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Cool Trends on Campus:
A Survey of Thermal Energy Storage (TES) Use in Campus District Energy (DE) Systems

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A survey was recently conducted to develop a database documenting and quantifying the use of Thermal Energy Storage (TES) in campus applications. Though data can often be dry and uninteresting, these data are decidedly "cool" and should lead to useful insights and conclusions to assist campus utility planners and operators, not to mention business officers and trustees.

The sheer number of campus TES installations, the cumulative impact on electric load management, the broad range of geographic locales and climatic conditions, and notably the large number of repeat users (either multiple TES phases at a single campus, or TES at multiple campuses within a campus system), are quite eye-opening, even to those who are already familiar with the TES marketplace.

Data on each installation has been compiled to document the campus, the location, the year of initial TES operation, the TES type and configuration, the TES capacity, and the estimated TES load shift. A summary of the data is presented here, illustrating such factors as:

- TES technology types, including ice and chilled water TES,
- physical configuration of TES, including above-ground and below-ground installations,
- campuses with multiple TES installations or multiple phases of TES capacity expansion,
- campus systems with TES at multiple campuses,
- geographic distribution, including individual U.S. states and other countries,
- the range and average for TES system capacity (in ton-hours), and
- the range and average for TES load shift (in cooling tons and electric MW).

To-date, **159 identified TES installations, on 124 campuses**, comprise more than **1.8 million ton-hours** of daily TES capacity and achieve an estimated total peak load shift of over **258,000 tons (or 194 MW)**. On average, they exhibit a TES capacity of 11,374 ton-hours and a peak load shift of 1,625 tons (or 1.2 MW) per installation, or **14,584 ton-hours and 2,083 tons (or 1.6 MW) per campus**.

Background

Throughout the past two decades, and increasingly in recent years, various instances of employing Thermal Energy Storage (TES) at individual college, university, and other campus applications of District Cooling have been documented. Many of these have been presented as Case Studies at IDEA conferences (including annual, campus and cooling conferences) or as articles in IDEA's *District Energy* magazine. The individual case studies have illustrated a wide range of the potential benefits, including:

TES benefits that are essentially universally available

- Peak electric load management / demand reduction
- Operating energy cost savings
- Enhanced system flexibility

Often TES benefits that are often available

- Capital cost savings (at times of new construction, campus expansion, or chiller plant rehab)
- Lower supply temperature (with ice or low temperature fluid TES)
- Dual-use as fire protection (with chilled water TES)
- Increased system redundancy and reliability (with any TES)
- Enhanced distribution network capacity (from remotely sited water or fluid TES)
- Flattened thermal and electric load profiles, enhancing the economics of CHP.

All the documentation of benefits for individual applications notwithstanding, it has remained unclear exactly how widespread the use of TES on campus has become. It was recognized that a survey to develop a database would provide meaningful and useful insights into the extent and form of campus TES systems. This "benchmarking" of the use of TES on campus could be beneficial, both to existing campus owners/operators of TES systems and to those considering (or even those who may not yet have considered) the use of TES on their campus.

The author, whose background has involved the analysis, design, and deployment of large TES systems for over 100 campus and other District Cooling applications during more than 20 years, determined to supplement his existing data regarding college and university applications of TES, through the execution of a more formal survey. Although some of the system data was obtained directly from the owners/operators, most of the data was developed by the author over a number of years and then recently expanded and confirmed through a survey of all the leading suppliers of latent heat (ice) TES and sensible heat (chilled water or low temperature fluid) TES systems.

