NREL
Transforming ENERGY

# Space Conditioning Tech Team Webinar:

## Thermal Energy Storage, the lowest cost storage


Michael Deru

Miles Hayes

Guest Speakers:

Mark MacCracken (Trane)

Karl Heine (NREL & Colorado School of Mines)

# Space Conditioning Tech Team Updates

- Recent Publications
  - SMC Technical Report
  - DWT Technical Report
  - Cooling Tower Water Treatment Technologies
- Advanced Rooftop Campaign Ramping Down
  - Feedback
- HVAC Resource Map Updates

# Thermal Battery Systems

Mark M. MacCracken
VP, CALMAC Portfolio
Trane Commercial HVAC NA

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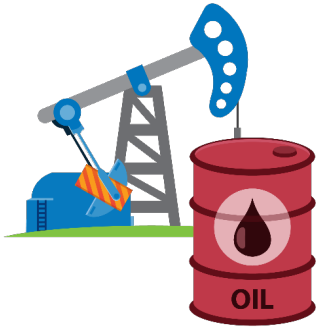
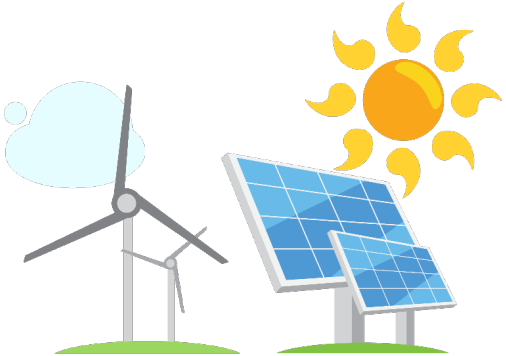


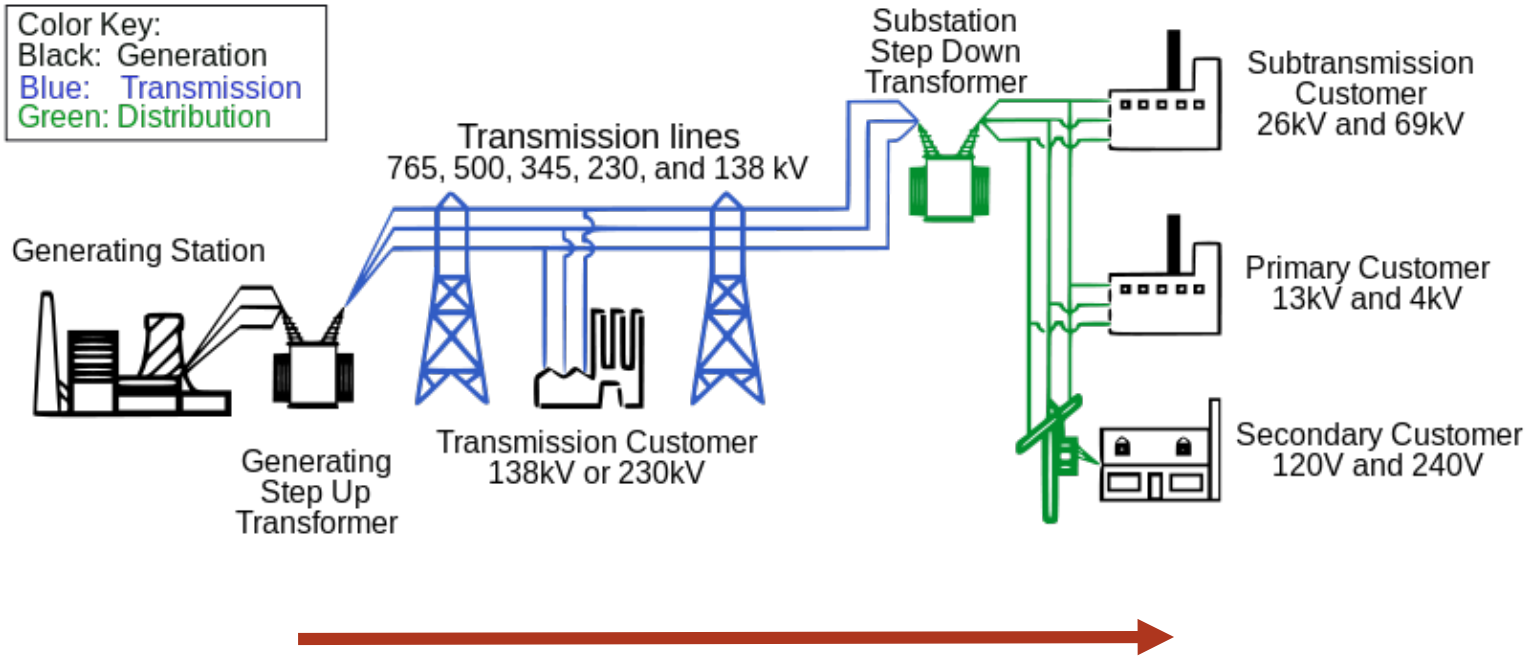

Stored Energy



Energy

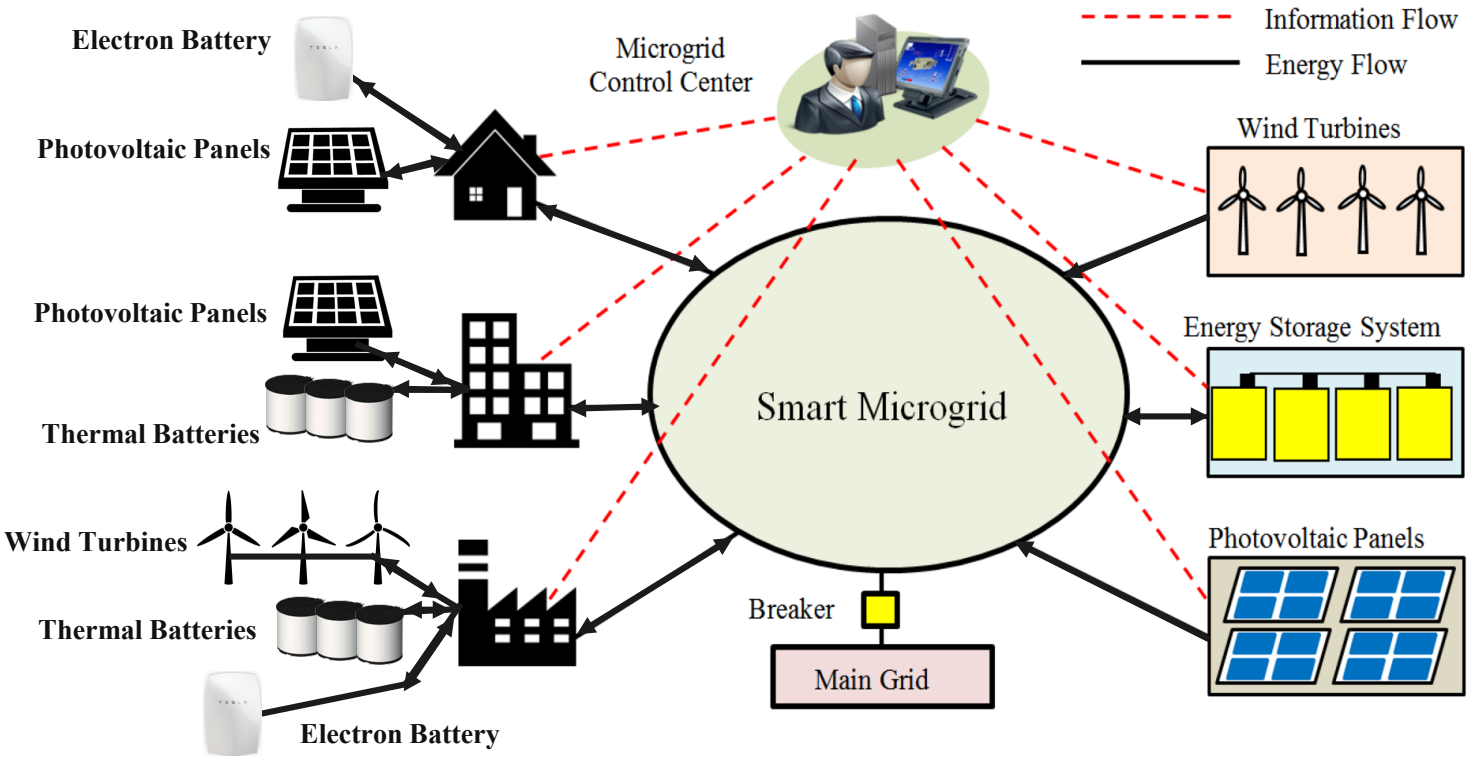
## Where is the storage?

# Old Grid:

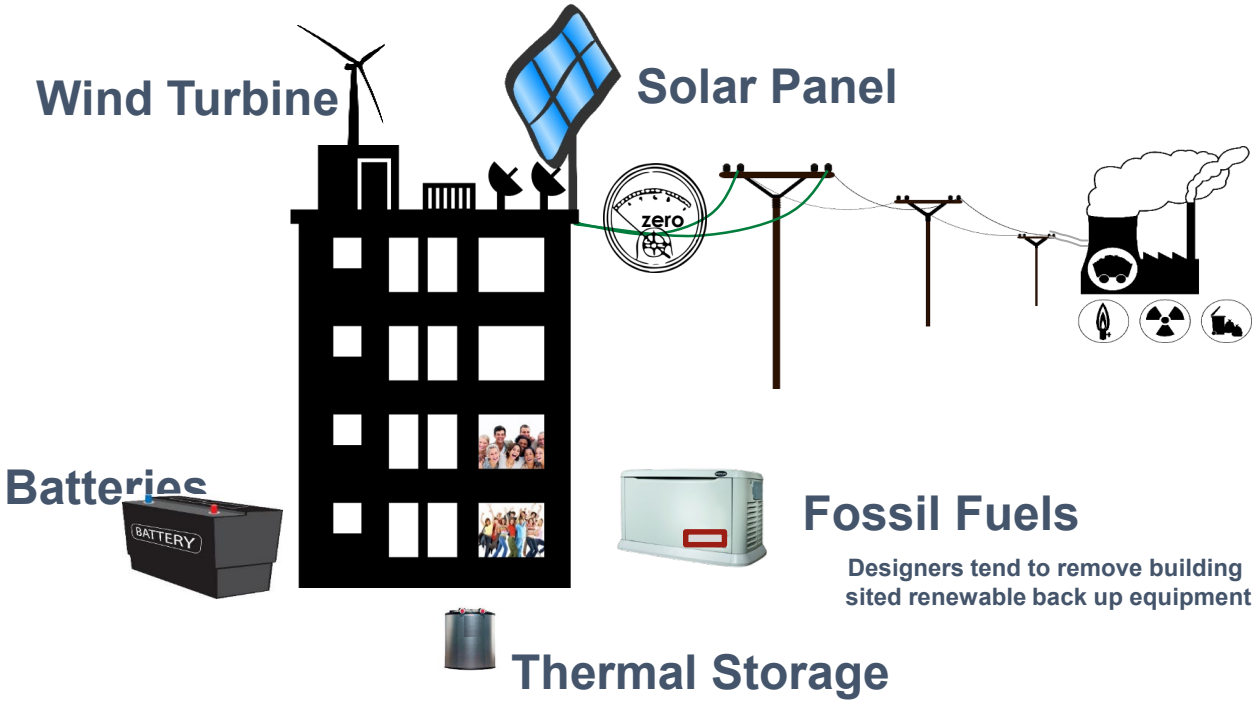



**Energy flows mostly one way**

# Modern Grid


Electron Battery
Photovoltaic Panels
Photovoltaic Panels
Thermal Batteries
Wind Turbines
Thermal Batteries
Electron Battery
Microgrid
Control Center
Information Flow
Energy Flow
Wind Turbines
Energy Storage System
Photovoltaic Panels
Smart Microgrid
Breaker
Main Grid

