Cool Trends on Campus:

A Survey of Thermal Energy Storage (TES) Use for Campus District Cooling

John S. Andrepont, President

The Cool Solutions Company

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Best Practice

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Learning Objectives

Upon completion of this program you will be able to:

1. understand the concept of TES use on campus,
2. know the range of applications of campus TES,
3. understand the benefits of TES use on campus,
4. compare your campus to others using TES, and
5. identify when and how TES could be of greatest value for your campus.

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Outline

- Introduction and Background
- Summaries of Database of Campus TES
  - Capacity
  - Geographical
  - Chronological
  - Technological
  - Equipment Suppliers
  - Repeat Users
- Specific Examples of Campus TES (5)
- Conclusions and Recommendations

Nomenclature

AHU	- Air-Handling Unit
CHP	- Combined Heat & Power
CHW	- Chilled Water
CHWS / R	- Chilled Water Supply / Return
DC	- District Cooling
DE	- District Energy
DSM	- Demand-Side Management
HW	- Hot Water
LTF	- Low Temperature Fluid
NPV	- Net Present Value
TES	- Thermal Energy Storage
UG	- Under Ground

Introduction and Background

This survey of TES on campus considers only:

- Cool TES (Ice, CHW, and LTF) for campus District Cooling (data through Sep 2004)
- Diurnal TES (not seasonal TES e.g. deep ocean, harbor, or lake water, nor UG aquifers)
- College/university applications, not schools, hospitals, other gov't (e.g. fed, state or local), urban DE utilities, or commercial/industrial applications

Data are approximate, and likely to include nearly all U.S. examples and many non-U.S. examples.

Types of TES

- Ice TES (latent heat)
  - Water is converted to ice off-peak; then ice is melted on-peak
  - Conventional or Low Temp CHWS possible (34 to 44 ºF typical)
- Chilled Water (CHW) TES (sensible heat)
  - An insulated tank with cooler denser CHWS stratified below warmer less dense CHWR
  - Conventional CHWS temps (39 to 42 ºF typ.)
- Low Temperature Fluid (LTF) TES
  - Similar to CHW TES, but using fluid <39 ºF
  - Lower supply temp (30 to 36 ºF typical)

Inherent Characteristics of TES

	Ice	CHW	LTF
Volume	good	poor	fair
Footprint	good	fair	good
Modularity	excell	poor	good
Economy-of-Scale	poor	excell	good
Energy Efficiency	fair	excell	good
Low Temp Capability	good	poor	excell
Ease of Retrofit	fair	excell	good
Rapid Charge/Dischrg Capability	fair	good	good
Simplicity and Reliability	fair	excell	good
Can Site Remotely from Chillers	poor	excell	excell
Dual-use as Fire Protection	poor	excell	poor

TES on Campus - Capacity Data

159 examples of TES identified on 124 campuses

- Total = 1,808,408 Ton-hours
- Average = 14,584 Ton-hrs per campus
- Smallest = 320 Ton-hrs
- Largest = 93,200 Ton-hrs

- Total peak cooling load from TES = 258,344 T
- Average peak cooling load served = 2,083 T

- Total peak elec load mgmt by TES = 194 MW
- Average peak electric load mgmt = 1.6 MW

TES on Campus - Geographical

159 identified examples – 1,808,408 Ton-hours

- U.S. Applications (in 24 states plus D.C.)
  - 149 installations (94% of world total)
  - 1,677,048 Ton-hrs (93% of world total)
  - 4 states (CA, TX, OH, FL) have 63% of T-hrs in U.S.
  - 23 in ERAPPA (CT, MD, NY, NJ, PA, RI, and D.C.)
- Non-U.S. Applications (in 6 countries)
  - 10 installations (6% of world total)
  - 131,360 Ton-hrs (7% of world total)
  - 2 countries (Malaysia and Australia) have 60% of installations and 43% of Ton-hrs, in non-U.S.
  - 1 country (Canada) in only a single installation, has 60,000 Ton-hrs and 46% of the non-U.S. capacity

TES on Campus - Chronological

Period	No.	New Ton-hrs	New T-hrs/yr
1981-85		70,000	14,000
1986-90		147,300	29,460
1991-95		571,127	114,225
1996-00		521,024	104,205
2001-04		498,957	124,739
24-yrs	159	1,808,408	75,350

TES on Campus - Technological

Latent Heat (Ice) TES – 86 examples (54%)

- Subtotal = 389,929 Ton-hrs (22%)
- Average = 4,534 Ton-hrs; Median = 2,350 Ton-hrs
- Smallest = 320 Ton-hrs; Largest = 93,200 Ton-hrs
- Demand Savings: Avg = 485 kW; Total = 42 MW

Sensible Heat (CHW and LTF) TES – 73 (46%)

- Subtotal = 1,418,479 Ton-hrs (78%)
- Avg = 19,431 Ton-hrs; Median = 16,000 Ton-hrs
- Smallest = 3,500 Ton-hrs; Largest = 60,000 T-hrs
- Demand Savings: Avg = 2.1 MW; Total = 152 MW

TES on Campus - Sensible Heat

- CHW (Chilled Water) TES – 1,365,312 T-hrs (96%)
- CHW (future LTF) TES – 161,200 T-hrs (11%)
- LTF (Lo Temp Fluid) TES – 40,000 T-hrs (3%)
- HW (Hot Water) TES – 13,167 T-hrs (1%)

- Above ground – 53 examples (77%)
- Fully below ground – 11 examples (16%)
- Partially below ground – 5 examples (7%)

