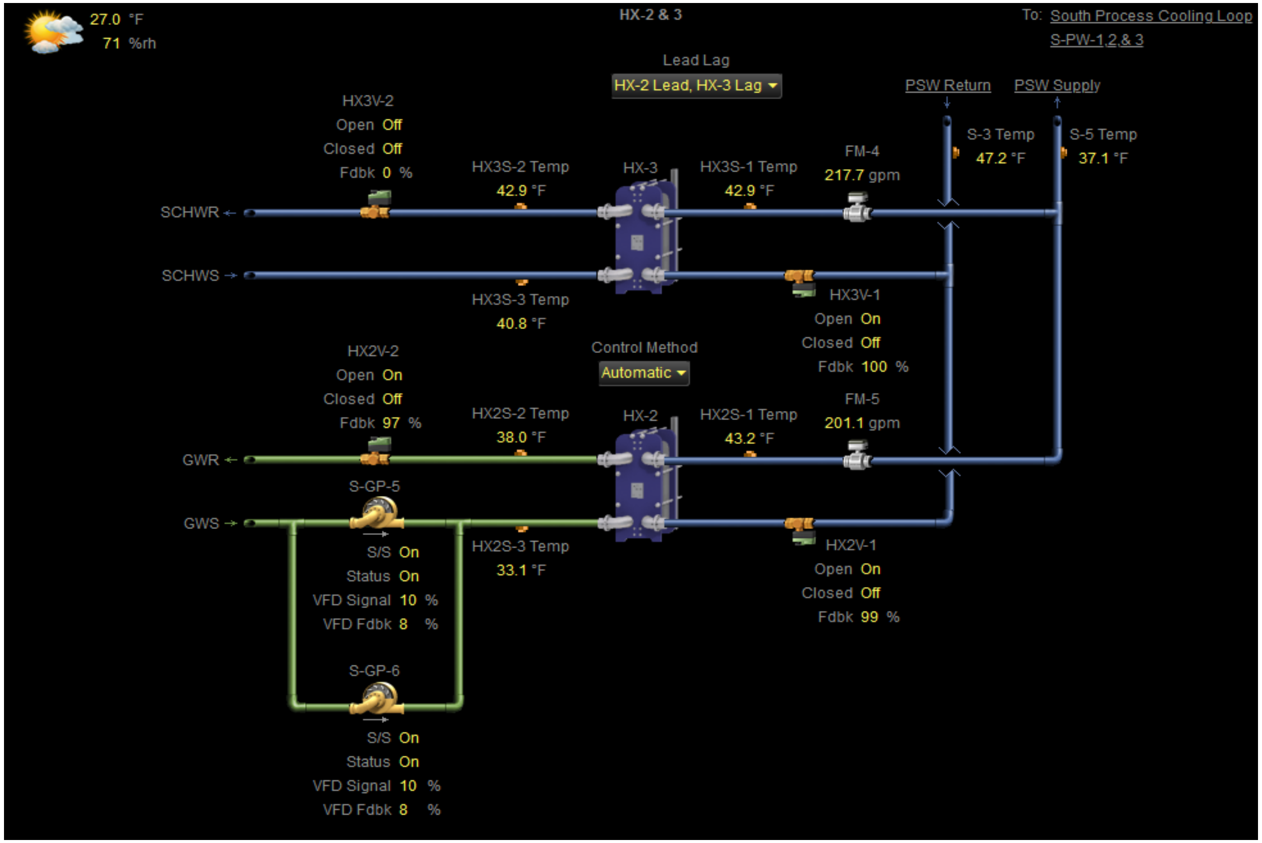
Interior View of Ice Tank Glycol Coil

Manufacturer: Baltimore Aircoil Company

Capacity: 4200 tons

Consists of 4 double walled tanks with copper coils inside. Chilled glycol (<32F) produced by the heat recovery chiller is run through the coils to cool the water around them, bubblers are used to prevent freezing and discourages temperature variations.

