Diurnal Ice Storage and Other PCM’s

October 22, 2008

Hosted by:
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Calmac Manufacturing

and

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Richard Stockton College of New Jersey
Overview

1. Overview of latent heat storage
2. Example of Applications
   - PCM building structure
   - Adsorption cooling
   - Thermo-chemical
   - Use of solar and UTES
3. Case Studies of Ice Storage
Example of heat and cold load duration diagrams (Andersson, 2007)
Thermal Energy of Sensible and Latent Heat of Water

Heat effect (Btu)

Latent heat
Sensible heat
Advantage of Latent Heat Compared with Sensible Heat Storage

- Latent Heat: 318 Btu
  - 2.2 lb Ice at 32 °F

- Sensible Heat: 318 Btu
  - 2.2 lb Water at 32 °F
  - 2.2 lb Water at 176 °F
Load Shifting Strategies from On-Peak to Off-Peak
Ice storage technologies commonly used

- Ice-on-coil
  - internal melt
  - external melt
- Ice slurry
- Encapsulated ice
Three Types of Ice Storage systems

(a) Ice on coil  
(b) Slurry  
(c) Encapsulated
Amount of material required for equivalent thermal mass

- gypsum
- wood
- concrete
- sandstone
- brick
- PCM
## Examples of Commercial PCM’s (see [http://www.fskab.com/Annex17/](http://www.fskab.com/Annex17/))

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Candidate

Flat plate collector

Source:
J. van Berkel, NL
**Thermal Energy Storage Technologies:**

- **Storage of Sensible Heat**
  \[ \approx 100 \text{ MJ/m}^3 / 40 \text{ m}^3 \]

- **Storage of Latent Heat**
  \[ \approx 300 - 500 \text{ MJ/m}^3 / 2.5 \text{ m}^3 \]

- **Thermochemical Heat Storage**
  \[ \approx 1000 \text{ MJ/m}^3 / 1 \text{ m}^3 \]
PCM as part of the interior surface of the building envelope
PCM used as an integral part of the building thermal envelope
Calorimetric data for microencapsulated PCM used during ORNL field experiments. (Source: BASF. Used by permission.)
Heat flux measured during the dynamic hot-box experiment performed on a 2×6 wood stud wall containing PCM-enhanced cellulose insulation.
Peak-hour load reductions observed at Charleston site:

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<th>Month</th>
<th>June</th>
<th>July</th>
<th>August</th>
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<td>29%</td>
<td>31%</td>
<td>18%</td>
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Reductions in heating and cooling loads observed at Oak Ridge site:

**Cooling Load Reduction**

<table>
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<th>Season</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
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<tr>
<td>Reduction</td>
<td>65%</td>
<td>42%</td>
<td>75%</td>
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**Heating Load Reduction**

<table>
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<th>Season</th>
<th>Spring</th>
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<tbody>
<tr>
<td>Reduction</td>
<td>10%</td>
<td>50%</td>
<td>16%</td>
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Comparative costs of installing fiber insulation and XPS foam sheathing and thermally equivalent PCM-enhanced cellulose insulation
Schematic diagram of a building structure heat storage system (Yamahà et al., 2003)
Floor heating system developed by Rubitherm GmbH (http://www.rubitherm.de/)

storage material: a granulate infiltrated with paraffin
Types of Storage

- **Examples:**
  - Pumping Water
  - Fly Wheel
  - Chemical Reaction
Thermochemical

Change of Volume $\rightarrow$ Condensation

Reactor $\rightarrow$ Condenser

$Q \rightarrow B \rightarrow B_{\text{Cond}}$

$S \rightarrow Q'$

$S'$

$T_a$

e.g. chemical reaction $\text{Mg(OH)}_2 \leftrightarrow \text{MgO} + \text{H}_2\text{O}$
Closed System

**Charging**
- Reactor: Mg(OH)₂ → MgO + H₂O
- Heat Q
- Entropy S
- Water Vapor

**Discharging**
- Reactor: MgO + H₂O → Mg(OH)₂
- Heat Q
- Entropy S
- Water Vapor

Condensator
- Water
  - Q' → S'
  - Ambient

Evaporator
- Water
  - Q' → S'
  - Ambient / Low Temp.
LiCl commercial unit

- Thermal Storage Using the Thermo-Chemical Accumulator
- Thermochemical Storage for Air-Conditioning Using Open Cycle Liquid Desiccant Technology

