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Case Study of Load Shifting Using Thermal Energy Ice Storage in Public Facilities

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ABSTRACT

Energy management is becoming increasingly important in the building sector due to the fact that it accounts for 50% of total energy consumption in industrial nations. The objective of this study was to compare a partial thermal energy storage system and a traditional air-cooled chiller system in a building retrofit in Alachua County, Florida in order to identify energy and cost savings and to quantify those savings. Initial costs, maintenance costs, energy consumption and utility rates were used to draw comparisons between the two systems. Findings include annual utility costs and annual operating costs for the two systems, and their simple payback period. The Thermal Energy System (TES) was found to be more beneficial in the long run, despite its higher cost of installation. Practical implications of implementing an advanced system such as TES are discussed to better prepare building professionals considering TES.

Keywords: thermal energy storage, annual operating cost, payback period, energy management, energy efficiency

INTRODUCTION

In light of high energy consumption in the building sector, pursuing energy efficiency in the built environment is now a well-established need (Santamouris, M, 2013; Aitken, 2003; Filippín & Larsen, 2007; International Energy Agency [IEA], 2013). Thermal Energy Storage (TES) is one of the several means employed to attain energy efficiency. It is a method by which thermal energy is stocked by "heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation" (International Renewable Energy Agency, 2013, p.1). While it has not been used widely in the United States, TES is seeing more widespread application in recent times. Some recent adopters of TES in the US are University of California Merced, the New York City headquarters of Teachers Insurance and Annuity Association, California State Lottery Headquarters, and Kapi'olani Medical Center in Hawaii.

This paper seeks to identify the advantages of TES in the built environment by analyzing and comparing the implementation of TES ice storage versus a traditional air-cooled chiller plant in a single site built environment located in a region with a humid, subtropical climate.

Research Questions

Although the literature reveals a considerable amount of work in terms of advancements in methods and materials used to store thermal energy as well as the applications of TES in building envelopes (Tian & Zhao, 2013, Kuravi et al., 2013; Pielichowska, & Pielichowski, 2014; Sharma et al., 2015; Nkwetta & Haghighat, 2014; Pomianowski et al., 2013), not much research has been done on whether the implementation of TES in the built environment has significant benefits in terms of cost savings. In response to this research gap, the research question addressed in this study is whether implementing TES in the built environment results in sufficient payback to offset the added costs of implementation and operation in a reasonably short period. And if so, this paper seeks to quantify the cost savings it results in.

LITERATURE REVIEW

Since 2013, commercial buildings have accounted for nearly one-fifth of the total energy consumption in the United States (U.S. Energy Information Administration, 2017). According to the IEA's Electrical and Heat Usage Statistics in the United States (2014), the commercial sector constitutes a third of electricity and heat usage. Retail rates for energy consumption in commercial buildings vary by utility and load. In addition to this, customers often have the option to choose between applicable rates. However, the utility rates for commercial buildings most often include the elements summarized in Table 1.

Although the electric rate structure differs across utilities, a common feature is the large price difference that exists between different periods. Periods with low electricity prices are denoted as "off-peak" periods, and periods with higher prices are denoted as "on-peak" periods. The price difference is a direct and effective incentive that encourages building owners and facilities managers to alter their load profiles using different peak demand management methods such as load shedding and load shifting. With an altered

TABLE 1.—Elements of Utility Rates in Commercial Buildings (Davidson et. Al, 2015)

Charge	Description
Fixed Charge	Fixed monthly charge independent of energy use. Can range from $15 for small businesses to more than $1,000 for large facilities.
Energy Charges	Rates based on energy consumption, usually in dollars per kilowatt-hour or cents per kilowatt-hour.
Demand Charges	Charges for peak power use over a particular time interval (typically 15, 30, or 60 minutes) within a billing cycle. Can be constant throughout the year, variable by the season, or variable by the hour

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 (IEA & Organization for Economic Cooperation and Development [OECD], 2003). Through peak demand management, an annual savings of $10-15 billion is possible in the US market alone (IEA & OECD, 2003).

