Deregulation of Energy

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1. Abstract

The world revolves around energy and money; however there is not enough to go around. Energy deregulation is designed to conserve both. Installations of thermal energy systems to cool buildings are targeted at large commercial and industrial buildings in order to improve energy efficiency, comfort, and also to lower peak demands.

Consumers have discovered financial benefits from shifting cooling loads from peak hours to off-peak hours. It not only saves money, energy providers benefit from making more efficient use of energy without wasting it. Both the consumer and producer therefore greatly lower waste of energy, causing the economy to flourish with long lasting energy.

2. Introduction

Energy is a major problem no matter what innovations are made. It is used to power almost everything in everyday life. Many people do not realize that energy is not magic; it does not come from a wall, but from a plant, where high demands meet consumer expectation. For large industrial companies, energy is a high price to pay; especially in the summer months. On top of their average load, or the machines they use, they run chillers to keep the building cool by using heating, ventilating, and air conditioning systems, “HVAC.”

Another downfall of high energy usage deals with peak hours and demand of the electricity company. Peak is the time of the day that the most significant amount of energy is used; generally between the hours 8:00 am and 8:00 pm. Off-peak is the opposite. The charge for off-peak always remains constant where as on peak is charged for the average use of energy of previous months. Peak hours run constant to the highest level of energy used, or system capacity (see Fig. 1). When peak hours are in effect, if the company runs over the allotted amount of energy, the charge for the amount of energy is elevated. Peak exists because it is the amount of energy provided to the industry. Once exceeded, the energy provider must supply more energy to the consumer. All industries on this system are allotted a certain amount of energy, which is mandatory by governmental law.

A proposed solution to this problem is thermal energy storage. Thermal energy storage refers to the production of ice or chilled water at night to cool during the day. The concept of this system is to produce the ice at night and use them in place of chillers during the day (see Fig. 3 and Fig 4. The additional costs are shown in Fig. 2). The ice produced is harvested and stored in large facilities located near the building. The systems used to produce the ice at night run at a very low rate per kilowatt-hour. Therefore, the megawatts used by chillers during the day are now eliminated with the exception of pumps. The pumps are used to flow a coolant through the pipes, past the ice. Pumps are much cheaper than using chillers during the day. Using completely ice throughout the day is full storage. Partial storage is when ice is used when the number of megawatts is greatest.

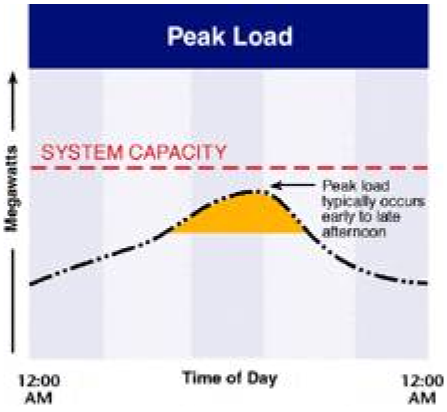

Fig. 1. The amount of megawatts used generally rise during the middle of the day.

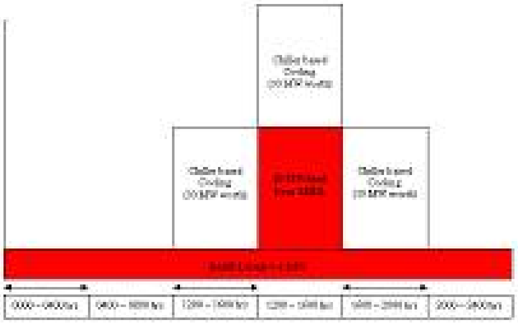

Fig. 2 Chiller costs are high when the mills are run between 12 and 4 PM.