Session 13B: Thermochemical Storage

2nd generation LiCl absorber
Munich / Germany

LiCl absorber installation Amberg / Germany
Commercial System

Thermo Chemical Accumulator By ClimateWell, Sweden

Charging
- To ambient 20-30 °C
- Condenser
- Heat source 70-90 °C
- Generator / Reactor

Discharging
- From ambient or cooling load 5-20 °C
- Evaporator
- To heat load or ambient 40-60 °C
- Absorber/Reactor

ClimateWell DB220 (v7)
- Two identical vessels
  - Alternate charge / discharge
- Connection via switching unit
- 10 / 18 kW max cooling / heating rate
- 56 / 76 kWh storage for cooling / heating
- Advanced controller
  - Not fully developed

Solar Energy Research Center SERC
TECHNOLOGY PLATFORM

(1) PV/Thermal Solar
(2) Grid tie inverter
(3) Thermal energy storage
(4) Solar lighting

A. System controller
B. Thermal storage tank
C. Refrigerant free Heat pump
D. Geothermal system
E. Zinc Bromine Energy Storage
F. Solar Lighting

New Age Energy design of Rutgers Visitors Center
Thermal Energy Storage: a System for the Green Capitalist
Agenda for Our *Green* Capitalist’s Discussion

What is TES or Off Peak Cooling?
LEED and Why is Storage *Green*?
Storage Benefits
Storage Myths
Look what it does for the Building Load Profile
How does OPC work?
How does it Work With the Utility Rate?
Conclusions
Off-Peak Cooling is growing for three reasons:

1. LEED, and sustainable designing.

2. Utility rates are becoming more favorable for storage.

3. Often it’s the superior lowest cost design
   - right sizing
   - redundancy
What is Off Peak Cooling?

TES is the process of generating and storing cooling at night-time.
What does Off Peak Cooling do?

1. Reduce peak daytime kW demand.
2. Reduce energy consumption.
3. Lower power plant emissions.
4. Enhances the viability of renewable energy sources.
One Metric for “Green” is LEED

LEED™ Green Building Rating System
LEED™ Credits

Sustainable Sites: 14 points
Water Efficiency: 5 points
Energy* & Atmosphere: 17 points
Materials & Resources: 13 points
Indoor Environment Quality: 15 points
Innovation & Design: 5 points

69 points

*10 Energy Credit are based on ASHRAE 90.1 which is based on Energy COST Reduction
LEED points awarded on COST REDUCTION

- LEED ignores the utility meter
- LEED reads the utility bill
- Meters don’t measure energy
- ASHRAE 90.1, 1999
  - Energy Cost Budget Method
LEED EAc1 Point Awards

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<td>38.5%</td>
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<td>9</td>
</tr>
<tr>
<td>42%</td>
<td>35%</td>
<td>10</td>
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</table>

2 Credits will be mandatory in EA Prerequisite 2

Reduce design energy cost over ASHRAE 90.1, 2004 Energy Cost Budget, or your local code (which ever is more stringent).
Storage is Natural
Most common TES System

Electric Water Heater
Assume one low flow showers running
\[(2.5 \text{ gpm} \times 8.33 \text{ lb/gal} \times (110-60))\]
\[\times 60 \text{ minutes/hr} / 3,414 \text{ Btu/kWh} = 18.3 \text{ kW}\]

Two low flow showers = \(36.6 \text{ kW}\)

Gas Water Heater
Design Load = 2 Showers at a time
\[36.6 \text{ kW} \times 3414 = 124,950 \text{ Btuh}\]

TES has already impacted US infrastructure
Speaking of INFRASTRUCTURE
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

In 2006, top 6,000 MW of Demand (21% of total peak demand) was for only 165 hours (1.9% of the year).

2006 Winter peak = 20,559 MW (73% of summer peak)

2006 Median Hourly Demand = 15,298 MW (Ave. = 15,100)

ISO-New England 2005 & 2006 Hourly MW Load Duration Curve, Top 1/2 Month of Hours

- Top 500 MW of Demand was for only 5 hours in 2006 (0.06% of year); 8 hours in 2005.
- Top 1,000 for 13 hrs. in '06 (0.1% of yr.); 11 hrs. in '05.
- Top 2,000 for 32 hrs. in '06 (0.4% of yr.); 34 hrs. in '05.
- Top 3,000 for 52 hrs. in '06 (0.6% of yr.); 106 hrs. in '05.
- Top 4,000 for 71 hrs. in '06 (0.8% of yr.); 184 hrs. in '05.
- Top 5,000 for 106 hrs. in '06 (1.2% of yr.); 316 hrs. in '05.
- Top 6,000 for 165 hrs. in '06 (1.9% of yr.); 498 hrs. in '05.
- Top 7,000 (25% of total) for 251 hrs. in 2006 (2.9% of yr.)