It is of course appropriate to recognize a few caveats regarding the data:

1. The survey was conducted only through September 2004.
2. The survey was limited to college and university campuses, plus a few national (U.S. and non-U.S.) research laboratory campuses. At this time we have not included other campus applications such as K-12 educational facilities, medical complexes (other than those on university campuses), museums, and airports, nor military, administrative, and other government campuses. Also, the database does not include campuses that purchase chilled water from District Energy utilities which may themselves employ TES.
3. Data from all leading TES equipment suppliers was included. For those not responding directly, a detailed review of their published literature was employed to accumulate data
4. Though surely falling short of identifying 100% of the campus TES systems, the database is judged to include the vast majority (perhaps 90% or more) of the U.S. installations and a lesser number of non-U.S. installations.
5. Quantitative data on individual installations are sometimes approximate, due to the necessary use of estimates in a few instances. In those very few instances where no quantitative individual data was available, the average value from similar installations was assumed. Cumulative data (e.g. totals, averages, and means) are judged to be relatively accurate.
6. On average, peak thermal load shifts (in tons) are estimated to be the ton-hour capacity divided by 7 hours. On average, peak electric load shifts are calculated at the rate of 0.75 kW per ton (including chillers, condenser water pumps, and cooling tower fans).
7. Abbreviations: "CHW" = Chilled Water. "HW" = Hot Water. "LTF" = Low Temperature Fluid.

Acknowledgement: The author thanks all those who have kindly contributed input for the development of the database employed in this survey.

Campus DE TES Summary – Geographical	No. of Installations	Ton-hours
All identified Campus DE Diurnal TES	159 installations	1,808,408
U.S. Campus DE TES Installations	149 (94% of total)	1,677,048 (93% of total)
California	36	715,325 (43% of U.S.)
Texas	25	163,835 (10%)
Ohio	11	87,040 (5%)
Florida	15	82,160 (5%)
Arizona	2	69,000 (4%)
Colorado	1	60,000 (4%)
New York	3	59,500 (4%)
Maryland	8	51,378 (3%)
New Jersey	3	45,450 (3%)
North Carolina	4	43,490 (3%)
Pennsylvania	3	38,260 (2%)
Michigan	7	37,350 (2%)
Illinois	1	31,000 (2%)
Connecticut	1	30,000 (2%)
Virginia	7	29,700 (2%)
Washington	2	24,550 (1%)
Oklahoma	3	22,500 (1%)
Washington, DC	3	21,300 (1%)
New Mexico	1	20,000 (1%)
Indiana	4	17,810 (1%)
Iowa	1	7,000 (0%)
Kansas	1	6,560 (0%)
Rhode Island	2	5,100 (0%)
Minnesota	1	5,000 (0%)
Idaho	4	3,740 (0%
Non-U.S. Campus DE TES Installations	10 (6% of total)	131,360 (7% of total)
Canada	1 (10% of non-U.S.)	60,000 (46% of non-U.S.)
Malaysia	3 (30%)	32,160 (24%)
Australia	3 (30%)	23,800 (18%)
Korea	1 (10%)	6,000 (5%)
The Netherlands	1 (10%)	5,100 (4%)
Spain	1 (10%)	4,300 (3%)

Chronological Distribution of Campus TES

The significant application of TES on campus began in the early 1980s. It then grew rapidly into the early 1990s, and has continued to remain high to the present day.

Chronological Growth of Campus TES

	Installed Campus TES Capacity	
5-Year Period	**Total (ton-hours)**	**Avg (ton-hrs/yr)**
1981 - 1985	70,000	14,000
1986 - 1990	147,300	29,460
1991 - 1995	571,127	114,225
1996 - 2000	521,024	104,205
2001 - 2005 (projected)	500,000 to 600,000	100,000 to 120,000

Incidences of Repeat Users of Campus TES

Repeat usage by customers is one of the hallmarks of a maturing product or technology. And TES on campus exhibits plenty of repeat users.

There are **20 examples** of individual campuses that have installed two or more phases of TES capacity. In total, these 20 institutions have executed 55 individual TES installations. In one instance, a single campus installed five phases of TES capacity.