# (Net) Zero Energy Building:



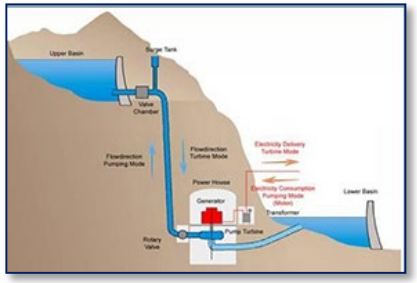
# Many types of Energy Storage will be needed on both sides of the electric meter for Renewable Energy, Net Zero Buildings and the Grid to Function Reliably

**Electric Meter**

| Grid Side | Building Side |
| --- | --- |
| Pumped Hydro | Chemical Batteries |
| Compressed Air | Thermal Mass (passive) |
| Fly Wheels | Thermal Batteries (active) |
| Super Capacitors | |

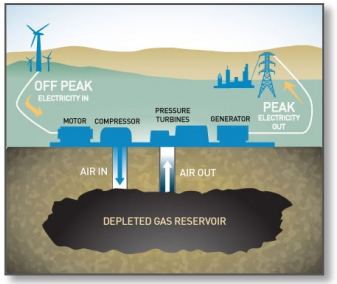
# Grid Side (of meter) Energy Storage Technologies

Pumped Hydro




Battery

Compressed Air

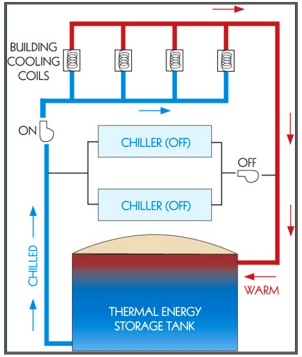


Flywheel

# Building side (of meter) Energy Storage Technologies

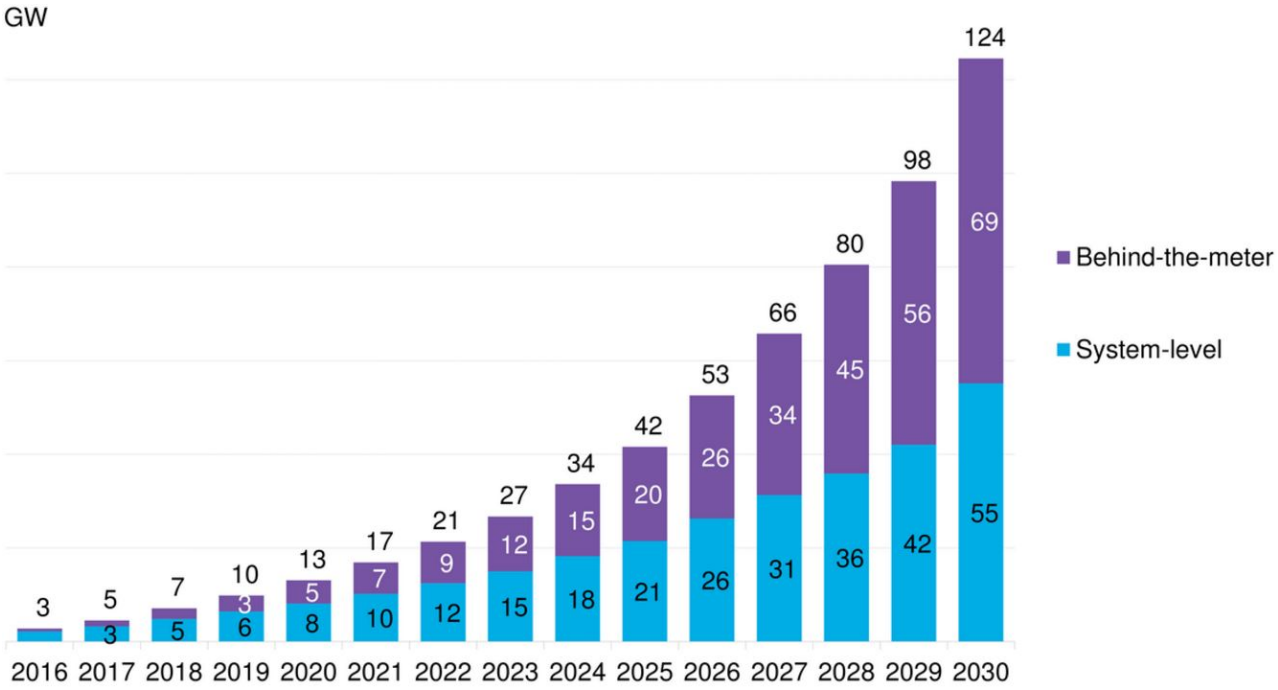
## Battery

## Thermal Energy Storage (TES) Hot, Cold or Ice, Active or Passive



# Buildings becoming part of the storage and distribution system

**BNEF projections of storage deployment over the next decade**



# Thermal Storage

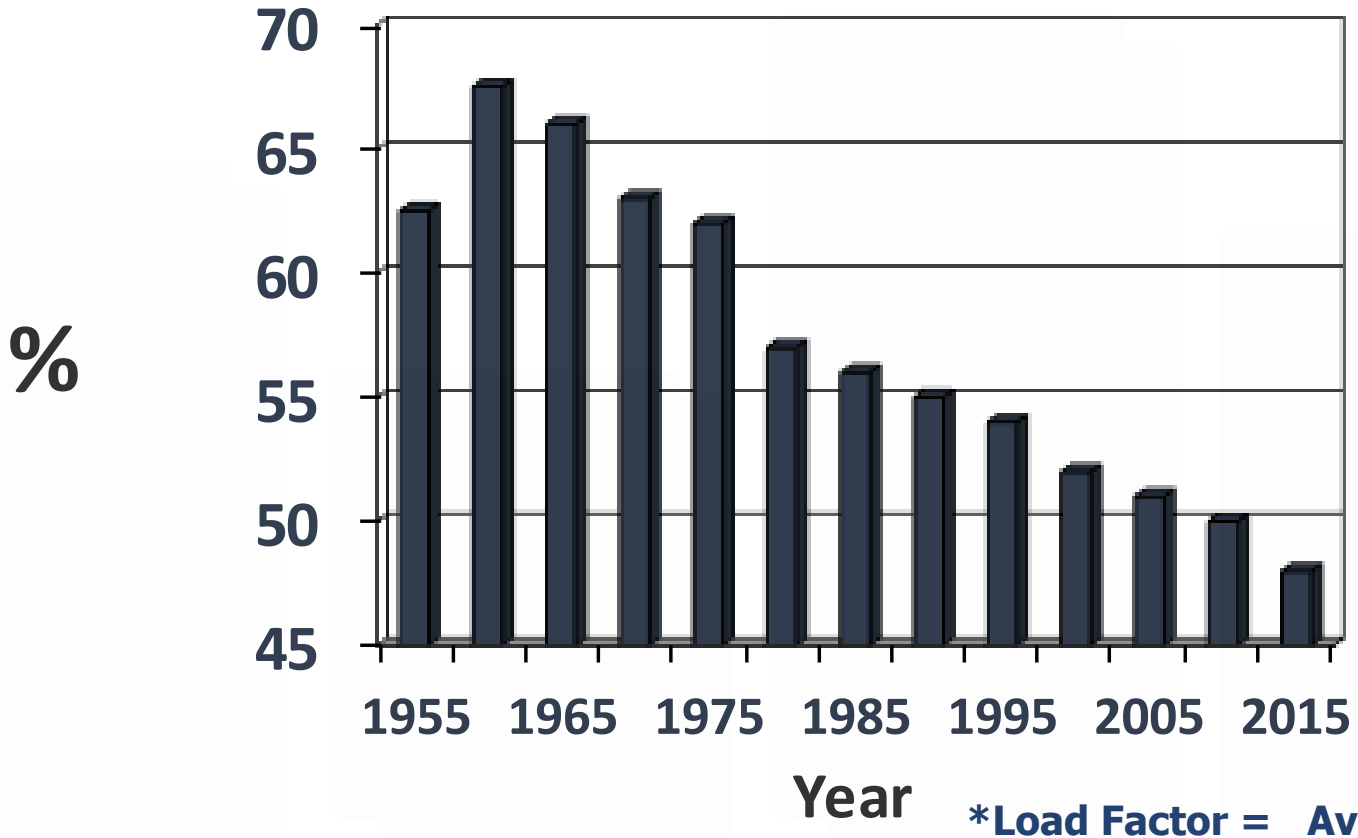
How many lbs. of ice do you need for each person for their drinks at a party? **~1 lbs.**

How many lbs. of ice do you need for each person each day at the office to cool them?

| | | | |
|---|---|---|---|
| **Architect** | **100 $ft^2$/per person** | **200 $ft^2$/per person** | |
| **Engineer** | **300 $ft^2$/ton** | **400 $ft^2$/ton** | **500 $ft^2$/ton** |