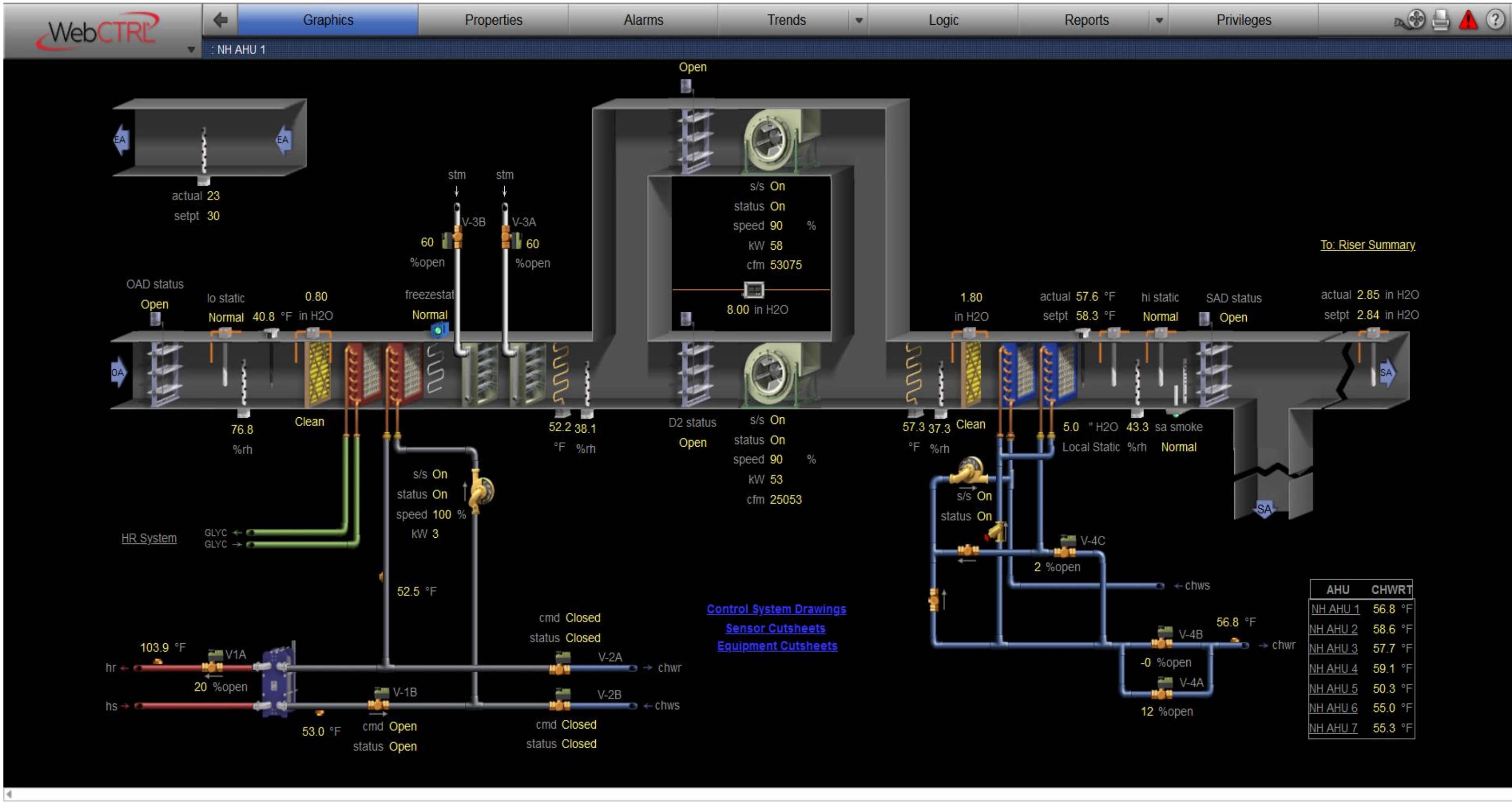
PROCESS COOLING LOOP



An independent chilled water loop for cooling heavy metal equipment, such as MRIs and other high power medical scanner devices. Ice water is used to supplement cooling when necessary.