Thermal Energy Storage

Thermal energy storage is the temporary storage of high or low-temperature energy for use at a later time. While it is considered an advanced energy technology today, it has been used for centuries when ice was harvested and stored for later use. Some other examples of TES include storing summer heat for use in winter, and storing heat or coolness that has been produced electrically during off-peak hours for use in subsequent peak demand hours. It is also being increasingly used in solar power systems as they help offset the fluctuations in solar energy input (Dincer & Dost, 1996; Dincer & Rosen, 2002). In addition to smoothening out the electricity supply from renewable energy sources, TES systems help in expanding the capacity of existing systems during high-demand periods, thereby reducing the need for new electrical generating facilities when energy demand is greater than supply (Dincer & Rosen, 2002). Another benefit of TES systems is its impact on the environment. During peak demand, coal or oil is usually the source of electricity. Load shifting by using thermal energy in their stead reduces demand during peak hours, which thereby reduces dependency on coal by using hydro, nuclear and renewable sources that are more sustainable (ISO New England, 2016; Buildings: Smarter Facility Management, 2008). Reduced energy demand during peak demand by shifting energy purchases to low-cost periods has the added benefit of cost savings (Dincer & Rosen, 2002). A constant power supply assured through energy storage also increases system reliability (Dincer & Rosen, 2002).

Despite its obvious advantages, TES adoption has been slow in the United States. The high installation cost of thermal energy systems is a major deterrent to a more widespread adoption of this technology. Another significant barrier is a lack of understanding of the system and its benefits. In the built environment, it is usually the facility manager who is tasked with the responsibilities of energy management and energy efficiency. It has been shown that facility managers have considerable impact in reducing energy consumption through improving centralized energy management of plant and equipment responsible for local heating, cooling and lighting (Goulden and Spence, 2015). However, the lack of independent information and trusted sources to build a business case has been found to be a barrier to improving energy efficiency in buildings through retrofits (Goulden & Spence, 2015). Towards this end, this study seeks to present unbiased information about TES by identifying the advantages of using TES in building retrofits, if any, and quantifying them to the extent possible.

METHODOLOGY

Data Sample & Context

Alachua County Library Headquarters in Florida was used as the focus of this study. Built in 1992, it 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 sq. ft. Library Administration building. It operates seven days a week and has an approximate average weekly occupancy of 80 hours (Alachua County Library District, n.d.).

Energy is a significant expense for the ACLD, second only to labor. The utility services to ACLD are provide by Gainesville Regional Utilities (GRU), which deploys some of the highest energy rates in the state of Florida (Florida Municipal Electrical Association, 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 uses time-of-use energy, which is a variable rate structure that charges for energy depending on the time of day, or a flat rate. ACLD is on a time-of-use rate price structure. A reduction in demand charges presented the biggest opportunity for savings since ACLD is charged approximately $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 the least expensive (10pm-6am). The largest energy consuming equipment at ACLD was an existing cooling system consisting of one 200-ton air-cooled chiller and two alternating primary pumps.

Comparative Research

A comparative research method was utilized, which is used to uncover differences between social entities, and reveal unique aspects of a particular entity that would be virtually impossible to detect otherwise (Mills et al., 2016). In particular, comparable cases strategy was used for this study. According to Lijphart (1975), this strategy is to be used when the entities to be compared are similar in a large