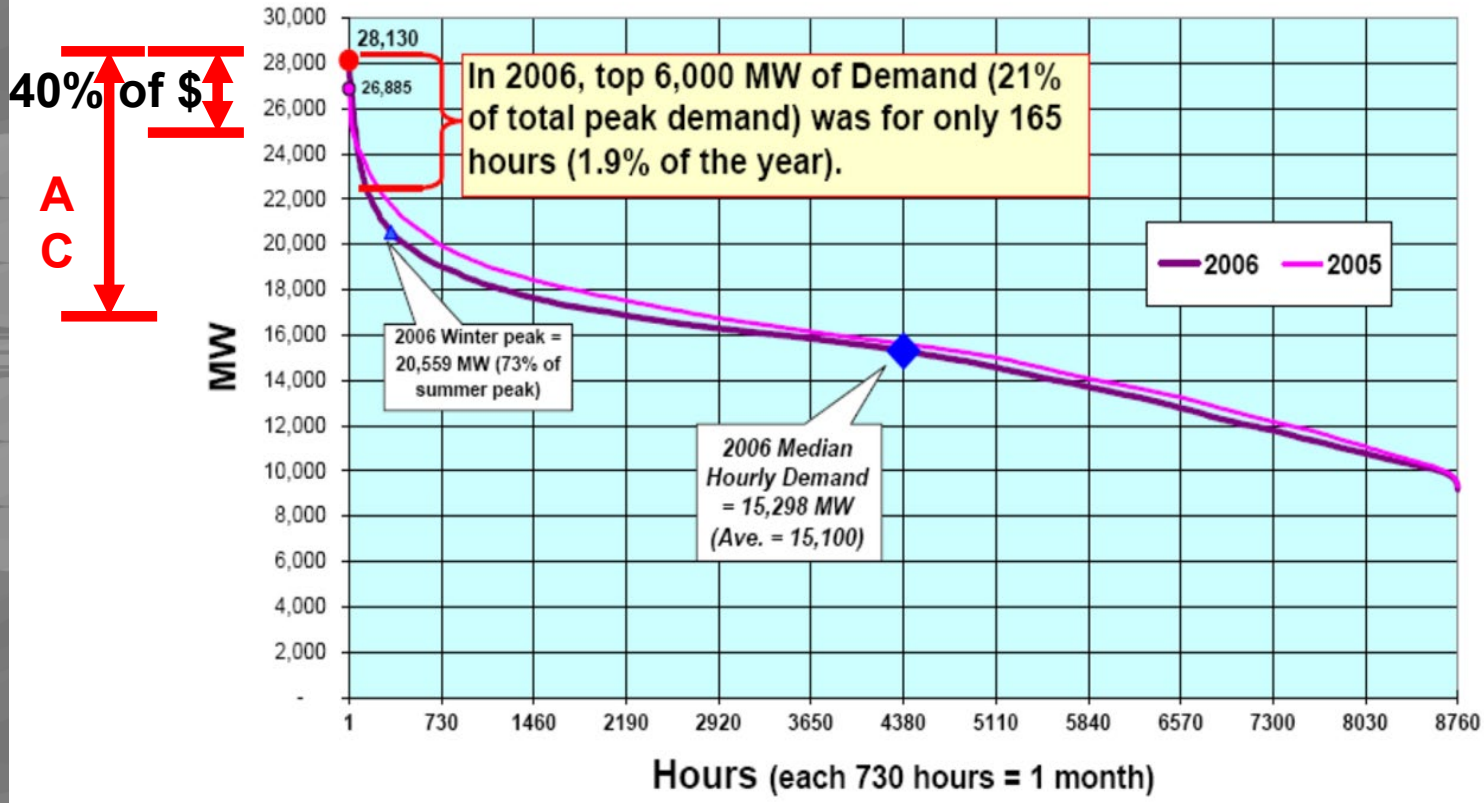
**100 $ft^2$/pp / 400 x 8hr = 2 ton-hrs. = 160 lbs. of Ice/Person/Day**
**200 $ft^2$/pp / 400 x 10hr = 5 ton-hrs. = 400 lbs. of Ice/Person/Day**

# Utility Load Factors* in the USA



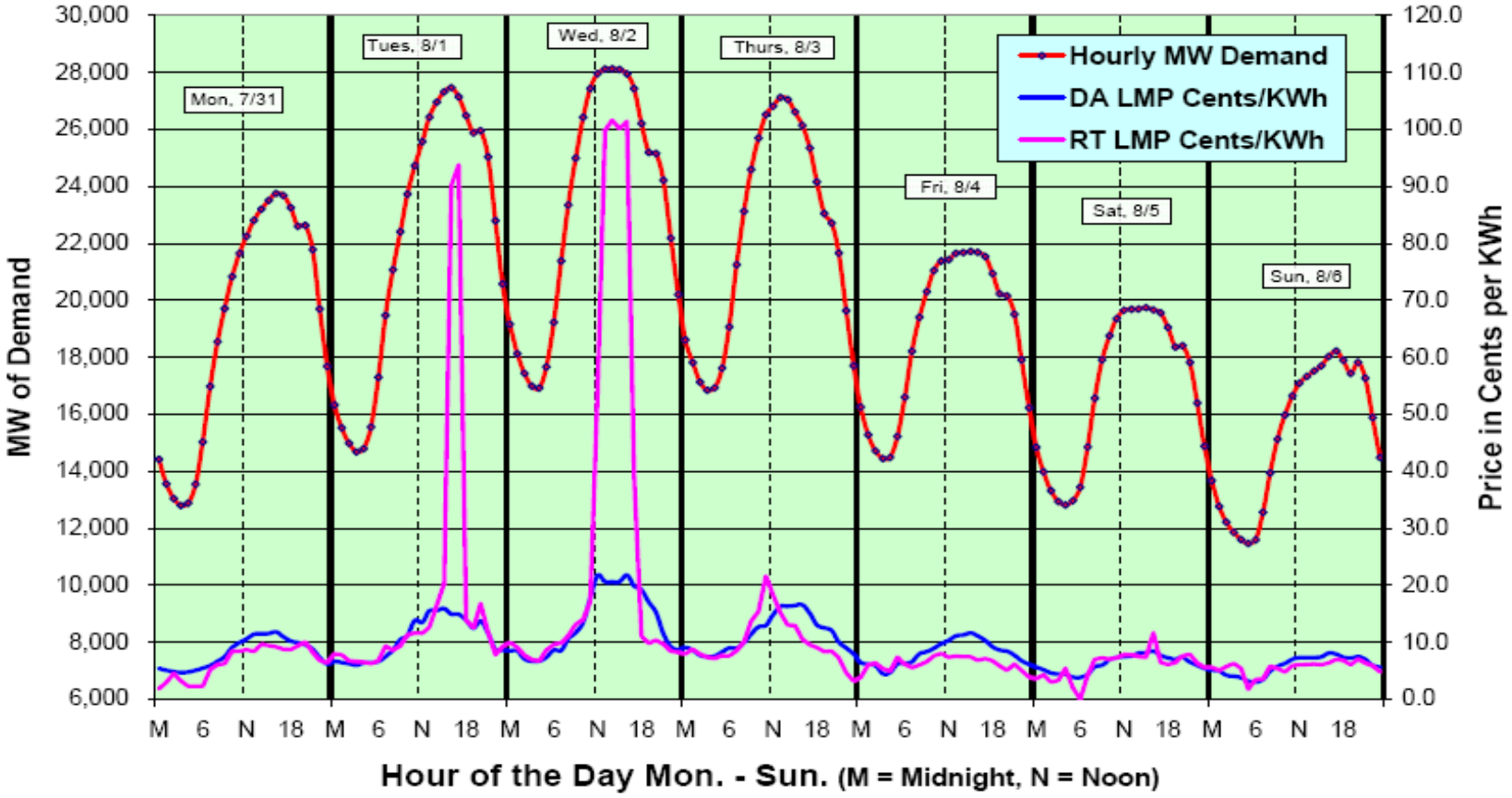

$$*\text{Load Factor} = \frac{\text{Avg. Load}}{\text{Peak Load}}$$

# 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

## Daytime

$ 2.49/gallon

## Nighttime

$ 0.99/gallon

**When Would you Fill-up?**

# The Demand Charge Effect Simplified

**Tucson Energy LSG -13 Rate**

Energy (usage):