24 Hour Blocks (= days), Total of Top 365 Hours (out of 8760) Shown

2006 Winter peak = 20,559 MW (73% of summer peak) or 7,571 MW less than summer.

Electricity Demand: *Structural* Volatility

Summer Peak Day Load Profile

- **A/C is 50% of peak demand**
- **Residential A/C**
- **Commercial A/C**
- **Commercial Lighting**
- **All other commercial, residential, industrial**

Demand (GW)
What is the Solution?

Wind
Solar
Clean Coal
Nuclear
Batteries
Replace

Stored Fossil Fuels

With Renewable Energy

Where is the storage?
Installed Costs of New Generation

- Combined Cycle Gas Turbine: $0.50 to $1.00/Watt
- Nuclear: $2.00 to $6.00/Watt
- New Coal Plant: $1.50/Watt
- New Clean Coal: $2.00/Watt
- Wind (30% Cap Factor ~ 0 Peak Reduction): $1.60/Watt
- PV (30% Cap Factor ~ 15% Peak Reduction*): $7.50/Watt
- Cool Storage: $0.50 to $1.00/Watt

*NREL Report
It is much more Energy Efficient to create and deliver a kWh of Electricity at night than during the hot of the day.

Report Published by the CEC for 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

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”

Is Off Peak Cooling Green? Can Off Peak Cooling Save Energy?

General perception is that:

Thermal Storage uses more energy and is not Green
Storage is **Green** Because...

- Storage reduces Energy Costs
- May Save Energy at Site
- **Always** Saves Energy at the Source of Generation
- Lowers Power Plant Emissions
Off-Peak Cooling is Green Because…

- **Storage saves energy:**
  - Base Load Plants 7900 to 8500 Btu/kW
  - Peaking Plants 9000 to 12000 Btu/kW
  - Spinning Reserve Losses
  - More Efficient Nighttime Transmission
  - Last Plant On- Twice As Dirty as First On
Thermal Energy Storage Benefits

- Reduces Peak Demand at most critical time: 20-40%
- Reduces first cost (sometimes): up to 10%
- Reduces consumer’s AC energy costs: 10-20%
- Reduces on site energy use (often): up to 14%
- Reduces source energy usage (always): 8-34%
- Increases Load Factor of Generation: up to 25%
- Reduces TEWI emissions: 30 to 50% vs. Absorption
- Provides operational flexibility for consumer in a deregulated energy market
Thermal Storage Myths

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

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 now-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 environmentally friendly air-conditioning systems.

The obvious reason for installing TES is to reduce energy costs. Although deregulation of the electric industry has increased localized variations in energy costs, the basic reality of supply and demand is that on-peak power is more expensive than off-peak power. One consistently proven aspect of TES is that it saves energy costs, which has more significance now that ANS/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 Technology Awards detail the cost-saving aspect. However, too much 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 air-cooled liquid cooled refrigeration systems, ice-making equipment, and others, were used successfully in other applications. However, 95% 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.

Chiller-based systems. For projects where space is not at as much of a consideration, chiller/water storage is becoming widely used. However, since as much HVAC work involves benefits where space is a concern, ice is the likely choice.

Closed system. Large district cooling systems use either water or ice as the storage media and use the least transfer fluid. These “open” systems create added hydraulically complications that tend to be

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Look What Storage Does

For the Building
For the Energy Provider
ASHRAE 90.1 Base Line Building
Non-Storage Electrical Profile

Total kWh = 28,000/day

Peak Load 2000 kW
Avg. Load 1050 kW

(Load Factor = 53%)
Design 30% better than 90.1
Non Storage Electrical Profile

Avg. Load
800 kW

Peak Load
1500 kW

Total kWh = 19,200/day
(Load Factor = 53%)
Off Peak Cooling (OPC) Electrical Profile

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

4 Buildings x 1 Megawatt
= 4 Megawatts
8,000 mWh Sold

5 Buildings with TES @ 0.8 mW
= 4 Megawatts
10,000 mWh Sold!

The same generator produces
25% more sellable kWh!
Higher Load Factors

Lower Energy Bills

The first law of electricity pricing:

“Load Factor IS The Only Factor”
What’s your load factor?