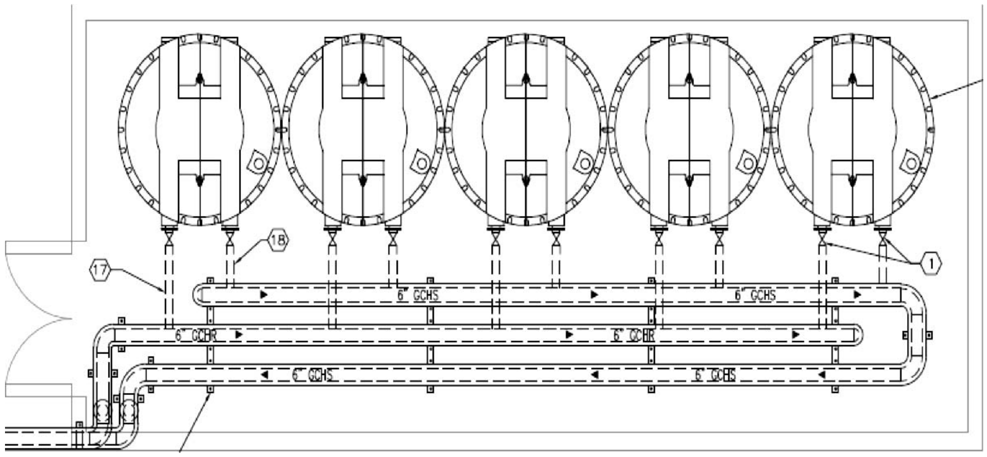

FIGURE 1.—Alternate 2: Partial TES Ice Storage System

number of important characteristics (variables), which one wants to treat as a constant, but dissimilar as far as those variables are concerned, which one wants to relate to each other. This strategy was selected for this study because there was a need to compare different systems, which are largely similar in terms of their function and other characteristics such as the utility rates would remain constant across the two systems.

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 – Standard CEP Retrofit, where the existing air-cooled chiller plant will be replaced with an identical system.
- Alternate #2 – Partial Thermal Ice Storage, where the existing system will be replaced with an air-cooler chiller along with a partial TES ice storage system. The partial system was to include two primary glycol pumps, two secondary chilled water building pumps, one heat exchanger and five 20-ton ice storage tanks with 30% ethylene glycol solution.

The next step was to determine the capacity of both the systems. The load profile yielded a total peak cooling load of 118 tons. However, the nominal building load was 180 tons; 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, as depicted in figure 1. 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 order to evaluate the performance of the two systems, a daily load profile using Trane Trace 700 was established using building characteristics such as lighting, space heating, space cooling, pumps, heat rejection, receptacles, time of day, and month of year. Twelve months of historical utility company consumption data and local utility rates were also used in the analysis. The rate structure included on-peak energy consumption (KWH), off-peak energy consumption (KWH), on-peak demand rates, and off-peak demand rates.

TABLE 2.—Building Load Profile for Alternates 1 and 2.

	Energy Consumption (Btu/hr)		Peak Capacity (kBtuh)	
	Alternate 1	Alternate 2	Alternate 1	Alternate 2
Lighting – conditioned	658.4	658.4	176	176
Space Heating	0.4	0.4	168	168
Space Cooling	898	720	538	303
Pumps	39.2	129.2	22	68
Heat Rejection	104.4	18.5	69	37
Receptacles - conditioned	1424	1424	380	380
Total Building Energy Consumption (Btu)	3124.4		2950.5	

RESULTS

Results of criteria that were used to draw comparisons between both the alternates are described below. A summary of the building load profile of ACLD is provided in Table 2, which compares the energy consumption and peak energy capacity for both the alternates across several functions such as lighting, heating and cooling. Table 3 depicts the first cost of Alternate 1 – Standard CEP Retrofit and Table 4 depicts the first cost of Alternate 2 – Partial TES System.

TABLE 3.—First Cost of Alternate 1 – Standard CEP Retrofit

Item	Cost/ Unit ($)	Unit Capacity	Unit of Measurement	Cost ($)
Chiller	1,250	180 Ton	$/Ton	225,000
Replacement of pumps, piping and valves	NA	NA	NA	25,000
Total First Cost (S)				250,000

TABLE 4.—First Cost of Alternate 2 – TES System

Item	Cost/ Unit ($)	Unit Capacity	Unit of Measurement	Cost ($)
Chiller	1,250	130 Ton	$/Ton	162,500
Ice tanks	NA	NA	$/Ton-hr	80,040
Heat exchanger	90	100 Ton-hr	$/Ton	9,000
Additional piping	NA	NA	$	30,000
Glycol	NA	NA	$	7,000
Total First Cost (S)				288,540

In addition to these data, historical utility company consumption data for the year 2014-2015 and local utility rates were used in the calculations, which are listed in tables 5 and 6. These data were provided by Gainesville Regional Utilities.