There are also **10 examples** of state-wide university systems (and local college districts) that have installed TES at two or more separate campuses. In total, these 10 campus systems have installed 40 TES installations on 37 individual campuses. In one instance, a single state university system has installed 16 TES installations on 14 separate campuses, totaling 278,000 ton-hours of TES capacity, and representing a peak cooling load shift of 40,000 tons and a peak electric demand reduction of 30 MW.

TES Technology Distribution of Campus TES

Sensible Heat TES, in which cooling is stored as the ***temperature*** change of a storage medium (generally as stratified chilled water, and sometimes as stratified Low Temperature Fluid or LTF), represents more than **1.4 million ton-hours (78%)** of TES capacity installed on campus.

- 73 individual installations range in TES capacity from 3,500 ton-hours to 60,000 ton-hours.
- The median TES capacity per installation is 16,000 ton-hours.
- The average TES capacity per installation is 19,431 ton-hours.
- The average peak cooling load shift per installation is 2,776 tons.
- The average peak electric demand reduction per installation is 2.1 MW.
- The total peak cooling load shift is **nearly 203,000 tons**.
- The total peak electric demand reduction is **over 152 MW**.

Latent Heat TES, in which cooling is stored as the ***phase*** change of a storage medium (generally as ice), represents nearly **400,000 ton-hours (22%)** of TES capacity installed on campus.

- 86 individual installations range in TES capacity from 320 ton-hours to 93,200 ton-hours.
- The median TES capacity per installation is 2,350 ton-hours.
- The average TES capacity per installation is 4,526 ton-hours.
- The average peak cooling load shift per installation is 647 tons.
- The average peak electric demand reduction per installation is 485 kW.
- The total peak cooling load shift is **over 55,000 tons**.
- The total peak electric demand reduction is **nearly 42 MW**.

Campus Sensible Heat TES by TES Storage Medium

Type of TES Technology	TES Storage Medium	Total Campus TES Installations by TES Supplier No.	Avg (ton-hrs)	Total (ton-hrs)	(% of total)
Sensible Heat TES	CHW	71	19,230	1,365,312	96%
Sensible Heat TES	CHW (LTF*)	4	40,300	161,200	11%
Sensible Heat TES	LTF	1	40,000	40,000	3%
Sensible Heat TES	HW	1	13,167	13,167	1%
All Sensible Heat TES	**all media**	**73**	**19,431**	**1,418,479**	**100%**

* Initially operating as CHW TES, but also designed for potential future expansion as LTF TES.

Campus Sensible Heat TES by TES Tank Location

Type of TES Technology	TES Tank Location	Total Campus TES Installations by TES Supplier No.	Avg (ton-hrs)	Total (ton-hrs)	(% of total)
Sensible Heat TES	above-ground	53	18,024	955,246	72%
Sensible Heat TES	below-ground	11	28,000	308,000	23%
Sensible Heat TES	partially buried	5	13,612	68,060	5%
Subtotal	**all locations**	**69**	**19,294**	**1,331,306**	**100%**
Sensible Heat TES	unidentified	4	21,793	87,173	
Total Sensible Heat TES	**all locations**	**73**	**19,431**	**1,418,479**	

Campus Sensible Heat TES by TES Tank Material of Construction

Type of TES Technology	TES Tank Material	Total Campus TES Installations by TES Supplier No.	Avg (ton-hrs)	Total (ton-hrs)	(% of total)
Sensible Heat TES	welded steel	52	18,284	950,746	71%
Sensible Heat TES	concrete	16	23,504	376,060	28%
Sensible Heat TES	aluminum	1	4,500	4,500	0%
Subtotal	**all materials**	**69**	**19,294**	**1,331,306**	**100%**
Sensible Heat TES	unidentified	4	21,793	87,173	
Total Sensible Heat TES	**all materials**	**73**	**19,431**	**1,418,479**	

