Implementing Load Shifting Using Thermal Energy Ice Storage

by

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ABSTRACT

For decades, load shifting control, one of the most effective peak demand management methods, has attracted attention from both researchers and engineers. Various load shifting controls have been developed and introduced in mainly commercial buildings. Utility companies typically penalize consumers with "demand rates". This along with increased population and increased customer energy demand will only increase the need for load shifting. There have been many white papers, thesis papers and case studies written on the different types of Thermal Energy Storage and their uses. Previous papers have been written by Engineers, Manufacturers and Researchers. This thesis paper is unique because it will be presented from the application and applied perspective of the Facilities Manager. There is a need in the field of Facilities Management for relevant applications. This paper will present and discuss the methodology, process applications and challenges of load shifting using (TES) Thermal Energy Storage, mainly ice storage.

DEDICATION

To my Beautiful Wife

ACKNOWLEDGMENTS

This thesis would not have been possible without the influence of Dr.Kenneth Sullivan.

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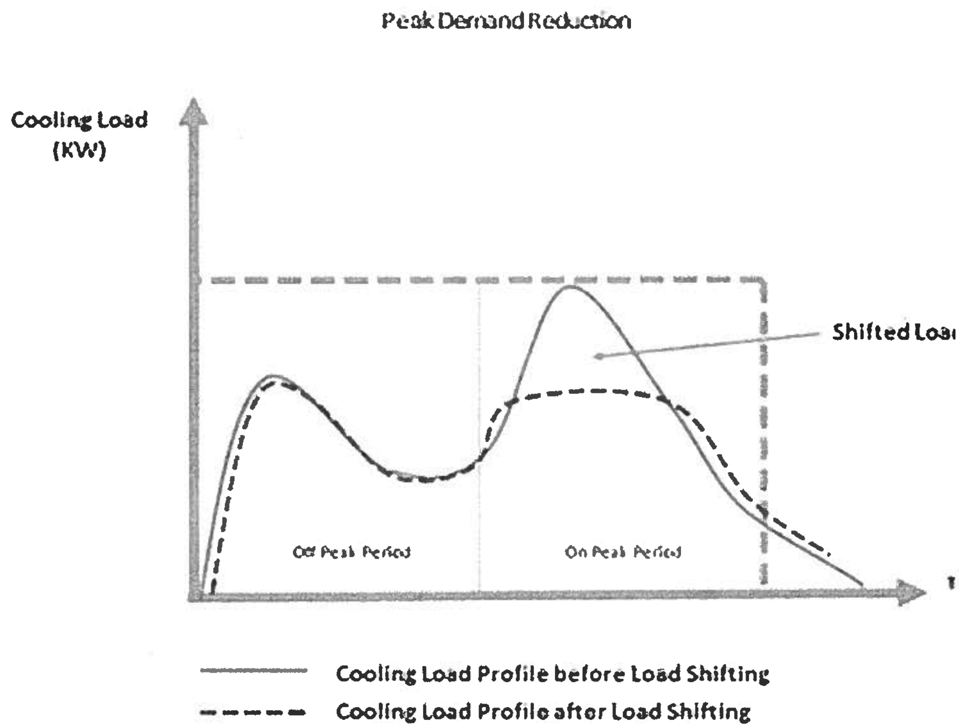
Introduction to Thermal Energy Storage (TES)

TES is a method by which energy is produced and stored at one time period for the use during a different time period. The most common application in the United States is for cooling (Curtland, 2012) and entails making ice during off-peak times (night) and storing it for use during peak demand periods (day). By shifting energy use, a TES system can reduce energy cost and reduce equipment size (Curtland, 2012). Another potential advantage to TES systems relate to the environment. Reducing energy consumption by using energy at night helps the environment. Electricity generated at night generally has a lower "heat rate" (lower fuel use per power output) and therefore a lower carbon dioxide and greenhouse gas emissions. Also, chiller size is reduced when coupled with TES which in turn reduces the amount of refrigerant in the system. Using smaller amounts of refrigerant also helps to reduce environmental impact.

Background

Owners of commercial buildings are commonly charged for electric power based upon energy consumption (KWH) and peak demand. Demand is defined as the energy consumed during a demand interval and peak demand is the maximum demand over a specified billing period (usually one month). Peak demand in commercial application usually lasts for a relatively short period of time (Seem, 1995). Therefore, peak energy demand management is usually performed to reduce the peak demand which results in substantial savings of peak demand cost (figure 1).