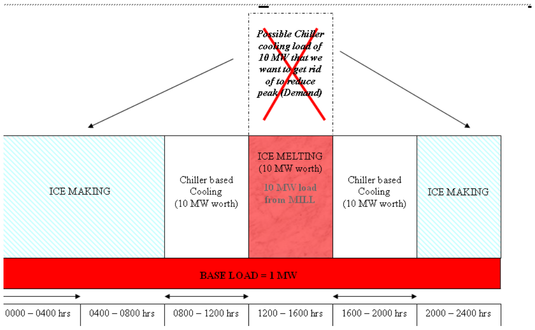

Fig. 3 Chillers are not needed during the mill running time; replaced with ice production during off-peak hours

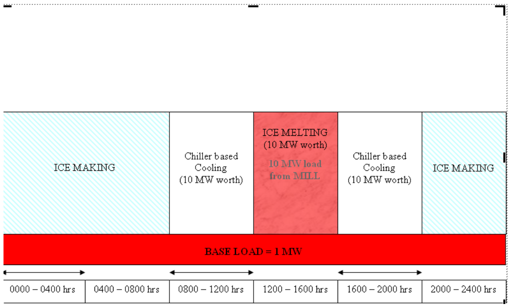

Fig. 4 Ice storage systems are run during off-peak hours to reduce cost during peak hours.

3. Background Information/Related Work

Ice storage isn't actually a new idea. In fact, it's been around for over a hundred years. One of the earliest examples goes back to 1880, when Madison Square Theater used four tons of ice and large fans to cool theatergoers. This system, created by B. F. Sturtevant Co., was considered to be one of the first engineered cooling systems and set the standards for ice storage systems in the United States [6].

Though the system itself isn't entirely new, the use of ice storage overnight to shift an industrial load to overnight hours and avoid peak charges has been around for only half as long as modernized air conditioning. And yet, it wasn't until the energy crisis of the 1970s that thermal energy storage really dug into the mindset of the American people.

Many colleges and universities in particular are turning to thermal energy storage. Florida Gulf Coast University is currently saving incredible amounts of money through the use of Icebank, an ice storage company. The system was installed in August 1997 when the university was built. Even though the initial installation cost was considerably more than conventional air conditioning, the payback was less than five years. In total, sixty-one 140 ton-hour tanks are installed above ground to cool the university. The ice is created by a 600-ton chiller during nighttime off-peak hours, and a backup 300-ton chiller is also running continuously. Two miles of piping bring the cold air to people on campus. The 3600 ton-hour plant is not only useful for off-peak ice making, but it can also be used as backup in the event of a chiller failure. Florida Gulf Coast University now saves $130,000 a year and keeps down the cost of tuition and educational taxes [3].

Brazosport College of Lake Jackson, Texas is also taking advantage of cheap nighttime energy costs. Off-peak cooling, starting in 1991, allowed the school to shift 570 kW of energy to the nighttime load. The annual savings amount to $62,500 [2].

The first use of thermal energy storage in Manhattan was the forty-one-story ENERGY STAR office building. Instead of the two original 750-ton chillers, a high-efficiency 1000-ton chiller and a 600-ton ice-making chiller were installed. The new chillers are capable of handling an extra 350 tons of cooling without any extra energy usage or cost [2].

The Rohm and Haas Research Facility of Spring House, Pennsylvania found that they saved money in more ways than one. Originally, they had installed a 4000 ton conventional cooling system. Chillers contributed to about 40% of the electricity costs. In 1995, a thermal storage system was installed. Since then, the research facility has reduced their peak energy demand by 70%. Because of this, air handlers did not need replacing because the storage system accounted for this [2].

The Dallas Veterans Affairs Medical Center is saving almost double the amount of money as Florida Gulf University; by installing ice storage tanks, they save roughly $225,000 in electricity costs a year. The thermal energy system involved a total of 24,628 kW and broke even within seven years [24].

Thermal energy storage is particularly useful in southern states such as Florida that have warm weather all year round. Fort Myers Regional Service Center, located in this state, now saves over $100,000 a year through nine hours of off-peak ice making and six hours of cooling through chillers in the morning. Their overall energy usage is significantly lower than the industrial average for the state of Florida – by 10% [2].