Day: ~~$0.054/kWh~~ **$0.146/kWh**

Night: ~~$0.054/kWh~~ **$0.054/kWh**

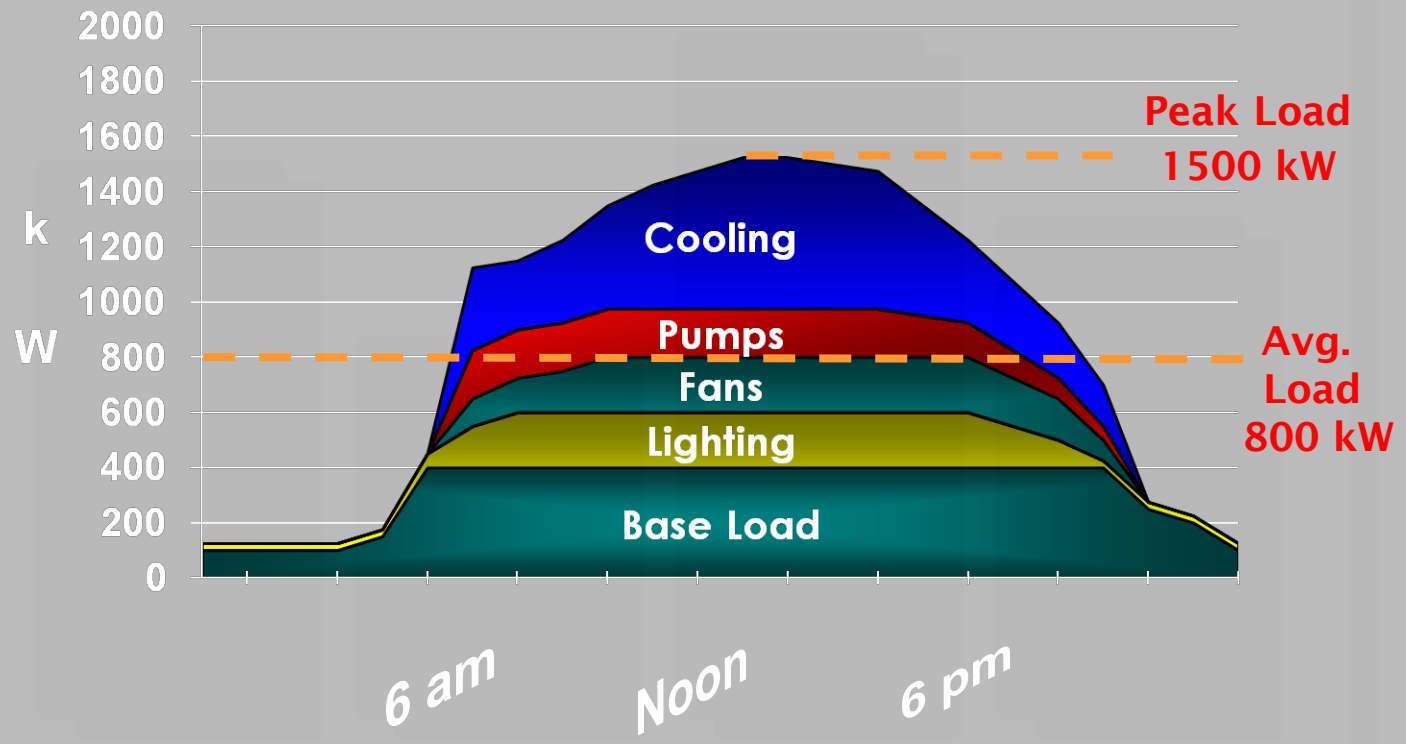
Demand: $15 ~~25/kW/Month~~

**How big an effect is the Demand Charge??**

**Energy is 63% less expensive at night**

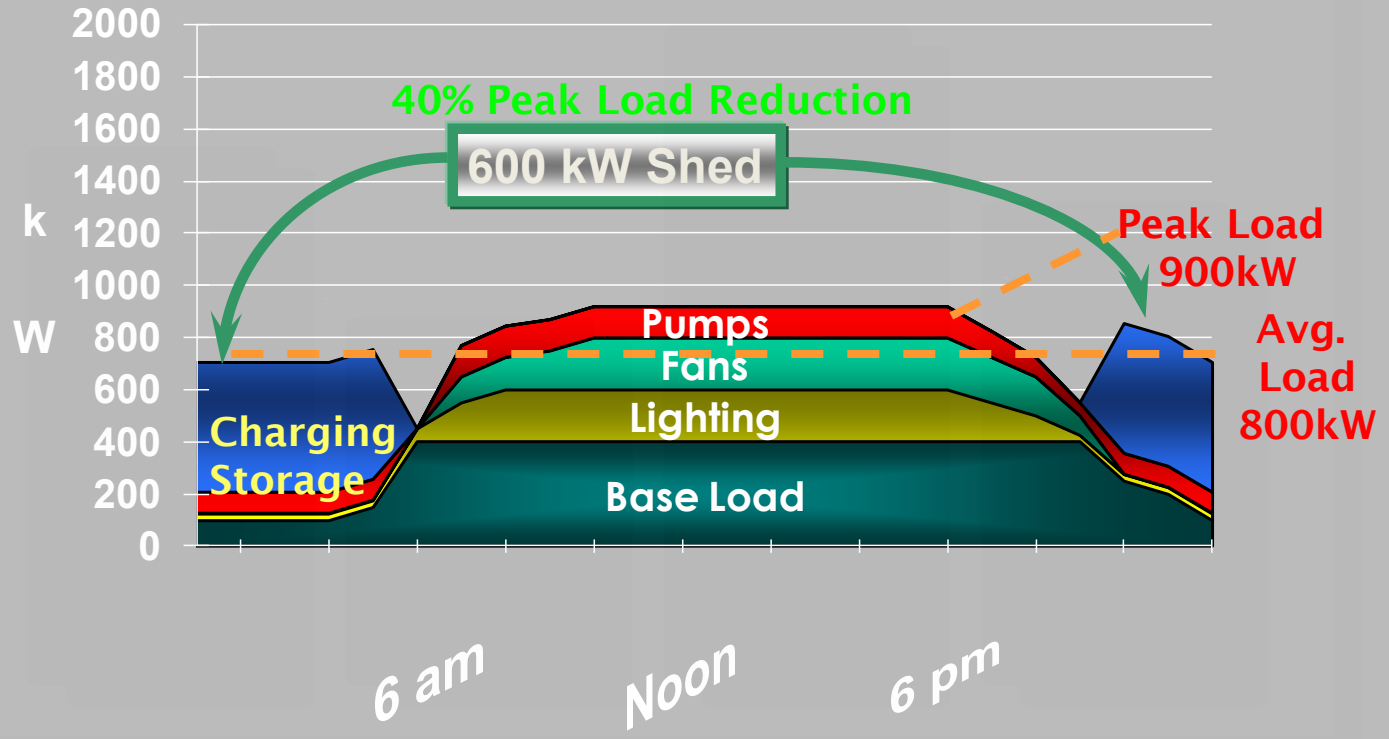
For a daytime peaking building

# ASHRAE 90.1 Building Electrical Profile



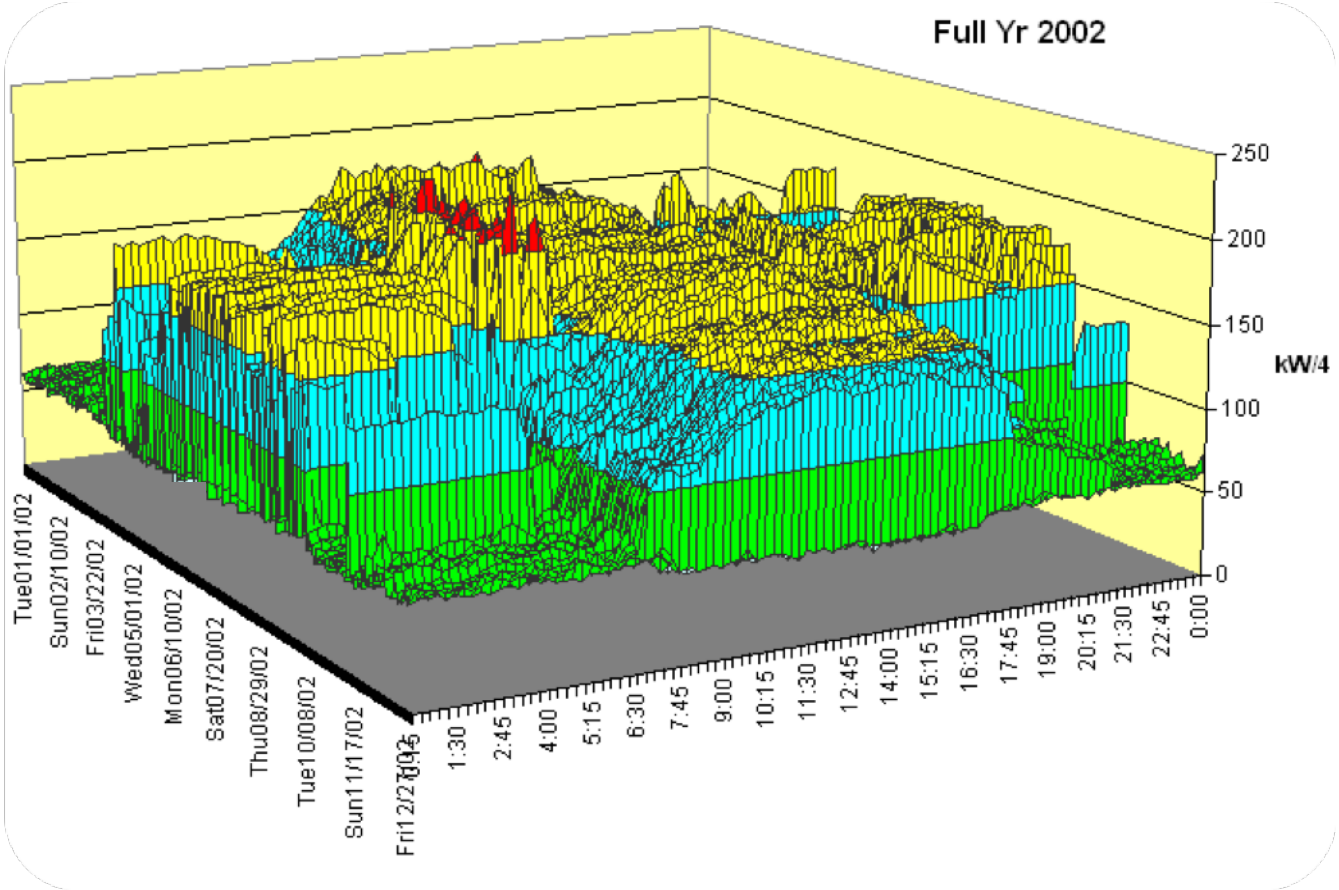

Total kWh = 19,200/day (Load Factor = 53%)