1 - *Load Profile before/after load shifting*

Although the electric rate structure from utilities differs, a common feature is that large price differences exist between different periods. For periods with low electricity prices, it is denoted as "off-peak" period. In contrast, the period with the higher price is denoted as "on-peak" period. The price difference is a direct and effective incentive which encourages building owners and facilities managers to alter their load profiles using difference peak demand management methods, *e.g.* load shedding and load shifting. With an altered load profile, benefits can be obtained in terms of a reduced power generation capacity. The International Energy Agency reported the wholesale price of electricity could be reduced up to 50% by decreasing a mere 5% of usage in the peak electrical demand time period (Sadineni, S., 2012). Through peak demand management, an annual savings of $10-15 billion is possible in the US market alone (Sadineni, S., 2012).

On the power demand side (customer), load shifting using TES systems can appear on the surface to be complicated and therefore is not widely known or implemented by the facility management professionals. It is only now that organizations are requiring a higher skill set and education level in their Facilities Department managers. The objective of this thesis paper is to improve upon the understanding of Thermal Energy Ice Storage and the "practical" application in load shifting and how it can be applied in the built environment. The thesis shows in detail that by taking advantage of the process and methodology listed below, facility management professionals along with building owners will see significant payback.

METHODOLOGY

This study was conducted in order to document the process of assessing the methods and outcomes of implementing TES ice storage in a single site built environment. To be able to gather the necessary data the facilities manager utilized a quantitative approach directly related to an existing single site built environment. The following is general information relating to subject site along with detailed parameters. The Alachua County Library Headquarters, built in 1992, is the central administrative location for the Alachua County Library District (ACLD), the sole public library services provider for Alachua County's nearly 250,000 residents. The building profile consists of one 80,000 sf Library Administration building. Operating consists of seven days a week and approximately 80 hours of occupancy. One of the challenges facing the facilities manager of a public entity is to spend taxpayer funds wisely in order to sustain its many activities and best serve patrons. This means making sure operating costs are minimized whenever possible. Energy is a significant expense for the ACLD, second only to labor. Gainesville Regional Utilities (GRU) supplies the ACLD and deploys some of the highest energy rates in the state of Florida (Florida Electric Bill Comparison, n.d.). In most areas of the country, night time energy can be as much as 50% less expensive than daytime energy. This is true whether a building is using time-of-use energy, which is a variable rate structure that charges for energy depending on the time of day or what is considered a flat rate, which is a fixed rate regardless of when energy is used. ACLD was and continues to be on a flat rate price structure; however, a reduction in demand charges presented the biggest opportunity for savings. GRU implements a demand charge that equates to roughly $9.25 in extra fees for each KW used during peak demand hours. In order to maximize savings ACLD needed to use energy when it was least expensive (10pm-6am). The largest energy consuming equipment was an existing chilled water cooling system consisting of one original 200 ton McQuay air-cooled chiller and two 50HP alternating primary pumps suppling 14 air-handler units. It should be noted all air-handler units (AHU) remained and were not considered for replacement.

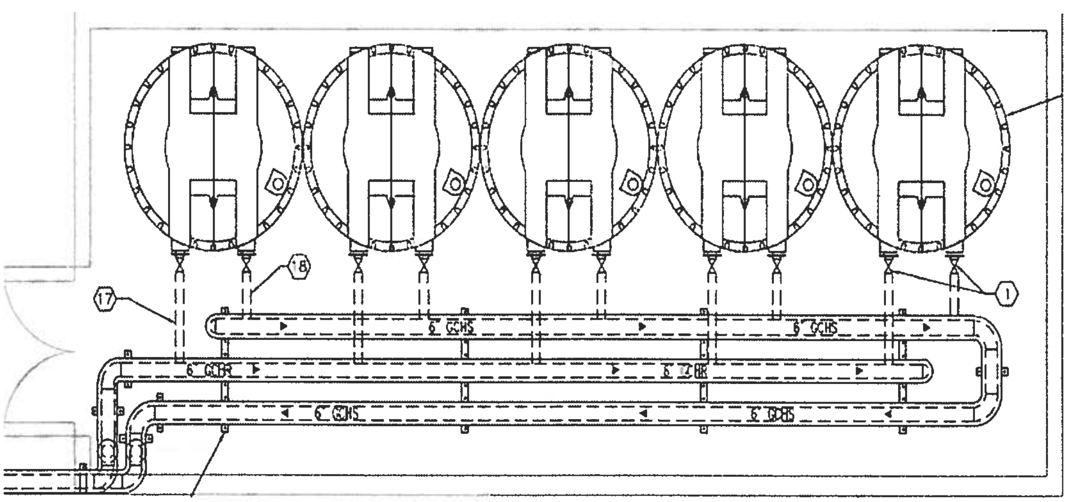
ACLD identified two replacement systems with the focus of reducing overall utility operating cost and shifting peak demand. The two systems under consideration were:

- Alternate #1 - Replacing the existing air-cooled chiller plant with an identical system consisting of new chiller and two primary pumps. It should be noted in addition to replacing existing pumps Variable Frequency Drives (VFD's) would be added to control pump speeds based on building demand.

- Alternate #2 - Replacing the existing system with air-cooler chiller along with partial TES ice storage system. The system included two VFD controlled primary glycol pumps, two VFD controlled secondary chilled water building pumps, one heat exchanger and five 20 ton ice storage tanks with 30% ethylene glycol solution. No heat exchanger was considered in Alt 1 for the following reason. Heat exchangers serve no purpose on a "straight" chilled water system due to constant water temperature that can be delivered directly to building AHU's. Heat exchangers are a medium to exchange differing energy (temperature differential), in a TES system there is extreme cold water (approximately 32 degrees) from the ice tanks that needs to be warmed before entering building side (for this site approximately 43 degrees). The best time to implement a thermal energy storage system is at the beginning of the HVAC design in new construction or while facing retirement of existing chillers in existing buildings (MacCracken, M., 2014).

In order to evaluate the performance of the two systems, a daily load profile using Trane Trace 700 was established using several building characteristics such as lighting, space heating, space cooling, pumps, heat rejection, receptacles, and time of day and month of year. Twelve months of historical utility company consumption data and local utility rates was also used in the analysis. Included in the rate structure were on-peak energy consumption (KWH), off-peak energy consumption (KWH), on-peak demand rates, and off-peak demand rates. Special attention should be given to local rate structure especially on/off peak demand rates as this will have an impact on the project outcome in regards to "Return on Investment". Commercial and industrial energy users require large amounts of electricity once in a while others, almost constantly. Meeting customers' needs requires keeping a vast array of expensive equipment - transformers, wires, substations, and generating stations - on constant standby." While in some areas all customers are assessed a demand charge, the idea is that the customers who create this exceptionally high demand are then correspondingly charged more for it. the higher the differential on/off peak demand rate the potential for a shorter ROI exist.

The next step was to evaluate the "First Cost" of both systems (actual cost provided by equipment supplier). The load profile yielded a total peak cooling load of 118 tons. The actual "nominal building load" was 180 ton therefore a 180 ton standard variable volume air cooled chiller was used for Alternate 1. This was done in an effort to keep the current system tonnage consistent. For Alternate 2 (partial ice storage), it was estimated that five CalMac ice tanks would fit the available area *(figure 2).*



2 - Alachua County Library District TES System

Because the stored ice "shares" the peak load with the chiller, the installed nominal tonnage for the TES chiller could be reduced to 130 tons. In addition to first cost, maintenance costs which are determined by industry standard based on chiller/CEP size were estimated to be $3,500 for the standard air cooled chiller system, and $4,500 for TES system. The greater cost for the TES system includes the glycol management needed to operate the system at the temperatures required to build ice.

RESULTS

As mentioned in methodologies the data listed below: Building Load Profile, Historical Consumption, Utility Rates, Equipment First Cost and Maintenance Cost support the clear delineation between Alternate 1 and Alternate 2.

Building Load Profile for 80,000 sf Library Administration building *(figure 3)*.