The efficacy of ice storage is supported by its use in the federal government. Fort Jackson, South Carolina has been using thermal energy storage since 1996 and has saved $400,000 annually. The U.S. Army Construction Engineering Research Laboratory (CERL) in Champaign, Illinois takes a slightly different approach: the company bought 125,000 Cryogel Ice Balls^{TM}. The balls freeze during off-peak hours and thaw during the day to provide cooling to the building. Though the efficiency was slightly lessened, the energy usage was also cut dramatically. Now, they can cool the same load with 35% less energy usage. Also, by merely shifting 200 kW worth of energy to off-peak hours, CERL was able to save $15,000 per year. Furthermore, a diurnal ice system (DIS) has saved Yuma Proving Ground, Arizona $22,500 a year since 1988 when the system was installed [20], and the Social Security Administration Building, Computer Data Center in Chicago began saving $8,000 annually when they removed four twenty-ton chillers [2].

Ice storage is also becoming an international movement. Cosmo Square in Osaka, Japan is an example of ice storage's global migration. The cooperative effort of Kansai Electric Power and Osaka Gas resulted in the installation of tanks for the World Trade Center and the Asian Trade Center. It has an ice storage capacity of 29,300 ton-hours and 103,000 kWh. Another example of the wide range of the use of thermal energy storage is the Chauffage Urbain Prodith office building in Lyon, France. The building has an area of 4.3 million square feet and combines thermal energy storage with a conventional cooling system. This has an ice storage capacity of 8530 ton-hours and 30,053 kWh [18].

Essentially, ice storage has been saving companies, corporations, schools, the government, and many other factions thousands of dollars throughout the last few decades. Though thermal energy storage is not ideal for every business, a result of this investment seems to be skewed in the direction of lower energy usage and a large amount of money that would have otherwise been spent on electricity.

4. Experimental Design

In our study, we analyzed the capital required and the gains associated with the implementation of Thermal Energy Storage. The experiment was based around the nearby urban region of Newark, where buildings in which we intend to utilize TES are bountiful. TES is beneficial to such properties because they are the ones steeply penalized for demand put on the grid. The first scenario considered was a commercial building without a TES system under the domain of an electric company which charges based upon a "Peak/Off-Peak Plan." Here, the site is operating on a constant Base Load of 1,000 kW. Additionally, the Mill is in operation from 12:00 pm until 4:00 pm at 10,000 kW. The building is then occupied between 8:00 am and 8:00 pm, during which time a comfortable temperature is required. Currently, a 10,000 kW chiller is in place which operates during these hours. Examining the load profile of the company, they require 1,000 kW * 24 h + 10,000 kW * 12 h + 10,000 kW * 4 h, coming to a total of 184,000 kWh of electricity. In Newark, electricity is $0.11/kWh. So, for a month, 184,000 kWh/Day *31 days * $0.11/kWh comes to $627,440.00/month for electric costs. Their peak demand would reach 21,000 kW, and with a demand rate of $9.81/kW, that portion of the bill would amount to $9.81/kW * 21,000kW = $206,010.00 each month. Therefore, between power consumption and demand charges, a building on a Peak/Off-Peak without a TES system would have a total monthly bill of $833,450.00 per month.

According to current industry relationships between chiller size and power consumption, this chiller would operate at 2,500 tons of cooling capacity. This unit of power, multiplied by time, would give the total energy used by the chiller. If 1 ton of refrigeration = 12,000 Btu's/hour and 1 kW = 3,412 Btu's, then 1 ton gives approximately 3.157 kW of cooling [13]. In our case, the 2,500 ton chiller would remove 7,892.5 kW of heat for the 12 hours it would be required to be in operation (79% efficiency is exceptional) [5].