Supplier Distribution of Campus TES

Campus TES by TES Equipment Supplier

TES Supplier	**Type of Technology (& tank construction)**	**Total Campus TES Installations by TES Supplier No.**	**Avg (ton-hrs)**	**Total (ton-hrs)**	**(% of total)**
Sensible Heat #1	CHW & LTF (steel)	39	20,317	792,367	55%
Latent Heat #1	Ice (steel or concrete)	14	12,895*	180,533	13%
Latent Heat #2	Ice (plastic)	65	2,746	178,480	12%
Sensible Heat #2	CHW (steel)	8	19,500	156,000	11%
Sensible Heat #3	CHW (concrete)	2	19,000	38,000	3%
Sensible Heat #4	CHW (concrete)	3	10,020	30,060	2%
Sensible Heat #5	CHW (steel)	4	6,875	27,500	2%
Latent Heat #3	Ice (various)	3	4,587	13,760	1%
Latent Heat #4	Ice (various)	3	3,967	11,900	1%
Subtotal	**all types**	**141**	**10,132**	**1,428,600**	**100%**
“One-off” designs	17 CHW & 1 Ice	18	21,100	379,808	
Total	**all types**	**159**	**11,374**	**1,808,408**	

* Note: excluding the largest installation (93,200 ton-hrs), this average would be 6,718 ton-hrs.

Phased Capacity Expansions of Campus TES

As was noted above, there are 20 campuses that have accomplished 35 subsequent phased installations of TES capacity expansions, beyond their 20 original TES installations. These capacity expansions were accomplished in a wide variety of ways:

- Sequential phases of TES equipment installation (for **62% to 950%** capacity increases)
- Conversion of an existing stratified chilled water TES tank to ice TES (**~133%** capacity increase)
- Increased height and volume of an existing chilled water TES tank (**50%** capacity increase)

In addition, some campuses employing chilled water TES have gained capacity over time as chilled water supply-to-return temperature differences have been increased (primarily through the conversion of building cooling loops from constant-flow 3-way control valve systems to variable-flow 2-way control valve systems). In this manner, some campuses which initially had a relatively poor (low) chilled water Delta T have gained **more than 100%** in TES capacity without any further investment in TES equipment.

Finally, a recent trend in new chilled water TES systems has been use of dual design points: one at a conventional supply temperature using chilled water TES, and a second at a reduced supply temperature using low temperature fluid (LTF). Four recent campus TES installations have employed this approach, allowing for potential future capacity increases of **43% to 122%** by conversion to a LTF storage medium.

Conclusions and Recommendations

TES is quite broadly applied in addressing campus cooling needs. Users include both public and private institutions, and range from very small colleges to very large universities.

One finds TES applications on campus in an extremely wide range of geographic locations (in 24 U.S. states, the District of Columbia, and in non-U.S. campuses on four continents). One also finds campus TES in an equally wide range of climate types, from hot-humid climates (e.g. Miami, Tallahassee, and Malaysia) to hot-arid climates (e.g. El Paso and Phoenix) and from year-round cooling locales (throughout the Southern U.S. "sunbelt" states) to sites with relatively brief cooling seasons (such as St. Paul, Minnesota and Edmonton, Alberta).

New TES installations have occurred continuously on campuses throughout the past 20 years. This has spanned the ups and downs in the economy, periods of high and low energy costs, and times of electric utility industry regulation, deregulation, and restructuring alike, including times before, during, and after the presence of Demand-Side Management (DSM) incentive programs.

It is asserted that this essentially universal applicability of TES throughout all these diverse situations is coupled to an often over-looked value of TES. Specifically, this is the value of TES as peak cooling ***capacity***, and often in fact TES as ***lower capital cost*** peak cooling capacity, when TES is added in lieu of conventional (non-TES) chiller plant capacity at times of either new construction, or campus expansions, or chiller plant rehabilitation or replacement. This economic benefit of TES is of course in addition to the value of TES as a lower operating cost approach.