The total operating cost for the systems was calculated based on the annual utility cost of the systems, as well as the annual maintenance cost of the systems. Calculations yielded an annual utility cost of $79,299 for Alternate 1 and $63,127 for Alternate 2. Comparing these numbers to existing annual energy cost of $103,000, the alternates result in annual savings of $23,701 and $39,873 respectively. Maintenance cost was determined by industry standards based on chiller/CEP size, and was estimated to be approximately $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. Adding maintenance costs to the first costs yields a total operating cost of $82,800 for Alternate 1 and $67,627 for Alternate 2, as shown in figure 2. Although the initial cost of Alternate 2 is higher by $53,540 than Alternate 1, the annual cost savings of Alternate 2 is also higher (by 16,172). Therefore, Alternate 2 will break even in 3.31 years sooner than Alternate 1.

CONCLUSION

Thermal Energy Ice Storage is a promising technology for single site new construction and applicable built environments. From the perspective of a Facility Manager, reducing overall energy cost and peak demand charges are paramount. The results of this study demonstrated that TES systems result in annual cost savings and that they break even sooner than a conventional air-cooled chiller. These findings can be leveraged by facility managers and other building professionals in order to achieve higher energy efficiency and cost savings. The authors propose conducting similar studies in different settings in order to ensure the reliability of the findings.

TABLE 5.—Historical Utility Company Consumption Data for 2014-2015

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Usage (kWh)	92.1	70.4	71.8	66.9	71.1	91.5	90.1	94.8	93.4	93.9	96.3	87.9

TABLE 6.—Local Utility Rates

Flat Rate Energy Criteria	Cost ($)
On-peak energy consumption (kWh)	0.0640
Off-peak energy consumption (kWh)	0.0160
On-peak energy demand (kW)	9.2500
Off-peak energy demand (kW)	0.0000

OTHER LESSONS LEARNED FROM IMPLEMENTATION

While the study demonstrated the advantage of using TES over a traditional air-cooled chiller system, the process of implementing TES also identified the following lessons learned that can guide future implementation of such systems:

- Due diligence on the front end ensures that all systems involved are compatible with each other. The existing Building Automation System (BAS) must be able to interface with other systems for the processes to work seamlessly.
- Maintenance and related costs have been shown to be minimal. Ice storage tanks have no moving parts, pumps need to be maintained based on hourly usage and the balance of equipment will be placed on normal maintenance schedule.
- There is a 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 witnessed a lack of initiative on the part of building mechanics to embrace the understanding of the TES process.

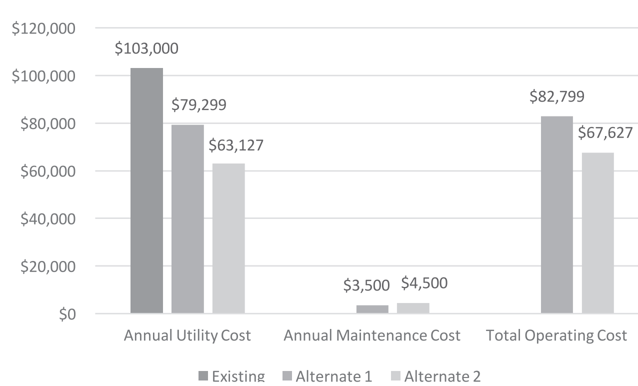

FIGURE 2.—Annual Costs for Existing Facility, Alternate 1 and Alternate 2

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