Building Load Profile

		Alt-1 Standard CEP Retrofit		Alt-2 Partial TES	
		Energy Btu/yr.	Peak kBtuh	Energy Btu/yr.	Peak kBtuh
Lighting – conditioned	Electric	658.4	176	658.4	176
Space Heating	Electric	0.4	168	0.4	168
Space Cooling	Electric	898	538	720	303
Pumps	Electric	39.2	22	129.2	68
Heat Rejection	Electric	104.4	69	18.5	37
Receptacles - conditioned	Electric	1424	380	1424	380
Total Building Consumption (Btu units)		**3124.4**		**2950.5**	

3- Alachua County Library District Administration Building Load Profile

Twelve months of historical utility company consumption data (*figure 4.)*

Monthly Energy Usage – Fiscal Year 2014-2015											
Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
92.1	70.4	71.8	66.9	71.1	91.5	90.1	94.8	93.4	93.9	96.3	87.9
Usage measured in KWH											

4- Monthly Energy Usage, Fiscal year 2014-2015, Gainesville Regional Utility Historical Utility Consumption

Local utility rates *(figure 5).*

Flat Rate Energy Cost	Alternate 1	Alternate 2
On Peak Energy Consumption (KWH) -	$0.0640	$0.0640
Off Peak Energy Consumption (KWH) -	$0.0160	$0.0160
On Peak Energy Demand (KW) -	$9.2500	$9.2500
Off Peak Energy Demand (KW) -	$0.0000	$0.0000

5- Local Utility Rages - raw data supplied by Gainesville Regional Utilities

Standard CEP/ Thermal Energy Storage Initial Cost *(figure 6)*.

Alternate 1 - Standard Air-Cooled Chilled Water System Initial First Cost.

Item	Cost/Unit	Unit	Unit Measurement	Total Cost
Chiller	$1,250.00	180	$/Ton	$225,000.00
Replacement of Pumps Piping and Valves.	NA	NA	NA	$25,000.00

6- TES System Cost

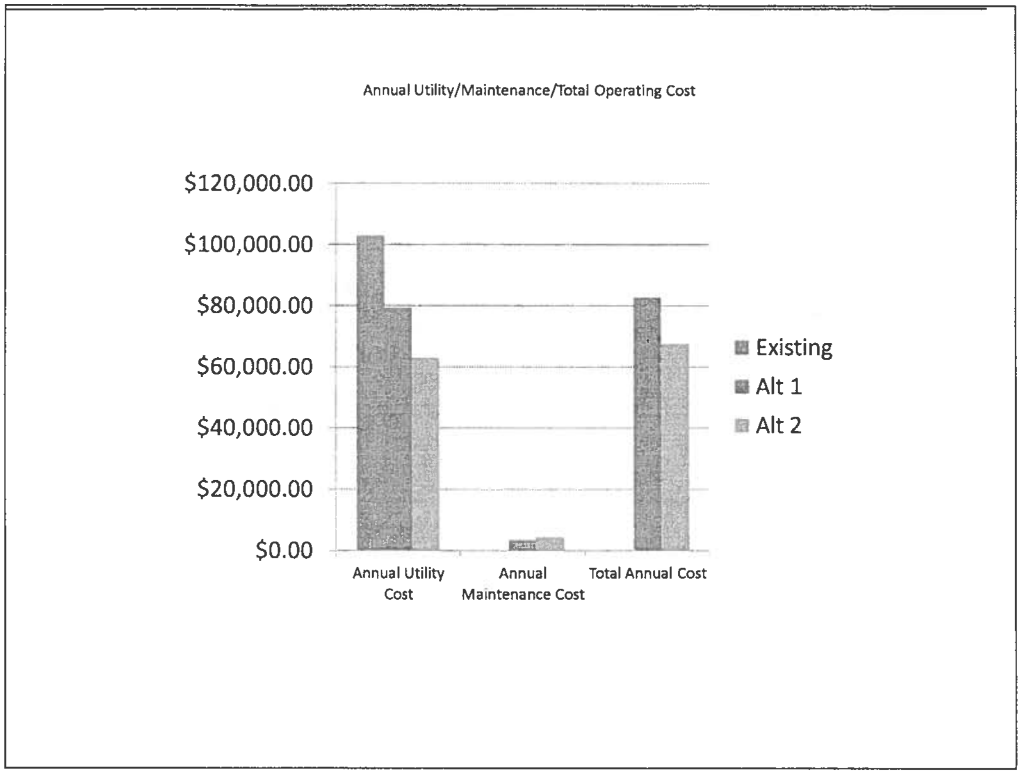
Alternate 2 – TES System Initial First Cost

Item	Cost/Unit	Unit	Unit Measurement	Total Cost
Chiller	$1,250.00	130	$/Ton	$162,500.00
Ice Tanks	$120.00	667	$/Ton-hr	$80,040.00
Heat Exchanger	$90.00	100	$/Ton	$9,000.00
Additional Piping	NA	NA	$	$30,000.00
Glycol	NA	NA	$	$7,000.00
Specialties*	NA	NA	$	$15,000.00

* Includes extra pumps, valves, filters and other accessories specific to TES

7- TES System Cost

Based on data obtained from figures 3, 4 and 5; results yielded an annual utility cost of $79,299.00 for Alternate 1 and $63,127.00 for Alternate 2. Results also show a yearly total operating cost of $82,800.00 for Alternate 1 and $67,627.00 for Alternate 2 *(figure 7)*.