To remove the spike of demand between the hours of 12:00 pm and 4:00 pm when the chiller and mill are required to run, the chiller may be utilized to build up ice in storage tanks during the night hours. This way the chiller doesn't need to run while the mill runs. The TES system would need to provide cooling only for those four hours on a partial-TES cooling plan, as from 8:00 am to 12:00 pm and from 4:00 pm to 8:00 pm the chiller may be switched on without increasing the peak demand for electricity. For four hours, the ice needs to remove 31570 kWh of heat. Assuming the melting process is 60% exergy efficient [22], this means that 31570/.6 = 52617 kWh of thermal energy must be stored in the ice. Since the chiller gives 86% efficiency in creating the ice [22], the chiller will require 52617 kWh/.86 = 61182 kWh to produce the necessary cooling energy.

If the chiller is a 10,000 kW chiller, it shall take 61182 kWh / 10,000 kW = 6.12 hours to produce enough ice. To store the ice, the ice container must be able to store 2,500 tons * 6.12 hours = 15295.5 ton-hours of capacity. Common vendors will sell in the region will sell containers of 486 ton-hours each [17]. This way, 32 tanks would be required. Although we are now using 6.12 * 10,000 kW = 61,200 kWh instead of 40,000 kWh to provide the same amount of cooling, peak has been reduced from 21,000 kW to 11,000 kW.

Under this system, a company will be billed for 1,000 kW * 24 h + 10,000 kW * 12 h + 10,000 kW * 6.1 h (as opposed to 4 h), which is 205,000 kWh of electricity per day. 205,000 kWh * 31 days * $0.11/kWh results in $699,050.00/month for electricity. The demand charge is 11,000 kW * $9.81/kW = $107,910.00/month. In a center with partial-TES cooling plan under a peak/off-peak electric tariff the total bill is $806,960.00/month, with an initial ice tank cost of $350,000.00 and a net saving of 4%.

If you were to replace all cooling with off-peak methods, using ice storage to replace 12 hours of chiller cooling, you would need store three times as much ice storage capacity. The cost of buying tanks would be increased to $1,050,000.00, the efficiency of the chiller would be reduced by 51.6% in the transfer of energy to ice and from ice (in reference to direct chiller cooling), the chiller would require 18 hours to create the ice – which is greater than nightly off-peak periods – so you would have to buy another chiller to accomplish this task in the limited time frame, and there would be no further benefit of peak reduction, because the mill and base load will still always require 11,000 kW. Therefore, full OPC is not beneficial in this situation.

If the business is located in a region in which electricity is sold on an hourly model, then the TES can be regulated such that the ice is produced during night hours in which electricity is the cheapest (and providing that the chiller is producing ice for several consecutive hours to maintain efficiency). Based upon rates from PSE&G [7], the purchase and use of cheaper energy during night hours could have yielded the following benefits in the summer months of 2005: May - $144,637.50, June - $161,677.30, July - $174,391.30, August - $192,147.60, September - $207,653.70. These five months were analyzed by selecting the cheapest consecutive 6.12 hours of electricity during each night during which to operate the chiller for ice creation, finding the kWh usage for each hour, finding the cost for each hour according to price and kWh usage, and then the total cost of ice production for each night was determined. Afterwards, the cost of running the chillers for the remaining time in the office was calculated for each day and added to the nightly cost, because under our plan the building would be running for this time under partial OPC as discussed earlier, and the ice created during the night would cool the building from 12:00pm – 4:00pm, but the chiller would cool the building directly from 8:00am -12:00pm and 4:00pm – 8:00pm. This total was compared to the cost of running the chillers for 12 hours (without TES) during the day at higher daytime rates, and then the difference between the OPC model cost and chiller-only cooling model cost was found for each day. The sum of these savings was also calculated for each month. According to historical weather patterns in Newark, these 5 months would be the only months in which cooling would be required [27]. In just these five months, however $880,497.40 could have been saved in using cheaper electricity. In addition, on an hourly system the demand rate is $8.60/kW. At this rate, the difference between OPC peak (11,000 kW) and the peak of the chiller and mill would achieve (21,000 kW) would also save (21,000 kW – 11,000 kW) * $8.60/kW = $86,000/ month in demand for peak reduction. Again, the cost of the ice tanks would be $350,000.00, but there would be a net saving of 18% in comparison to an hourly model without TES.