# ASHRAE 90.1 Building Electric Profile with Thermal Energy Storage




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

# 3D Electric Profile, Full Year

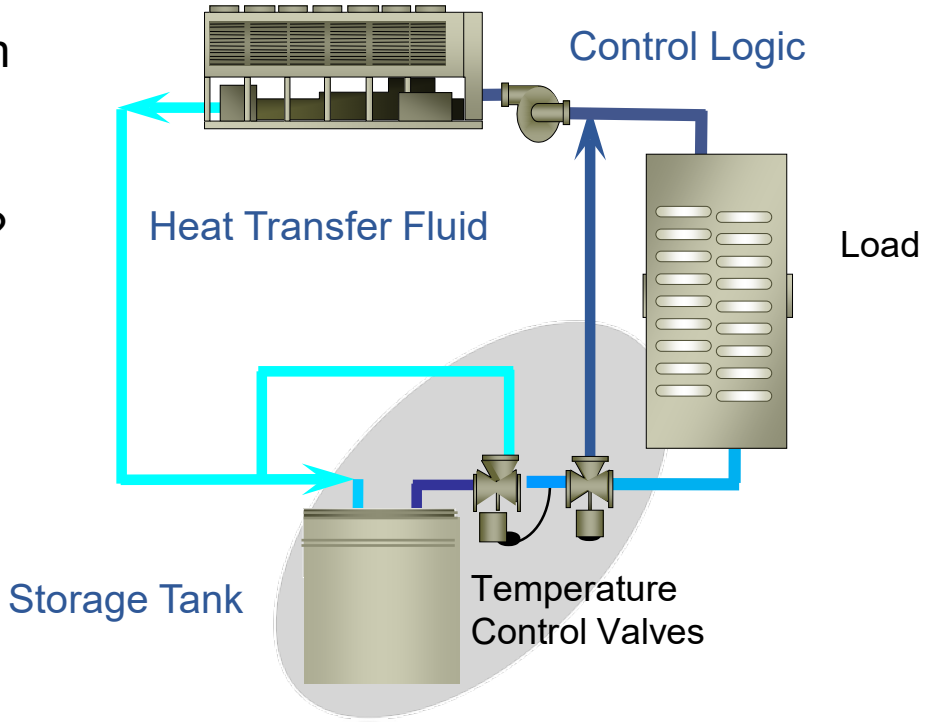


# Ice Storage Systems

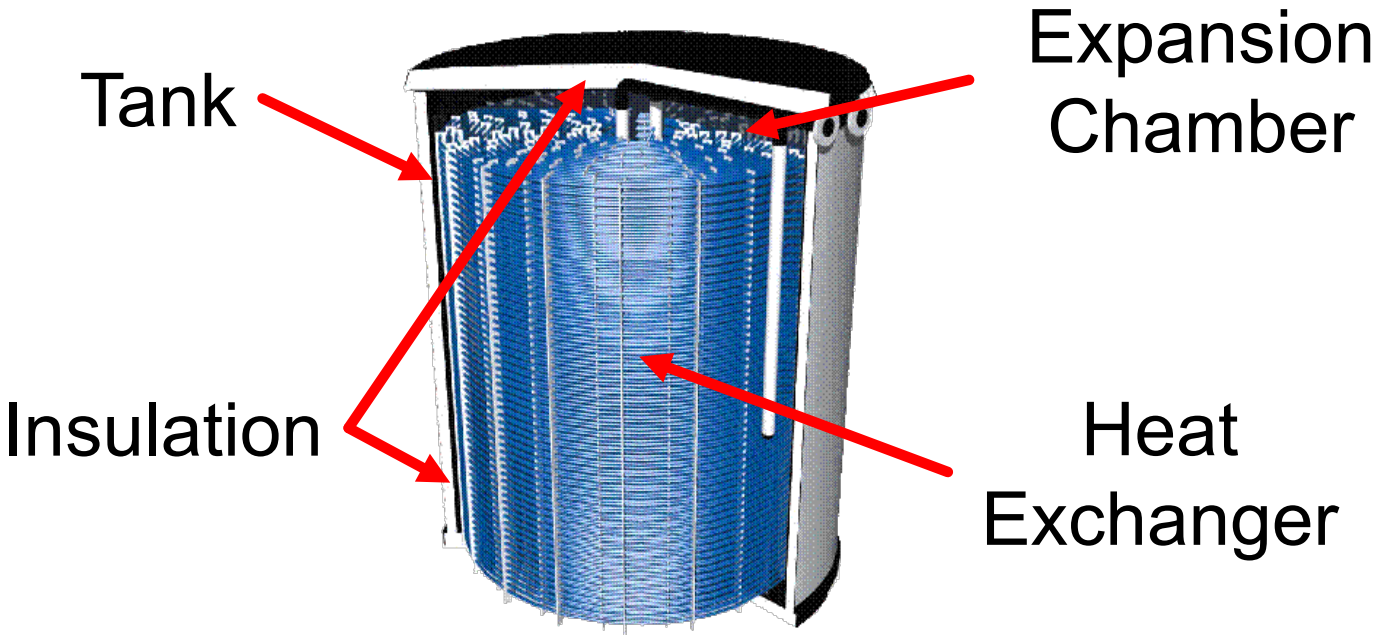
Chiller Based System

Closed System

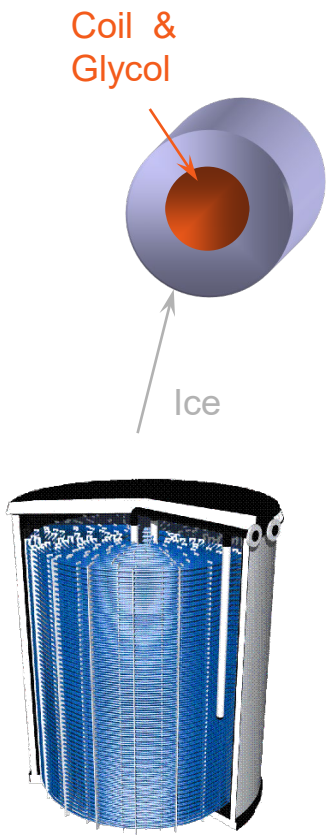
So What is Different?