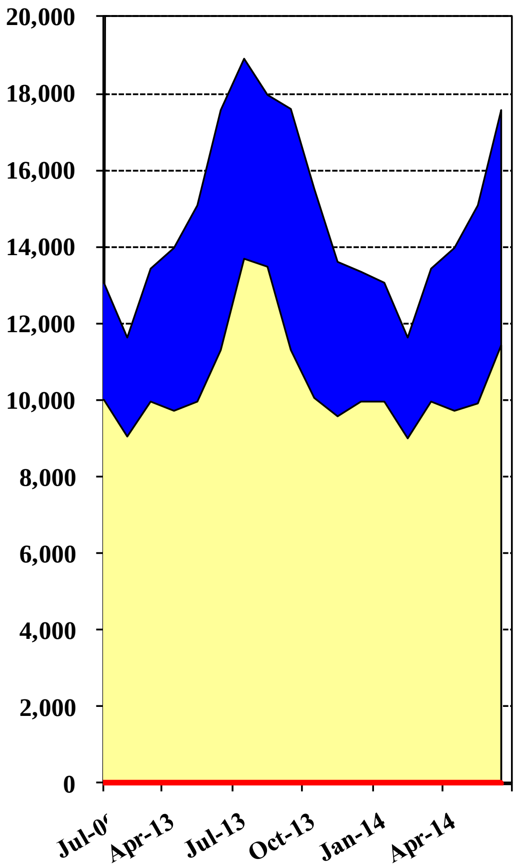
AIR HANDLER UPGRADES

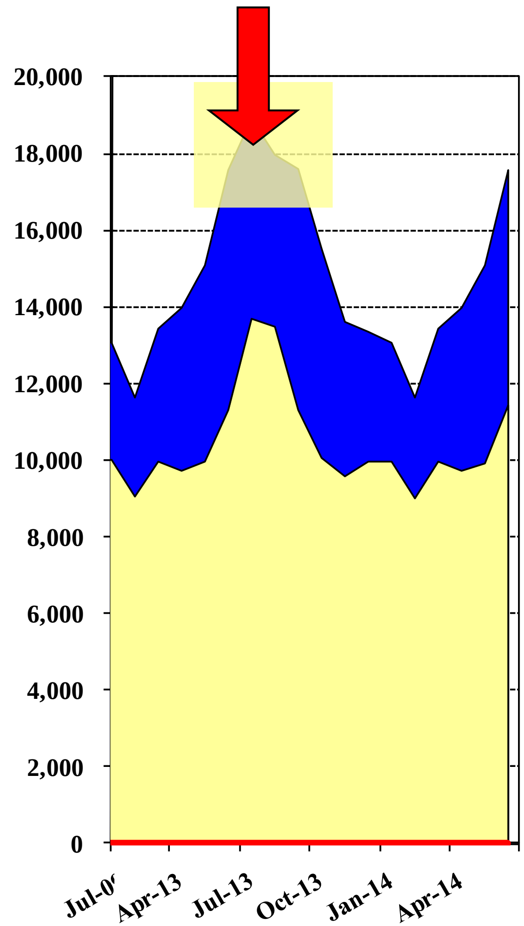
UNIVERSITY of MARYLAND MEDICAL CENTER



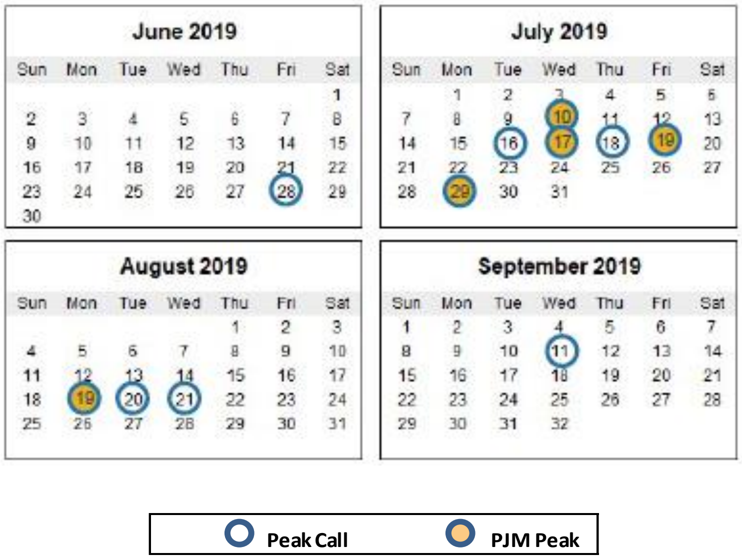
Peak Shaving

Reduces capacity charges ($100k/MW)