- Steel tanks – 52 examples (75%)
- Concrete tanks – 16 examples (23%)
- Aluminum tanks – 1 examples (1%)

TES on Campus - by TES Supplier

TES supplier (tank type)	No.	Ton-hrs	% of Total
CHW #1 & LTF (steel)	39	792,367	55%
Ice #1 (steel or concrete)	14	180,533	13%
Ice #2 (plastic)	65	178,480	12%
CHW #2 (steel)	8	156,000	11%
CHW #3 (concrete)	2	38,000	3%
CHW #4 (concrete)	3	30,060	2%
CHW #5 (steel)	4	27,500	2%
Ice #3 (various)	3	13,760	1%
Ice #4 (various)	3	11,900	1%
Sub-totals	141	1,428,600	100%
“one-off” (17 CHW, 1 Ice)	18	379,808 (mostly older)	

TES on Campus - Repeat TES Users

Campuses with TES in Multiple Phases

- 20 campuses with 55 TES installation phases
- multiple phases of TES (62 to 950% increases)
- 1 converted CHW to Ice TES (133% increase)
- 1 added height to CHW TES (50% increase)
- 4 CHW TES designed for future LTF (43 to 122%)

University Systems with TES at Multiple Campuses

- 10 systems have 40 TES, on 37 campuses
- 1 has 16 CHW TES, on 14 campuses (278,000 T-h)
- 1 has 8 CHW TES, on 7 campuses (254,000 T-h)

TES at U of Texas - El Paso (UTEP)

(photo compliments of Chicago Bridge & Iron Co.)

- 1999 - 30,000 Ton-hours CHW TES, at 40 / 53 ºF CHWS / R temps
- 4 million gallons
- Performs dual-service as CHW TES and fire protection water storage

2002 - 10,000 Ton-hours CHW TES at U of Texas Pan American – Edinburg
2008/09 - 41,000(58,000) Ton-hours CHW(LTF) TES at U of Texas at Austin

TES at California State U - Sacramento

(photos compliments of Chicago Bridge & Iron Co.)

- 1991 - 12,300 Ton-hours CHW TES, at 42 / 62 ºF CHWS / R temps
- 62 ft diameter x 48 ft high (1,084,000 gallons)
- 2002 - 18,450 Ton-hours CHW TES, at 42 / 62 ºF CHWS / R temps
- 62 ft diameter x 72 ft high (1,626,000 gallons)

16 CHW TES (278,000 T-hrs) now at 14 CSU campuses (30 MW of DSM)

TES at Princeton U - Princeton, NJ

(photo compliments of Chicago Bridge & Iron Co.)

- 2005 - 40,000 Ton-hrs 5.7 wgt% aqueous LTF TES, at 32/56 ºF CHWS/R temps
- 2,700,000 gallons (steel tank, within an excavated pit, to limit height)
- Low supply temp plus high Delta T maximize capacity in CHW network

  Meets up to 10,000 Tons of peak campus load (7 to 8 MW of DSM)
- Also provides Turbine Inlet Cooling (more summer MWs) at CHP Gas Turbine

TES at DFW International Airport, TX

(photo compliments of Chicago Bridge & Iron Co.)

- 2004 - 90,000 Ton-hours LTF TES, at 36 / 60 ºF LTF S / R temps
- 6 million gallons
- 3 weight% aqueous LTF, in TES and throughout airport DC & AHUs
- Low supply temp plus high Delta T maximize capacity in airport CHW piping

Meets up to 15,000 Tons of peak airport load (over 10 MW of DSM)

TES at U of Alberta - Edmonton

- An urban university campus with academic and medical facilities
- 2005 - 60,000 Ton-hours CHW TES, at 41 / 53.6 ºF CHWS / R temps
- 150 ft diameter x 60 ft high (8 million gallons)
- TES acts as satellite plant, at opposite corner of campus from central CHW plant
- Solved CHW distribution piping network "bottleneck" problems
- Meets up to 7,215 Tons of peak campus load (5.4 MW of DSM)
- Avoided equivalent capacity of new CHW plant
- Immediate capital cost savings = C$6 million (30%)
- Annual operating cost savings = C$800,000 to C$900,000 (12%)
- 20-yr NPV of capital + operating savings = C$13 million (US$10.4 million)

Pre-designed for conversion to LTF TES (70% increase to 102,000 Ton-hrs)

Conclusions and Recommendations

1. TES is already very widely used in campus DC
2. Over 150 examples compiled: 1.8 million T-hrs, with 258,000 Tons and 194 MW of load mgmt
3. Avg of 14,600 T-hrs for 2,100 T and 1.6 MW
4. Sizes range from 320 to 93,200 Ton-hrs
5. Widespread throughout U.S. and the world
6. All climates (hot dry, hot wet, seasonally hot)
7. Latent heat (Ice) and sensible heat (CHW and LTF) technologies are well represented
8. Rapid growth throughout the 1980s
9. Continued high use from 1990 to present
10. Numerous examples of repeat users

A Final Note

- This survey of TES addressed Campus DC applications only.
- A similar survey conducted in 2005, covered TES in DE Utility systems. It had similar totals, growth, and other results, but showed a somewhat greater incidence of non-U.S. installations.
- TES use in private commercial / industrial DE systems (and medical DE systems) is expected to exhibit comparably large or larger numbers.

Questions / Discussion

This concludes the American Institute of Architects Continuing Education Systems Program

The Cool Solutions Company

www.CoolSolutionsCo.com

tel: 630-353-9690