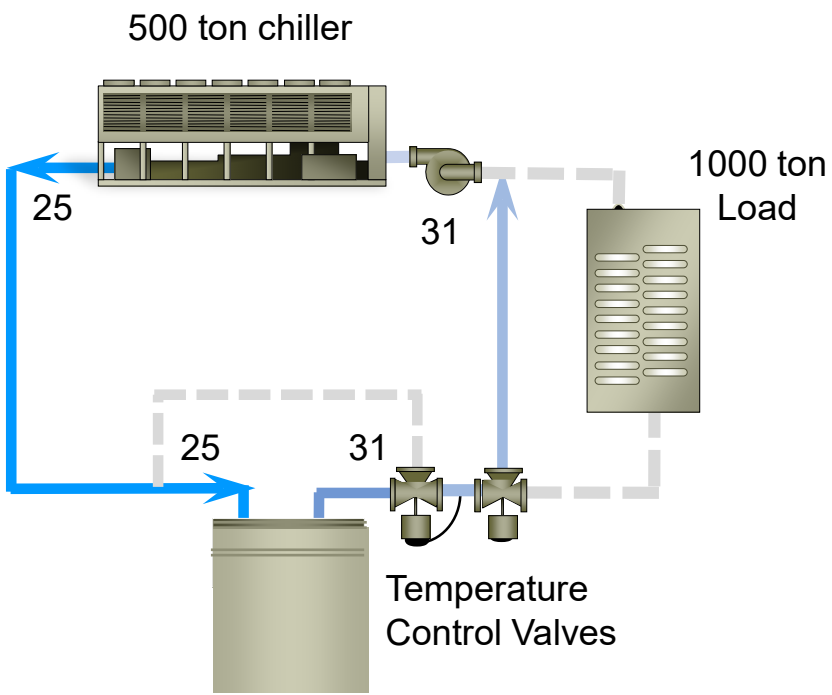


# Thermal Storage Tank Ice-on-Coil Internal Melt

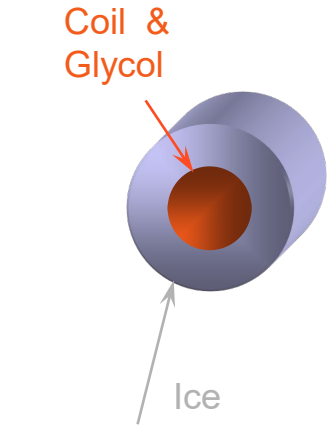


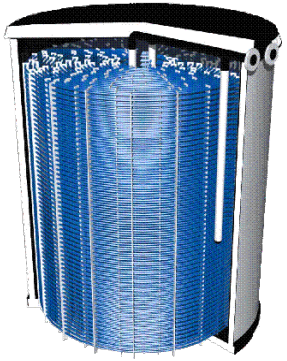
# Ice Making

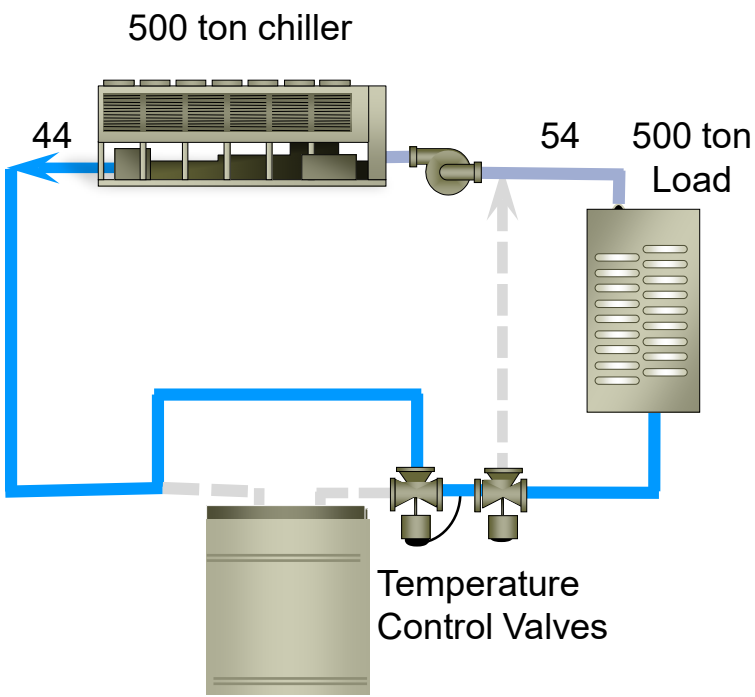

Coil &
Glycol
Ice


500 ton chiller
25
31
1000 ton
Load
25
31
Temperature
Control Valves

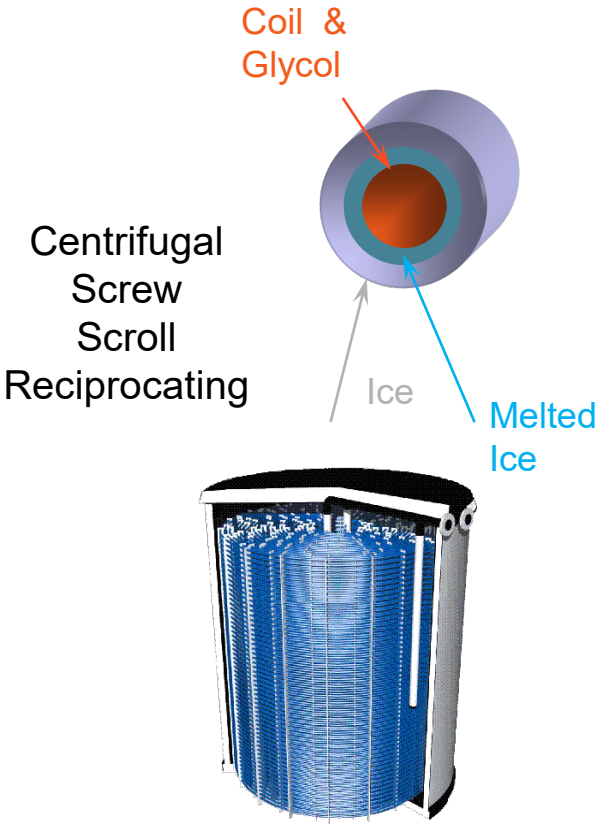
# Direct Cooling

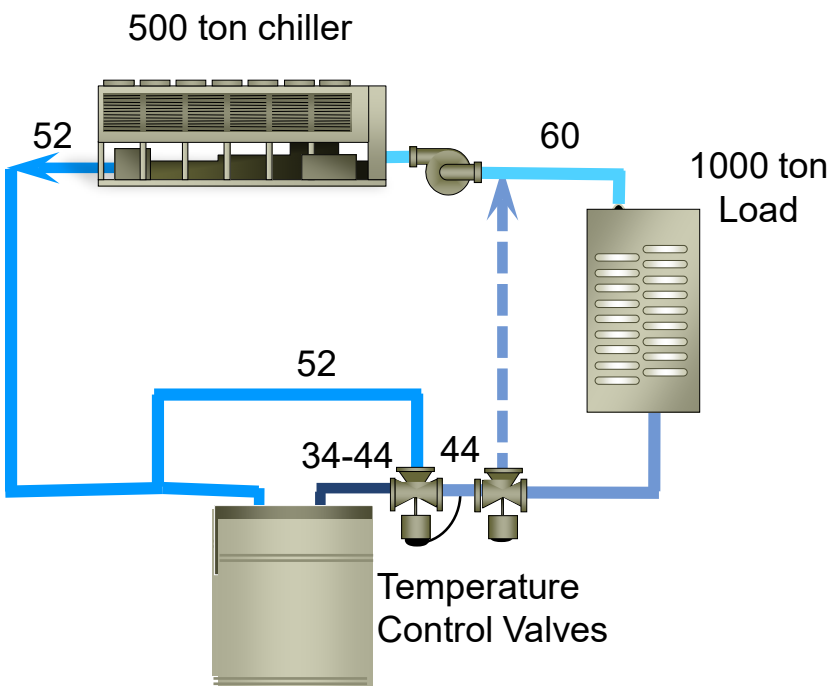




# Ice Melting and Chilling

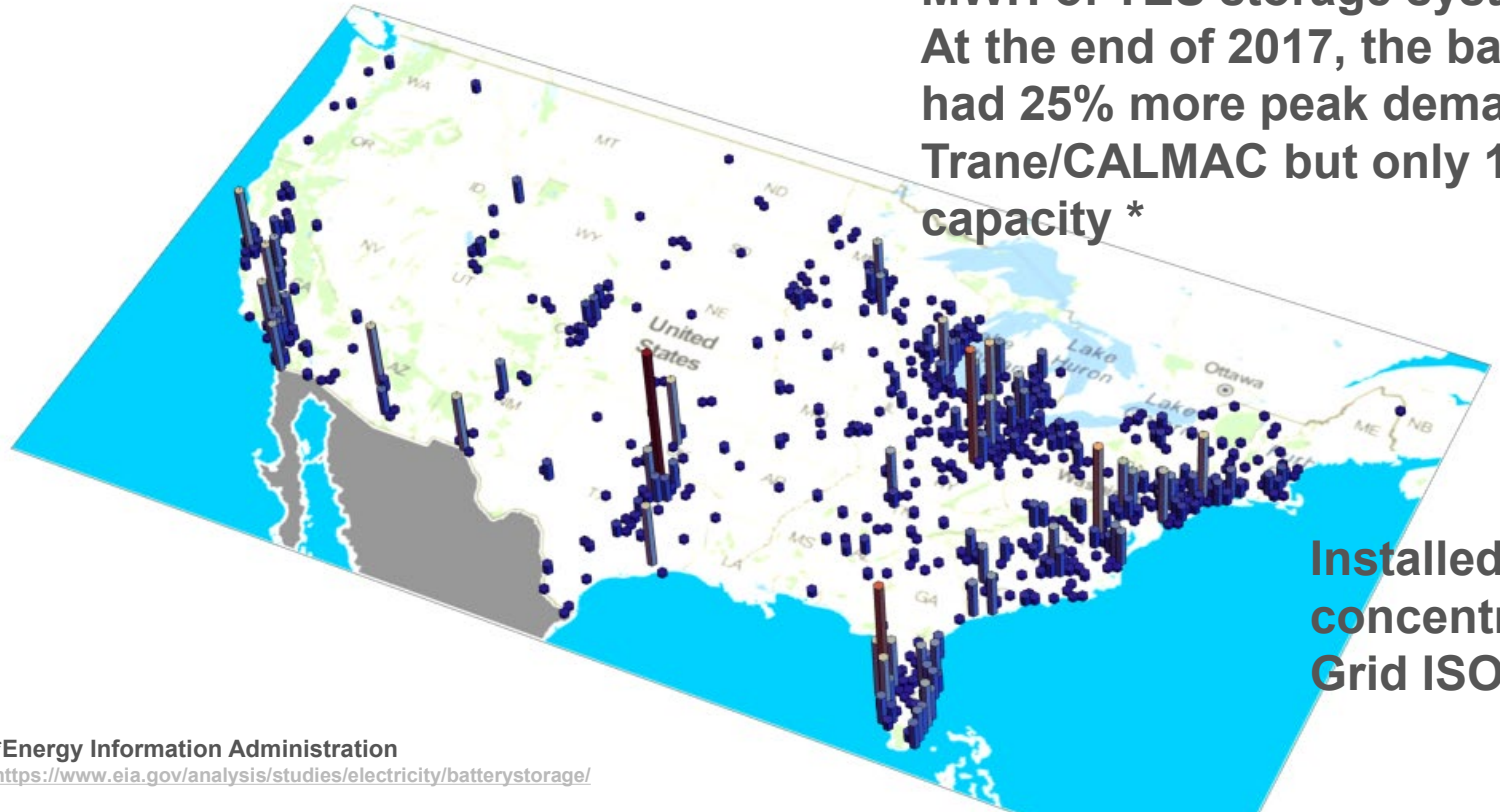


# Jefferson Community College-Watertown, NY

# 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!

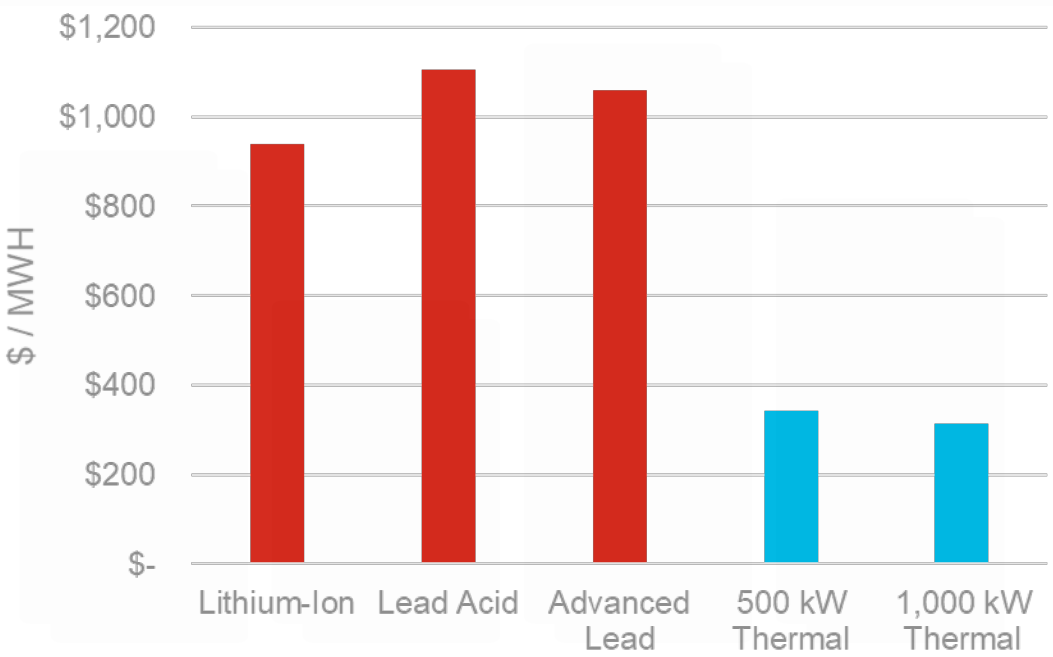
*Energy Information Administration
https://www.eia.gov/analysis/studies/electricity/batterystorage/

# NYC Thermal Battery (Ice) Installations

## ~ 120 Megawatt-hrs. of Energy Storage

# TES is 1/3 the cost of battery systems for C&I

## Levelized Technology Cost for BTM Applications[1,2]




- Cost advantages
  - ✓ No inverter expense
  - ✓ Lower component costs, including balance of system; lower O&M
  - ✓ No need for capacity addition due to degradation
- Lower capital costs mean lower financing costs

1. Costs represent average of range pulled from LCOS 3.0 for battery technologies.
2. Conservative case that includes full cost of chiller.

Source: Ingersoll Rand

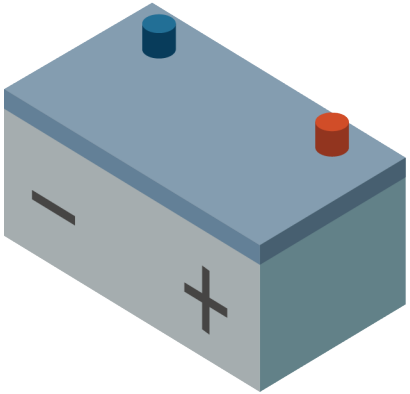
# Energy Storage Options Costs*

| Energy Storage Technology | Tech Maturity | Useful Eff (%) | Life (Yrs.) | Capital Costs ($/kWh) |
|---|---|---|---|---|
| Pumped Hydro | mature | 70-80 | 40+ | 310-380 |
| Na-S Batteries | mature | 80 | 5 | 650-700 |
| Lead-acid Batteries | mature | 85-90 | 7-15 | 500-750 |
| Li-Ion Batteries | new | 80-90 | 7-10 | 450-1125 |
| Flywheels | new | 90 | 20 | 7800-9000 |
| Compressed Air | demo | 70-80 | 40+ | 80-150 |
| **Thermal Storage** | **mature** | **90-100+/-** | **50+** | **30-500** |

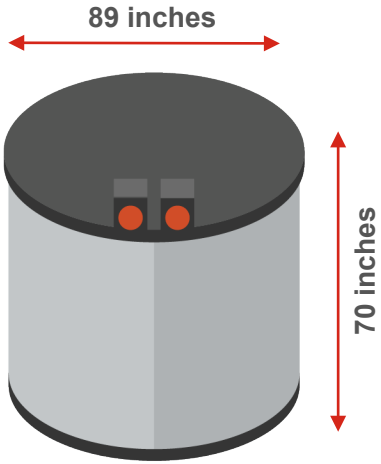
**Thermal Energy Storage (TES) has low initial cost, high efficiency, and longer useful life**

*Data gathered by ASHRAE TC 6.9 members from published industry articles in past 3 years

# Chemical Battery vs with Thermal Storage (Battery)



18 kW shift over 3-6 hours




18 kW shift over 6 hours
Cool 7,500 sq. ft. 6-8 hours

# Comparison Costs*

| | Equip | Hours of discharge | Impact Output | kWh per day | Installed cost | Cost / kW | Cost / kWh |
|---|---|---|---|---|---|---|---|
| **Ice Storage** | Qty-1 Ice Tank | 1 Ice Tank discharging over 6 hrs. | 18 kW Cooling | 108 | $22,000 $7,000 | $1,222 / kW $ 388/ kW | $ 203 / kWh $ 64 / kWh |
| **Battery** | Qty. 6 18 kWh Batteries | 6 Batteries discharging over 6 hrs. | 18 kW Electron | 108 | $100,000 | $5,600 / kW | $925 / kWh |
| **Battery** | Qty-3 18 kWh Batteries | 3 Batteries discharging over 3 hrs. | 18 kW Electron | 54 | $50,000 | $2,800 / kW | $925/ kWh |

* COSTS ARE APPROXIMATE AND VARY BY LOCATION AND PROJECT

# Commercial Building Example

| | Equip | kW | kWh per day | Installed cost | Cost / kW | Cost / kWh |
|---|---|---|---|---|---|---|
| **Ice Storage** | (20) Ice Tanks | 360 | 2160 | $440,000<br>$140,000 | $1,222<br>$ 388 | $ 203<br>$ 64 |
| **Battery** | (60) 18 kW Batteries | 360 | 1080 | $1,000,000 | $2,800 | $925 |
| **Ice with Battery** | 14-1098 Ice tanks with 20 -18kW Batteries | 360 | 1872 | $641,000<br>$441,000 | $1,780<br>$ 1,226 | $342<br>$236 |

* COSTS ARE APPROXIMATE AND VARY BY LOCATION AND PROJECT

# Incentive Programs*

1. New York City (ConEdison)
- $50+ per kW demand charge – #1 in nation
- As of 4/24/2019 new Incentive structure ($1,400/kW for 4-hr duration)

2. Boston, MA (Eversource)
- $40/kW demand charge – #3 in nation
- Incentive money may soon be made available through the Mass Dept. of Energy Resources

3. Long Island, NY (PSEG LI)
- $30/kW demand charge
- $1000 per kW rebate from the utility; additional rebates very likely coming from NYSERDA

4. Florida (FP&L)
- $12/kW demand charge, 3 cent day/night delta
- $600 per kW incentive from FP&L

5. North Carolina (Duke Energy, Duke Progress, various municipal utilities)
- $12-14/kW demand charges across both Duke-owned utilities, and available thermal storage rates
- $150 per kW incentive from Duke