After such exploration, the best model is the partial-OPC cooling model in which 32 486 ton-hour ice containers would store ice which would be produced by an already-installed 25,000 ton chiller. The ice would be frozen at night, and used to cool the facility during mill operations and reduce the peak and demand portion of electrical billing. Though because of a reduction in cooling efficiency more electricity would be used, the reduction in peak would result in a $1,177,200.00 saving. With this system, the hourly model yields 50% more savings than a Peak/Off-Peak model. This is because you could save not only $1,032,000 in peak reduction, per year, but $100,000 to $200,000 every month in cheaper electricity.

5. Results

The results of our study speak for themselves. By comparing the costs of running a thermal energy storage system against the costs of running a traditional system, not only can we evaluate the viability and financial advantages of ice storage, but we can assess the massive impact of demand charges on an industrial power bill. Also, returns on investment can be calculated, thus exposing information that may be imperative to an industry's decision to utilize this technology.

Our calculations produced a figure of $3,049,650 for the summer cost of a traditional system on a Peak/Off-peak rate structure. This figure factors in the hourly rate and demand charges for the necessary hours. On the other hand, a system supplemented by thermal energy storage only costs $2,912,580, including the additional cost of overnight ice-making, to provide an equal amount of cooling .

At first glance, it would seem that because the thermal energy storage system runs the chiller for longer hours, and thus consumes more power, it would be the more expensive system. However, the savings come from the drastic reduction in the demand charge. By cutting peak usage nearly in half, from 21MW to 11MW, the thermal energy storage system has provided savings of $137,070 annually.

Thermal energy storage, being a proven, if underused, technology, causes no surprise by enabling substantial savings. The question that remains is under which rate structure does thermal energy storage provide the most benefit? The calculations for the cost of a thermal energy storage system under the real-time/hourly rate structure yield an annual cost of $1,906,750 [7]. This cost suggests an annual cooling cost savings of $1,005,830 against an energy-storage enabled peak/off-peak system, and $880,497 against a system with no energy storage at all on the hourly rate structure [7]

This cost is substantially lower than the one provided for by a thermal energy storage system under the peak/off-peak rate structure. Since the hourly cost of power is on average higher in the hourly rate structure than in the peak/off-peak rate structure, we can conclude that the demand charge is the determining factor when comparing costs. Substantial savings can be achieved by cutting peak usage and opting for the pricing plan that is the most financially lenient with regards to demand.

Of course, the most useful calculation to industries all over the world is that of "payback". Industries are only interested in a technology if it enables them to quickly recoup their initial investment and begin showing a profit. The initial investment in this case is comprised of equipment costs and installation costs. The equipment required includes an adequate number of ice storage tanks, necessary piping, insulation to maximize efficiency, a pump to circulate the coolant, and a heat exchanger. The storage tanks are the most considerable physical expense, weighing in at $10,000 per tank. Our case requires 32 tanks to contain the necessary quantity of ice. Installation costs are estimated at $25,000, and the other necessary pipes and parts total to $1550. All of these items amount to an initial investment of nearly $350,000.

While this investment may seem daunting, the savings our group has projected in a real-time/hourly rate structure will easily pay for the equipment in its first year, as well as a hefty return on investment. By the three-year mark, we project over three million dollars in pure profit. At ten years, the return is estimated at over eleven million dollars.

Even in the less economically efficient peak/off-peak rate structure, with projected savings of $137,070 annually, the equipment and installation will be fully paid for within 3 years. The 3 year milestone has a $61,000 return on investment, while the ten-year marker sees a total profit of just over one million dollars.