11 dispatches, 5 out of 5 peaks captured



Pros and Cons of Ice Storage

Pros

Provides redundancy via thermal storage
Stable water temperatures
Ability to peak shave
Potential energy savings (off-peak usage)
Low maintenance

Cons

High first costs
Flood potential
Requires Space

Questions?

Ice Storage in Arizona

Heather Jackson

1/16/2020

Affordable.

Grid Benefits?

Sustainable?

For utilities and building owners:

- Find each other!
  - District cooling, schools, hospitals, hotels, cold storage warehouses
- Create a triple win
  - System owner
  - Utility
  - environment

District

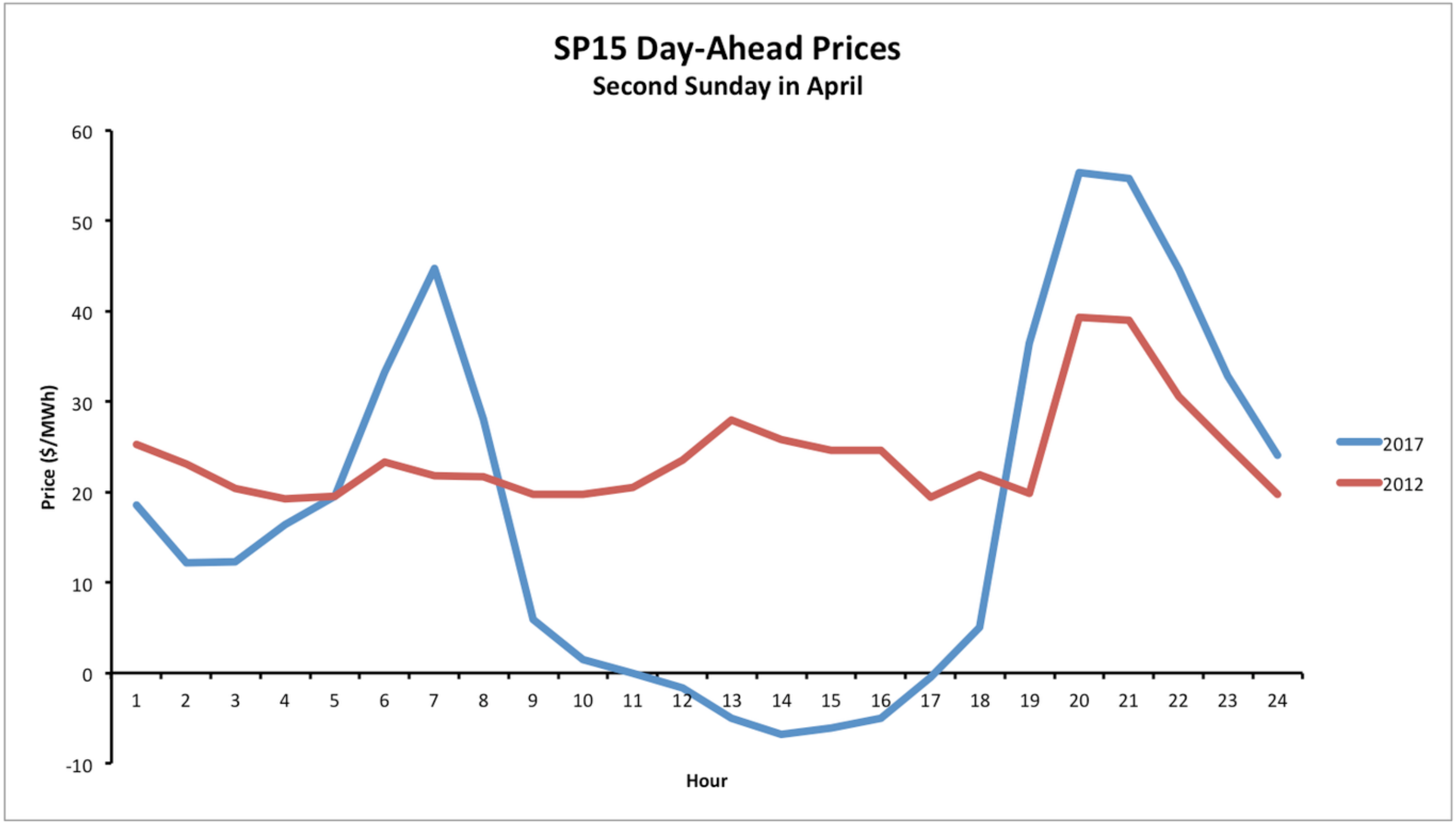
Large facility

Energy Storage scale and cost

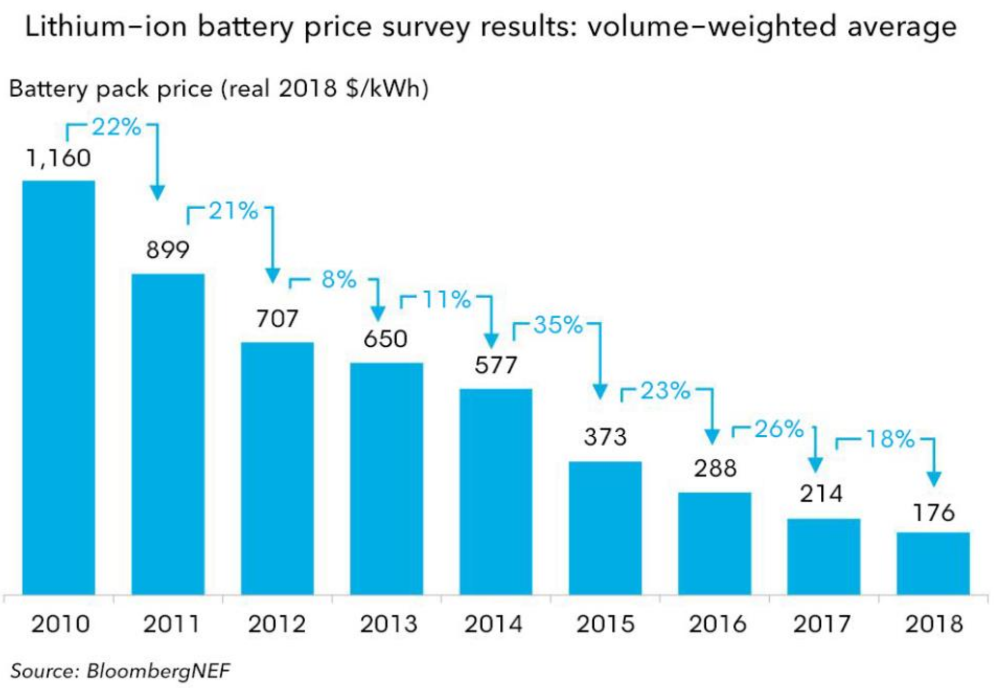
- Existing infrastructure
  - District cooling: 10’s of MWh
  - Large facility: MWh scale
- New infrastructure
  - Already cost-competitive for high density cooling loads
  - Special rates
  - Utility incentives?

What we're doing to expand ice storage in Arizona

- Connecting with owners of ice storage systems
- Rates
  - Make ice when renewables are abundant
- Incentive Programs: must societal cost test
- Finding large / new cooling loads


SP15 Day-Ahead Prices
Second Sunday in April
Price ($/MWh)
60
50
40
30
20
10
0
-10
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Hour
2017
2012

Value for the Power Grid



District Cooling loads could function like $3-$10M batteries

Large facility cooling loads could function like $500k - $3M batteries

Seasonality: Minimum cooling load?

How can utilities help drive adoption of ice storage cooling?

- Please reach out with ideas
- Heather.Jackson@aps.com

OPEN Q&A

Submit Questions via chat box

Thermal Energy Storage Webinar Series

Stay tuned for the next installment