6. Minnesota (Xcel, various municipal utilities)
- Xcel has $16/kW demand charges, large delta between on-peak and off-peak kWh, and available incentives

7. Texas (Austin Energy, Oncor, El Paso Electric, CenterPoint)
- Incentives across most of the larger utilities
- Austin Energy and El Paso Electric have excellent rates for TES

8. Connecticut (United Illuminating Co., Eversource CT)
- $18-25/kW demand charge; ability to negotiate better rate with better load profile
- Opportunity to negotiate better rates with higher load factor

9. Colorado (Xcel territory)
- Xcel has $20+/kW demand charges, low energy (kWh) charges.
- New custom thermal storage incentive, $500/kW shifted from 2pm to 6pm, summer months

*10. Michigan (Consumers Energy, DTE)
- Consumers Energy, which covers much of the state, has $25/kW demand charge

***Programs change often-Check websites for current details**

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# Modeling Thermal Energy Storage

Karl Heine
Colorado School of Mines

# Agenda

1. Motivation: Modeling Challenges
2. Improving the Models
3. Identifying Potential Benefits
4. Example Results
5. Distributed Ice Storage Systems

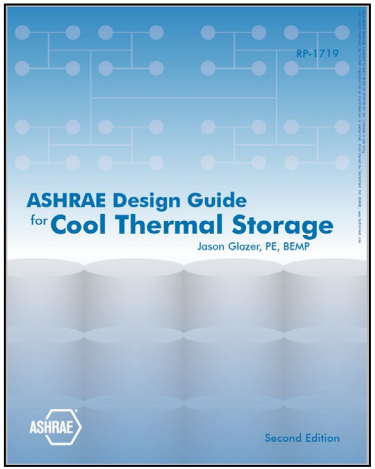
# Modeling Challenges

- Models are Tedious to Build
  - TES is ignored as a design option
- Implementing Control Strategies Not Obvious
  - “Optimal” operating points unidentifiable
  - Imposing power limits on hardware not easy
- Limited Performance Data Available
  - Generic curves used

# Improving Models

- Goal: Make ASHRAE Design Guide for Cool Thermal Storage recommendations available to energy modelers using EnergyPlus
  - Design Configuration Options
  - Storage Objective Options
  - High-level Operating Strategy Options
  - Provide Load Limiting Options on Chiller

- Method: OpenStudio Measure Scripting



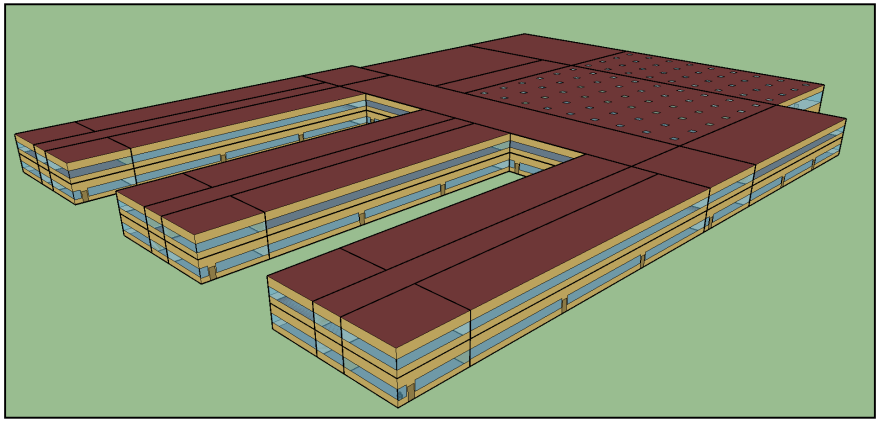

ASHRAE Design Guide for CTES

# Potential Benefits of Ice Thermal Storage

- Chiller Downsizing
  - Reduced Capital Costs
  - Higher Average Part-Load Operation
- Improved Average Efficiency
- Reduction in Annual Electricity Use!
- Effective Load-Shifting Out of On-Peak Hours
- Controllable Energy Storage

# Example Results
# Central Ice

- School with Air-Cooled Chiller in Houston (TMY3)
- DOE Prototype 90.1-2010 Model



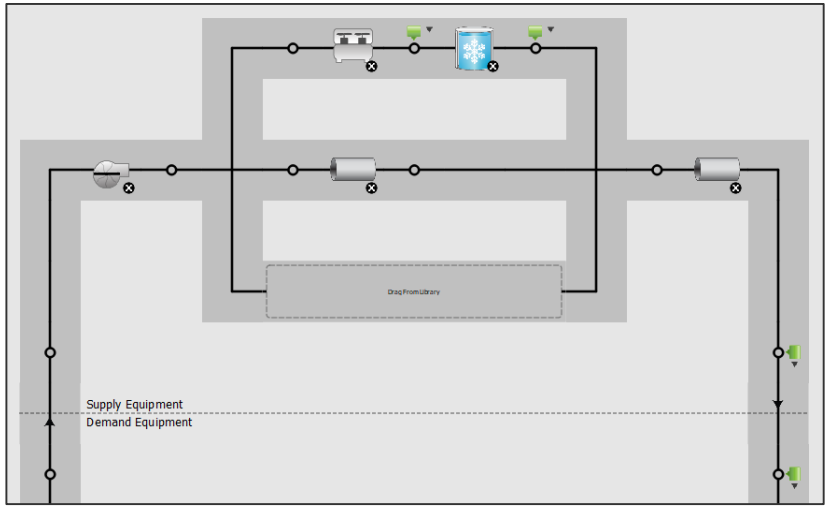
https://www.energycodes.gov/development/commercial/prototype_models

# Example Results
# Central Ice

Model Articulations:

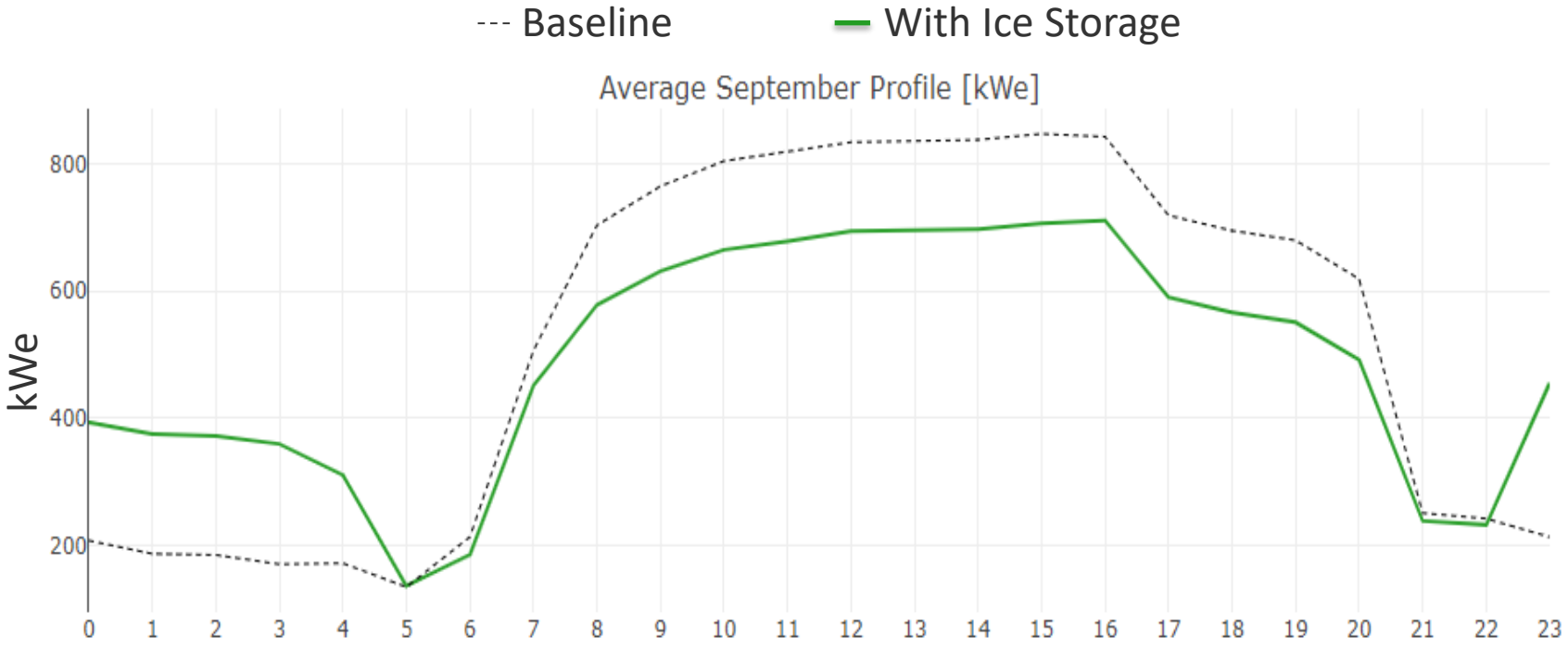
- Hardware:
  - Chiller Downsized by 30%
  - 2000 Ton-Hours of Ice
  - Chiller Upstream

- High-Level Control Strategy:
  - Ice Priority up to 30% of Design Load
  - 0800-2000 on Weekdays