Load Factor = \frac{\text{Total kWh}}{\text{Peak kW} \times 720 \text{ Hours}}
Prospecting Guide

1. Is the job chilled water?
2. Is the job over 100 tons?
3. Is there time to make ice?
4. Is this a LEED design?
What job types are best?

New Construction

or

New Chiller Plants

BEST
What about retrofit?

They’re good but *need*

**Opportunity for** *avoided capital cost*

Best When:
- Replacing old chillers
- Capacity increase required

*Operating savings alone NEVER JUSTIFY STORAGE.*
What building types are best?

- K-12 Schools
- Community Colleges
- Arenas, Theaters, Conference Centers
- Office Buildings
- Libraries
- Churches
- Solving Redundancy and Infrastructure Issues
The Conventional Way…

Travel

- Oversized for Most Use
- Plenty Horsepower
- Anytime Utility
- Expensive to Operate
The Conventional Way...

Travel
• Oversized for Most Use
• Plenty Horsepower
• Anytime Utility
• Expensive to Operate

Cooling
• Oversized for Most Use
• Plenty Tons or Refrigeration
• Anytime Cooling
• Expensive to Operate
Hybrid Car

Reduced Size
Handles load most of the time.

Stored Energy
Batteries drive electric motors when extra power is needed.

Recharge Storage
Batteries charged by engine, or when plugged in, or by braking.
Hybrid Car

- Reduced Size
  Handles load most of the time.
- Stored Energy
  Batteries drive electric motors when extra power is needed.
- Recharge Storage
  Batteries charged by engine, when plugged in, or by braking.

“Right” Sized Cooling
Handles load most of the time.
**Hybrid Car**

- **Reduced Size**
  - Handles load most of the time.

- **Stored Energy**
  - Batteries drive electric motors when extra power is needed.

- **Recharge Storage**
  - Batteries charged by engine, when plugged in, or by braking.

**Hybrid Cooling**

- **“Right” Sized Cooling**
  - Handles load most of the time.

- **Discharge Stored Cooling**
  - Ice kicks in when energy is costly load or demand is high or renewables are not available.
Discharge Stored Cooling—Ice kicks in when energy is costly load or demand is high or renewables are not available.

Charge Storage—IceBanks charged at night usoff peak or renewable energy. Costs & emissions are low.

“Right” Sized Cooling Handles load most of the time.

Reduced Size Handles load most of the time.

Stored Energy Batteries drive electric motors when extra power is needed.

Recharge Storage Batteries charged by engine, when plugged in, or by braking.
Full Storage

![Bar chart showing Tons of Ice Cooling and Ice Making over Time]

- **Y-axis**: Tons
- **X-axis**: Time
- **Legend**: Ice Cooling (light blue), Ice Making (green)

The bar chart illustrates the storage capacity and usage over time, with peak periods noted in the data.
Partial Storage

- Ice Making
- Chiller Cooling
- Ice Cooling

Tons

0

1200

1000

800

600

400

200

0

Time
Partial Storage- Non-Design Day
Myth: Storage is Complicated

True or False?
Simple System

Almost like Non-Storage System

Chiller Based System
- No Refrigeration Piping
- Closed System
- Coolant fluid is not storage media

So what is “Different”? 

Storage Tanks

Control Logic

Heat Transfer Fluid

Two Valves
Two Bypasses
Thermal Storage Tank

- Seamless Polyethylene Tank
- Polystyrene Insulation
- Expansion Chamber
- All Welded Polyethylene Heat Exchanger
INTERNAL HEAT EXCHANGER

14,000 FT OF HX TUBING

FUSION WELDED POLYETHYLENE TUBING

CORROSION PROOF

PREDICTABLE & REPEATABLE PERFORMANCE

100% SERVICEABLE

SIMPLE FLANGE CONNECTIONS
ALL WELDED HX CONSTRUCTION
INTERNAL HEADERING
UL
8,000 Ton-Hr
2.5 days to install
Operating Sequences
BASIC DIAGRAM