8- Annual Utility/Maintenance Total Cost - ACLD Administration Building

Comparing these numbers to existing annual energy cost of $103,000.00, this yielded an annual savings of $23,701 and $39,873, respectively. Although Alternate 2 had the higher initial cost (figure 5), the energy costs saved by the implementation of thermal energy storage provided a simple payback of 3.31 years in comparison to Alternate 1. When comparing Alternate 1, Alternate 2 to Existing CEP in place the findings show a simple payback of 10.5 for Alt 1 and 7.61 for Alt 2 respectively *(figure 8).*

Simple Payback Alt 1 v. Alt 2 and Alt 1 v. Alt 2 in comparison to Existing CEP

Payback Alternate 1 v. Alternate 2			Payback Alt 1/ Alt 2 v. Existing CEP		
	Alt. 1	Alt. 2	Existing CEP	Alt 1	Alt 2
Initial Cost	$250,000	$303,540	$0.00	$250,000	$303,540
Annual Cost	$23,701	$39,873	$0.00	$23,701	$39,873
Payback Period in years	- 0	3.31	$0.00	10.5	7.61

9- *Payback Alternate 1 v. Alternate 2 in comparison to existing annual utility cost*

CONCLUSION

Thermal Energy Ice Storage is a promising technology for single site new construction and applicable built environments. From the perspective of the Facilities Manager, reducing overall energy cost and peak demand charges are paramount. The results demonstrate that a clear set of parameters and a systematic due diligence process and successful conclusion can be determined whether to pursue the implementation of a TES system.

The results of implementing TES also identified the following:

- Due diligent on the front end is a must to ensure all systems involved are compatible. The existing Building Automation System (BAS) must be able to interface with other systems for the process to work seamlessly.
- Maintenance and cost of maintaining has shown to be minimal. All maintenance is addressed by in-house maintenance staff. Ice storage tanks have no moving parts, tanks water levels are checked bi-annually (manufacture recommendation). Leak inspection is performed daily. Pumps are maintained based on hourly usage tracked through BAS and the balance of equipment placed on normal maintenance schedule. It should be noted the TES is a closed system, unless there is a leak the addition of glycol solution along with any make-up water would not be necessary.
- Redundancy of TES system: Alternate 1 leaves no chance for redundancy in case of chiller fault. With TES if the ice tanks do not fully discharge there is cooling energy available depending on the amount of ice left in the tanks. The only guarantee for redundancy would be to have a backup

chiller. To summarize Alternate 1 offers no chance of cooling energy in case of chiller fault, Alternate 2 offers a potential of cooling energy based on remaining ice storage.

- Growing need for trained building technicians. Companies are looking for new ways to retrofit existing assets to make them more energy efficient; TES is a potential part of this technology. The most relevant professions to accomplish this sustainability renaissance are that of the Facility Professional. Unfortunately, ACLD has witnessed a lack of initiative on the part of building mechanics to embrace the understanding of the TES process. ACLD has offered conferences, seminars and information regarding facility associations such as International Facilities Management Association (IFMA). We will continue to encourage the maintenance staff to increase their knowledge base and review hiring criteria.

REFERENCES

Curtland, C. (2012, August 24). Is Your Building a Candidate for Thermal Energy Storage? Retrieved February 26, 2016, from www.building.com/articledetails/tabid/3334/articleID/ 13850/default.aspx

Florida Electric Bill Comparisons - Florida Municipal Electric Association. (n.d.). Retrieved July 07, 2016, from http://publicpower.com/electric-rate-comparisons/

MacCracken, M. (2014, June). 64-68. Retrieved June, 2016, from www.IFMA.org/fmj.

(3) Sadineni, S. (2012). Measurements and simulations for peak electrical load reduction in cooling dominated climate. *Energy 2012,* 689-697. Retrieved May 5, 2016.

Seem, J. (1995). Adaptive demand limiting control using load shedding/shifting. *HVAC&R Res,* 21-24. Retrieved June 1, 2016.