The very high incidence of ***repeat*** users of TES speaks volumes regarding customer satisfaction with, and the value obtained from, TES on campus. These repeat users frequently include:

1. incidences of multiple phases of TES installations on individual campuses and
2. the installation of TES on multiple campuses within a university or community college system.

TES on campus has been documented to come in all shapes and sizes:

- using water, ice, or low temperature fluid storage
- in storage tanks of various materials of construction
- sited above or below ground (or partially below-grade)
- located outside of or within campus buildings
- located at or remotely from central chiller plants.

Sensible heat TES systems (stratified chilled water or low temperature fluid) generally dominate among the examples of larger campus TES applications, while latent heat TES (ice) generally dominates among the smaller examples. Nevertheless, the largest single campus TES installation is an ice TES example (93,200 ton-hours) that was a retrofit of ice TES equipment into an existing stratified chilled water TES tank, as a means of capacity expansion.

Large sensible heat TES installations predominantly employ above-ground welded-steel tanks (due to simple economic drivers). However, in-ground concrete tanks are also employed, generally for reasons of space allocation, in spite of severe economic premiums.

The ideal type and configuration of TES is driven by the unique situation, requirements, and goals of each individual application. All options should be carefully evaluated during campus planning, in order to identify and capture the maximum benefits of TES. ***TES should be considered whenever cooling capacity investments are being anticipated.*** This is true on campus, as well as for other District Cooling applications.

Photo Captions

Note: 3 photos were submitted separately on a CD mailed by CB&I. The suggested captions for those three photos are listed here:

CB&I photo file 7220-34-21.tif (tank and buildings with tennis courts in foreground)

> Caption - The California State University - Sacramento. First operational in 1991, this 12,300 ton-hr chilled water TES installation (dark green tank at right rear) was later expanded to 18,450 ton-hrs in 2002, via a 50% increase in the storage tank height and volume. The first TES installation of its type for the Cal State University System, it has now been joined by 14 similar TES installations at 13 other CSU campuses throughout the State, bringing the total CSU System stratified TES capacity to 278,000 ton-hrs, representing a peak electric load shift of approximately 30 megawatts, or more than 2 MW per installation.

CB&I photo file 7220-55-6.tif (tank behind stone wall)

> Caption - The University of Texas - El Paso. This 30,000 ton-hr stratified chilled water TES installation, which began operation in 1999, was designed to complement the architectural style prevalent on the campus. Such installations are often sited remotely from the main campus chiller plants, which allows TES to behave during on-peak discharge periods equivalent to a satellite chiller plant; in this manner, TES can act not only to peak shave electric power demand, but also to enhance campus distribution network capacity.

CB&I photo file 7220-60-1 (tank behind plant building, with flowers in foreground)

> Caption - The University of California - Irvine. Installed in 1996, this 46,150 ton-hr chilled water TES tank is the largest of 8 similar installations at 7 University of California campuses around the State. Total stratified chilled water TES capacity at the UC System campuses is 254,000 ton-hrs, representing a peak electric load shift of approximately 27 megawatts, or 3.4 MW per installation. Large TES installations, added in lieu of conventional chiller plant capacity at times of system expansion, often provide very significant capital cost savings, as well as operating cost savings.

All three photo citations should credit "Chicago Bridge & Iron Company (CB&I)."

Author's Bio

John S. Andrepont is the founder and president of The Cool Solutions Company, which provides consulting services in the focused areas of Thermal Energy Storage (TES), District Cooling (DC), and Turbine Inlet Cooling (TIC). John has been involved in over 100 large TES installations, dozens of campus, commercial/industrial, and thermal utility DC systems, and small and large TIC installations during the past quarter century, on five continents. He is a long-time active member of IDEA, ASHRAE and TICA, holds Bachelors and Masters degrees in Mechanical Engineering from Rensselaer Polytechnic Institute, and is the inventor of over one dozen patented inventions. He can be reached at CoolSolutionsCo@aol.com. Further information is available at website www.CoolSolutionsCo.com.