SERIES FLOW – CHILLER UPSTREAM

CHILLER

ICE BANK®

Back Pressure
Regulating Valve

Air Handlers

V1

V2

P1

P2
CHILLER

ICE BANK®

V1

V2

P1

P2

Back Pressure Regulating Valve

Air Handlers

26F-22F

32-28F

42F

58F

CHARGING, and WITH COOLING
SERIES FLOW – CHILLER UPSTREAM

COOLING CHILLER ONLY

CHILLER

ICE BANK®

Air Handlers

Back Pressure Regulating Valve

V1

V2

P1

P2

42F-50F

42F-58F

58F

42F

42F
SERIES FLOW – CHILLER UPSTREAM

COOLING ICE ONLY

CHILLER

ICE BANK®

Back Pressure Regulating Valve

Air Handlers

P1

P2

V1

V2

42F-58F

32F-42F

42F

58F

42F
### EQUIPMENT SCHEDULE

<table>
<thead>
<tr>
<th></th>
<th>CHILLER</th>
<th>P1</th>
<th>P2</th>
<th>V1</th>
<th>V2</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging</td>
<td>ON</td>
<td>ON</td>
<td>OFF</td>
<td>B-C</td>
<td>A-C</td>
<td>*V2 modulates when primary loop temperature is lower than secondary loop temperature</td>
</tr>
<tr>
<td>Charging with cooling</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
<td>B-C</td>
<td>MOD</td>
<td></td>
</tr>
<tr>
<td>Cooling Chiller only</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
<td>A-C</td>
<td>B-C/Mod*</td>
<td></td>
</tr>
<tr>
<td>Cooling Ice only</td>
<td>OFF</td>
<td>ON</td>
<td>ON</td>
<td>MOD</td>
<td>B-C/Mod*</td>
<td></td>
</tr>
<tr>
<td>Cooling Chiller &amp; Ice</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
<td>MOD</td>
<td>B-C/Mod*</td>
<td></td>
</tr>
</tbody>
</table>
Parallel Flow

PARALLEL FLOW
195 ton peak cooling

205 gpm day
273 gpm ice build

Assumes 2-way valves On AHU’s

54°F SUPPLY

Pc 307 gpm

CHILLER
120 ton day
60 ton ice build

44°F SUPPLY
512 gpm @ peak

WORK IN PROGRESS 081010
How Much Space?

- 0.70% of cooled floor space*
- If Ice provides about 33% of a cooling system reducing ice tank floor space to 0.23% of cooled floor space.

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

Same ratio as the water heater in your house

1 ton cools 500 ft²
1 tank provides 20 tons
1 tank cools 10,000 ft²
1 tank needs 70 ft² (60 ft²)
Ice Storage Tanks for the entire Project

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
Right Sizing and Redundancy
Myth, it’s Expensive

Non-Storage System  3-400 ton Chiller x $1100/ton    =$ 1,320,000

Partial Storage System  2-400 ton Chiller x $1100/ton  =  $ 880,000
                      3500 ton-hr x $125/ton-hr    =  $ 490,000
                      $1,370,000

In this example the storage system is essentially the same as conventional.
Numerous real examples in ASHRAE Documents
Installation Savings

Smaller chiller
Smaller piping
Smaller pumps
Smaller electrical
Safety Factors (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 to this Rock-and-a Hard Place dilemma
Some Rules of Thumb

• Design for high dT, 14 to 18 F dT

• Typical systems store about 1/4 to 1/3 of the total design day ton-hours.

• Two tanks (model 1190C) per 100 tons of peak load (but not always).

• Chiller reduction
  To 50% in schools, 40% office buildings

• Chiller looses 1/3 of capacity during ice build
Electricity Costs are Going UP!

**DEREGULATED, WITH RATE CAP**

These states still have a cap or other state oversight of utility rates but do permit retail competition.

<table>
<thead>
<tr>
<th>State</th>
<th>2006 Price (in cents)</th>
<th>% Change, 2002 to 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona</td>
<td>9.35</td>
<td>13.0%</td>
</tr>
<tr>
<td>Michigan</td>
<td>10.02</td>
<td>21.0%</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>14.85</td>
<td>24.9%</td>
</tr>
<tr>
<td>Ohio</td>
<td>9.42</td>
<td>14.3%</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>10.41</td>
<td>6.8%</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>15.09</td>
<td>47.5%</td>
</tr>
</tbody>
</table>

**DEREGULATED, NO RATE CAP**

These states no longer oversee the generation price on the utility bill and, except for California, have opened their markets to retail competition.