Nearly any industry can benefit form the substantial returns on investment calculated here. With proper planning and quality equipment, one is certainly hard pressed to find much fault with this underused technology.

6. Applied Use

Ice storage can be incredibly beneficial to a company. Before the payback, which we have discovered to be 2.55 years for peak/off-peak and .398 years for hourly rates, ice storage is not an effective means of saving money due to the initial costs of installation of the new system and the amount of money that this system saves per year. However, after 2.55 years the amount of money saved will surpass the amount of money spent and become a significant advantage for the company.

However, thermal energy storage in the form of ice storage is not completely appealing to many companies because of the relatively long payback period. If a company is new and needs money to pay their bills immediately, they will not choose to use thermal energy storage because initially it will be more expensive. Therefore, ice storage systems are more feasible in large businesses that are able to invest in these systems for a few years until they reach the payback. These ice storage systems are most practical for large industries like car manufacturers, steel manufacturers, food industries, and even colleges. However, thermal energy storage can also be used in hospitals and corporate facilities that would benefit from the money that can be saved through ice storage.

Through our results suggest that using thermal energy storage is a very reasonable way to save money, the results may be somewhat skewed because the load profile we examined was very simplistic and not completely realistic. The load profiles that our study investigated and analyzed were strictly simplified versions of typical load profiles. Around midday the load spiked during the on-peak part of the day and cut drastically down during the off-peak part of the day. However, in reality the load profile of a large company is more curved and has other smaller peaks throughout the day. In spite of this, most load profiles do follow the basic trend that we studied. Therefore, in order for thermal energy storage to be a workable solution to saving money and energy, the average load profile of the company would have to follow the same basic trend that we studied.

In many cases thermal energy systems should not be considered. However, the main reasons to consider switching to ice storage systems include needing to find an alternative energy system if a company's energy system is old and needs to be replaced or needs maintenance. In addition, if a company is expanding, ice storage systems can be implemented to save money for the company in the future. Being energy efficient also can improve the reputation of the company and can increase business which is yet another way to raise money for the company.

Thermal energy storage systems provide enormous cooling capacity. However, there's a difference between the cooling capacity of full storage and partial storage systems. In order to save the most money over a long period of time, full storage systems are the most beneficial. On the other hand, full storage systems also cost a significant amount of money initially and necessitate a longer period of time before the payback time. This may not be the best option for many companies who do not have the resources to survive during that period of time when no profit is being made. Partial storage systems are very advantageous in many cases because there is a shorter payback time, but once that point is reached, money is still being actively saved.

The use of ice storage systems will probably increase greatly in the next few decades for several reasons; it saves companies money, and it is also very environmentally friendly. This is particularly important in helping to control the use of energy as global warming becomes a central issue to society. However, if too many companies shift to off-peak cooling systems, demand for nighttime electricity will increase (and with it, prices), and the whole trend will reverse itself.

7. Conclusions

Through our studies, we can conclude that using thermal energy storage, more specifically ice storage, can be used effectively to save energy and costs in a commercial setting. Thermal energy storage systems should be installed to save money and reduce the peak load of a cooling system.

Many case studies have been conducted of ice storage systems and each has revealed that after the payback the ice storage systems have been very lucrative to the companies in which that have been implemented. Since ice storage became a prominent way to save energy, case studies have concluded that installation cost of chillers and ice storage systems run far higher than the installation of simple air conditioning. However, after a period of time the companies have found the ice storage systems to be more lucrative.

When examining the load profiles of many companies, specifically PSE&G in Newark, it can be concluded that the peak load is in the middle of the day when the most energy is required to power the building. However, our study team was able to discover that by implementing ice storage during the nighttime hours, the peak load would be significantly reduced and would be very profitable for the company. In addition, making ice at night would entail using energy during nighttime off-peak hours, which would significantly reduce energy bills. Though in each case thermal energy system implementation is different, in general ice storage systems are very efficient in saving utility costs and reducing peak load.

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