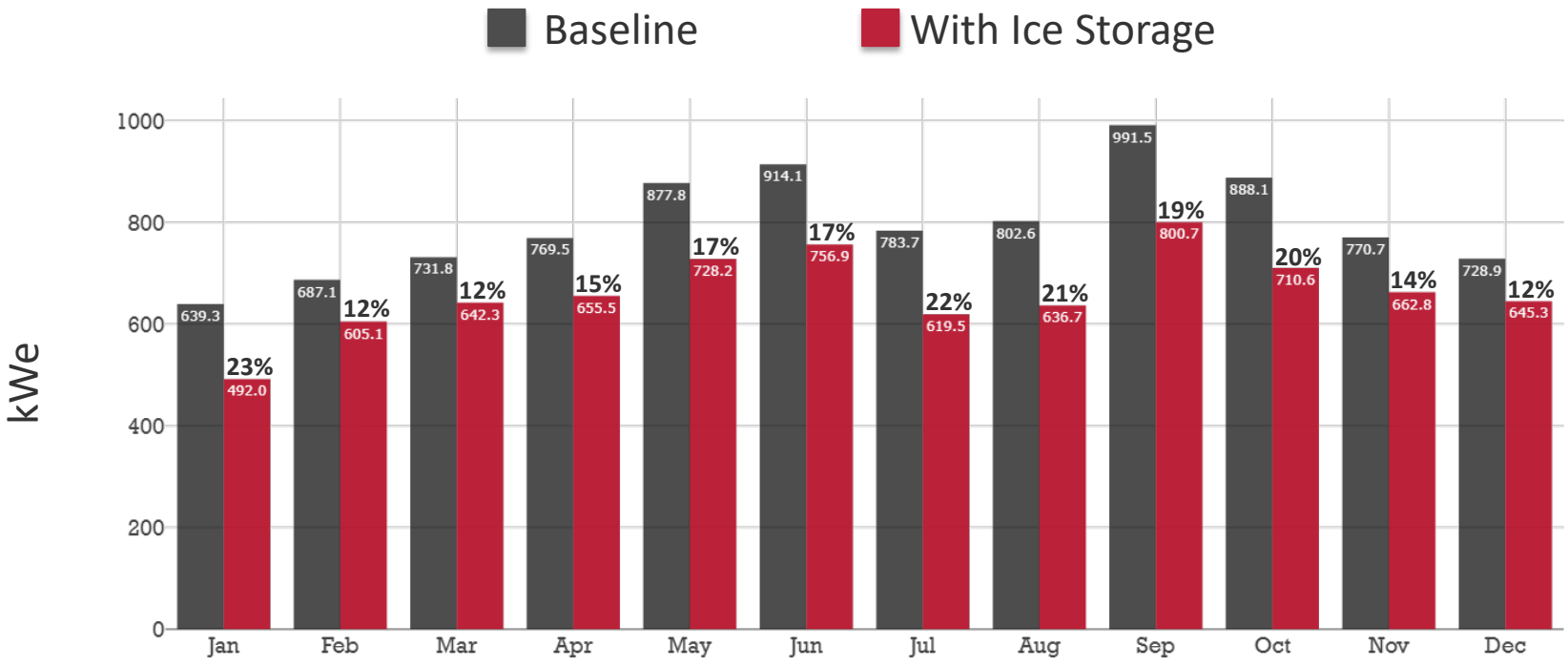



- Chiller Limit: 65% of Nominal Capacity During Ice Discharge

# Average Daily Profile for Facility Electric Load



# Maximum Monthly Facility Electric Demand



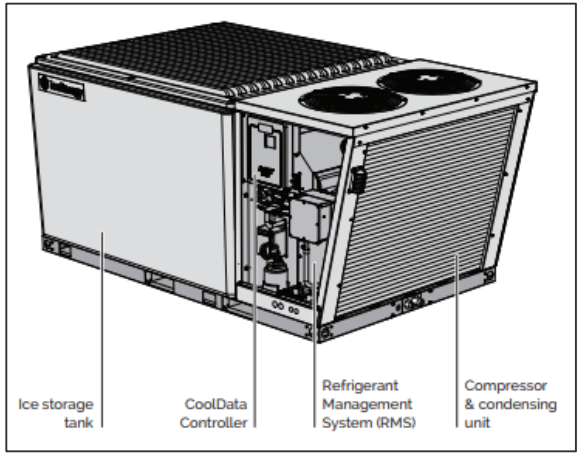
# Results Summary

| Model | EUI [kWh/m$^2$] | Average Peak Demand [kW] | Chiller Annual Electricity [MWh] | Chiller Average COP | Chiller Runtime Hours |
|---|---|---|---|---|---|
| School Baseline | 157.7 | 799 | 973 | 2.55 | 5947 |
| School With Ice* | 150.5 (-4%) | 662 (-17%) | 845 (-23%) | 3.07 (+20%) | 5768 (-3%) |

* Includes downsized chiller yet produced no change in unmet-hours compared to baseline model.

# Distributed Ice Storage

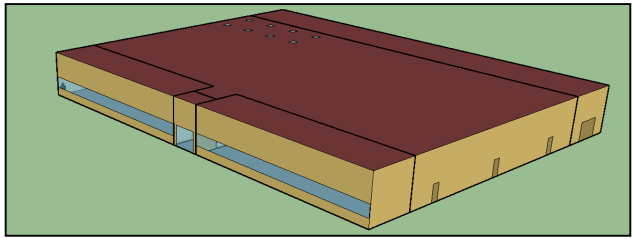
- Unitary Thermal Storage Systems (UTSS) provide smaller-scale, distributed ice storage solutions
- 40 ton-hours of storage
- Compatible with 3-20 ton AC units
- 4-6 hours of shifted cooling load
- Adds cooling coil to air stream



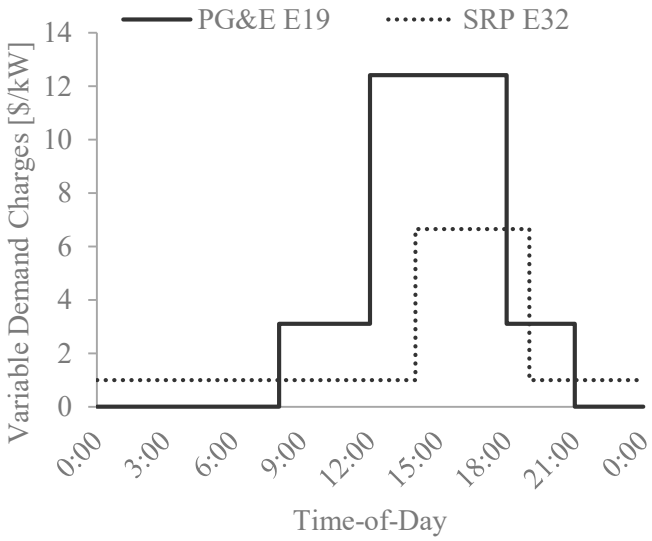

www.ice-energy.com

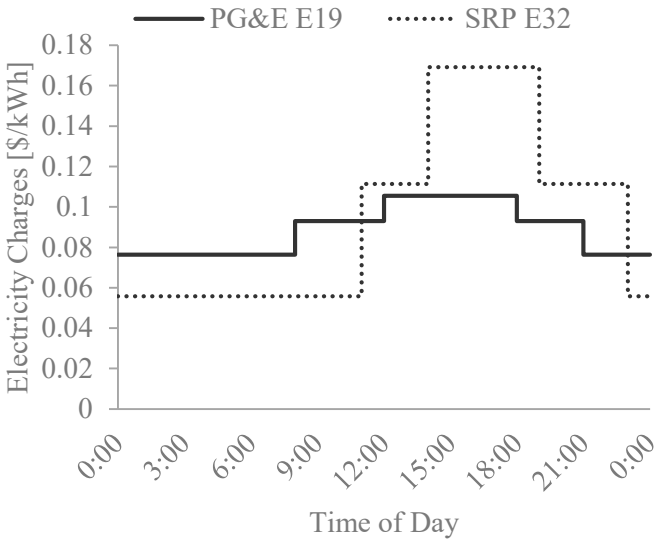
# Example Results Distributed Ice

- Stand-Alone Retail with 4 RTU's
- DOE Prototype Models in 15 Climate Zones (TMY3)
- Ice Batteries Added to Each RTU
- Sized to Meet Climate Zone-Specific Loads
- Utility Rates with 5-6 Hour Daily On-Peak Price Periods

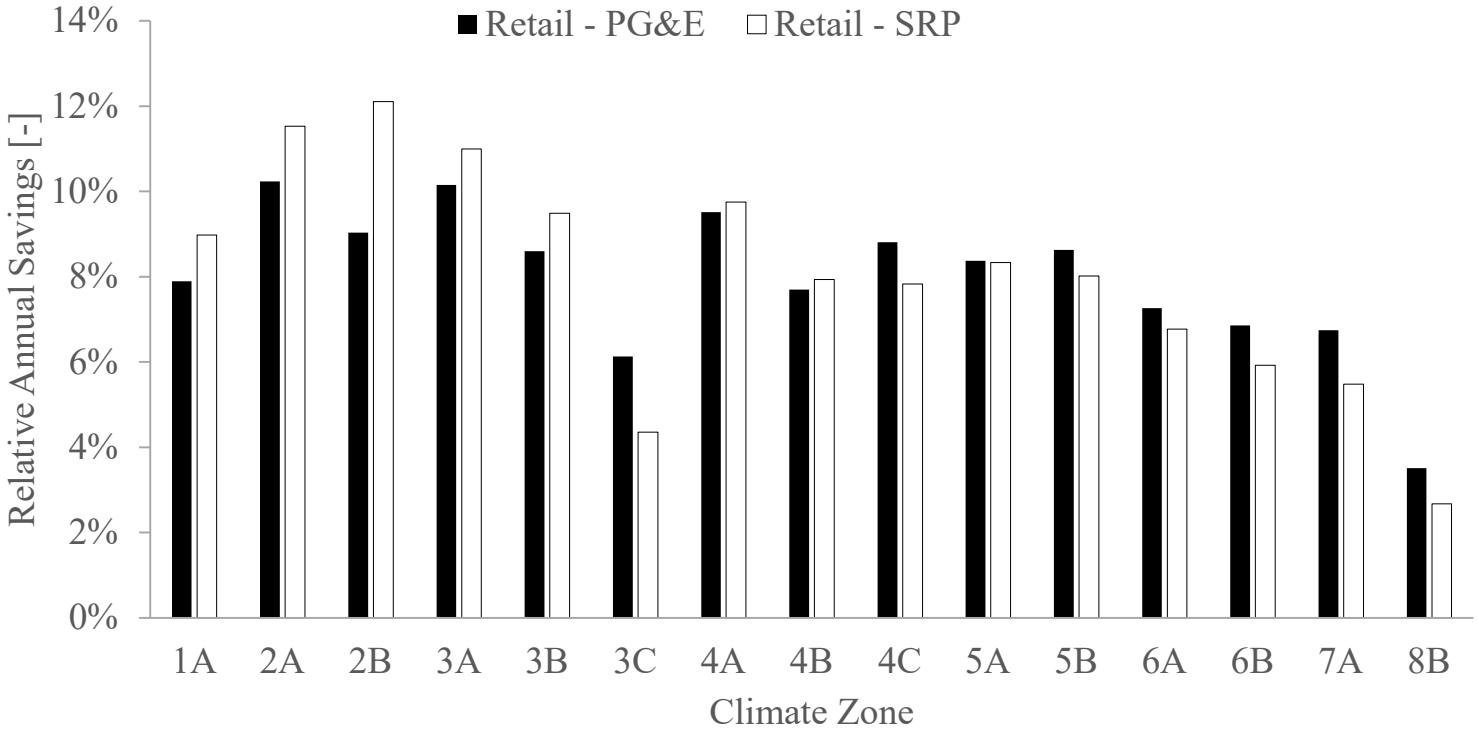


# Economic Impact of Distributed Ice Storage



# Electricity Bill Savings with Distributed Ice



# Summary

1. Modeling Challenges
2. Improving the Models
3. Identifying Potential Benefits
4. Example Results
5. Distributed Ice Storage Systems

# Questions?

Karl Heine

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# Looking ahead

We are mapping out our upcoming year and looking for feedback

- Thermal Energy Storage Landscaping Study
- GEB RFI Field Study Participants
  - Joint RFI between the GSA proving grounds program and the DOE High Impact Technology Catalyst program and we are looking for active BB members who might want to participate in a field study focused on continuous demand management and building load flexibility
  - NEED by SEPT 6th - Please contact miles.hayes@nrel.gov