<table>
<thead>
<tr>
<th>State</th>
<th>2006 Price (in cents)</th>
<th>% Change, 2002 to 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>14.34</td>
<td>13.5%</td>
</tr>
<tr>
<td>Connecticut</td>
<td>16.79</td>
<td>53.2%</td>
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<tr>
<td>Delaware</td>
<td>11.62</td>
<td>33.6%</td>
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<tr>
<td>District of Columbia</td>
<td>9.88</td>
<td>23.8%</td>
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<tr>
<td>Illinois</td>
<td>8.51</td>
<td>1.5%</td>
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<tr>
<td>Maine</td>
<td>14.47</td>
<td>13.5%</td>
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<tr>
<td>Maryland</td>
<td>9.72</td>
<td>25.6%</td>
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<tr>
<td>Massachusetts</td>
<td>17.01</td>
<td>55.6%</td>
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<tr>
<td>Montana</td>
<td>9.29</td>
<td>14.5%</td>
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<tr>
<td><strong>New Jersey</strong></td>
<td><strong>12.87</strong></td>
<td><strong>24.0%</strong></td>
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<tr>
<td>New York</td>
<td>16.69</td>
<td>23.2%</td>
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<tr>
<td>Texas</td>
<td>12.70</td>
<td>57.7%</td>
</tr>
</tbody>
</table>

**REGULATED**

These states must approve the rates of their utilities, which supply much of their own power and generally face no competition.

<table>
<thead>
<tr>
<th>State</th>
<th>2006 Price (in cents)</th>
<th>% Change, 2002 to 2006</th>
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</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>8.72</td>
<td>22.4%</td>
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<tr>
<td>Alaska</td>
<td>14.92</td>
<td>23.9%</td>
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<td>Arkansas</td>
<td>8.87</td>
<td>10.6%</td>
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<td>Colorado</td>
<td>9.04</td>
<td>22.0%</td>
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<td>Florida</td>
<td>11.31</td>
<td>38.6%</td>
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<tr>
<td>Georgia</td>
<td>9.00</td>
<td>19.1%</td>
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<tr>
<td>Hawaii</td>
<td>23.36</td>
<td>40.4%</td>
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<tr>
<td>Idaho</td>
<td>0.12</td>
<td>-7.1%</td>
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<td>Indiana</td>
<td>8.22</td>
<td>19.0%</td>
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<td>Iowa</td>
<td>9.09</td>
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<td>Kansas</td>
<td>8.18</td>
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<td>Kentucky</td>
<td>7.13</td>
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<td>9.17</td>
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<td>Minnesota</td>
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<td>Mississippi</td>
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<td>Missouri</td>
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<td>Nebraska</td>
<td>7.42</td>
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<tr>
<td>Nevada</td>
<td>11.07</td>
<td>17.6%</td>
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<tr>
<td>New Mexico</td>
<td>9.07</td>
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<tr>
<td>North Carolina</td>
<td>9.12</td>
<td>11.3%</td>
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<tr>
<td>North Dakota</td>
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<td>11.0%</td>
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<tr>
<td>Oklahoma</td>
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<td>Oregon</td>
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<td>5.1%</td>
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<td>South Carolina</td>
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<tr>
<td>South Dakota</td>
<td>7.05</td>
<td>0.0%</td>
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<td>Tennessee</td>
<td>7.74</td>
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<tr>
<td>Utah</td>
<td>7.61</td>
<td>12.0%</td>
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<tr>
<td>Vermont</td>
<td>13.54</td>
<td>6.0%</td>
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<tr>
<td>Virginia</td>
<td>8.49</td>
<td>9.0%</td>
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<tr>
<td>Washington</td>
<td>6.81</td>
<td>8.3%</td>
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<td>West Virginia</td>
<td>6.32</td>
<td>1.4%</td>
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<tr>
<td>Wisconsin</td>
<td>10.43</td>
<td>27.6%</td>
</tr>
<tr>
<td>Wyoming</td>
<td>7.76</td>
<td>11.4%</td>
</tr>
</tbody>
</table>

**U.S. average** 10.40  23.2%
Durst Retrofit in New York City

1155 6TH AVENUE-NYC
41 Stories
3400 Ton Hours Storage
Avoids $\approx 600kW$ out of $3500kW$ Original Total
Ice Plant in Series with chilled water

Demand limited to 700 tons

490 ice-making tons

VFD Pump

Ice Storage

TO LOAD

FROM LOAD

TS

HX
EPA/DOE Energy Star Building Label Program

The Centex Building in Dallas Texas is the highest rated building with an unprecedented 99 out of 100 rating. It has the lowest Site Energy Intensity. It has 2400 Ton-hr of Ice Thermal Storage and a water cooled screw chiller.

(www.energystar.gov)
Union County Vo-Tech before
Union County Vo-Tech after
1 Bryant Park
Bank of America Tower
2.2 Million Sq.ft.

New York’s Most Environmentally Friendly Office Tower.
Q&A

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