BATTERIES AS PART OF AN ENERGY EFFICIENT INFRASTRUCTURE

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ABSTRACT

Achieving the maximum possible life from a battery system has been the goal of battery engineers and users since the invention of the secondary battery. The over riding concern has been that the battery costs had to be amortized over the longest possible time, while still providing adequate capacity to support the critical load.

Recent evolutionary advances in electronic equipment design and materials have vastly reduced the dependence on being held at low temperatures. Because of these advancements, critical environment design concepts have changed, and the temperatures of data centers and equipment rooms have been allowed to rise to levels that were previously unsustainable due to equipment failure concerns. Coupled with increased concern for the environment, and the rise in energy costs that have become the new status quo, these new developments have caused some to begin rethinking every aspect of the cost and reliability of the infrastructure that maintains their operations. To this point ASHRAE TC9.9 has republished Thermal Guidelines for Information Technology Spaces where the recommended temperature limit has been increase from 74.5°F to 80.6°F.

INTRODUCTION

Recent history has seen energy demands rise at exponential rates, while energy sources, particularly those based on fossil fuels, have displayed a relatively flat or declining growth rate. Increasing resistance by some environmental groups to any form of fossil fuel use or extraction has required that alternative sources be developed very rapidly. Unfortunately, these alternate sources may be many years from providing large enough quantities of energy to make an impact on the market.

Looking through recent news articles regarding the energy industry indicates that previously approved fossil fuel plants have been cancelled, and nuclear plants, even when approved, will require many years to begin commercial production of power. What this means to each consumer, whether a commercial consumer or an individual, is that power will continue to rise in cost for the foreseeable future. The end result of this energy "crunch" is that each consumer must consider ways to reduce their energy consumption, or face rapidly increasing utility bills. There has been a significant amount of research into methods of reducing these energy costs, and some of this research has already made profound impacts on where and how energy is used. It seems that each time a new study appears, more people are looking into the results, and we have more and more of those moments where someone says, "Hmmm. What if…."

Innovative thinking and looking at common situations from a new perspective have provided some users with significant reductions in utility usage. The use of the most efficient available components when building or upgrading facilities should be considered as an investment, and may increase the initial project costs. These investments will, however, return significant savings over the life of the equipment or facility. The difference of reducing power consumption by only 1% efficiency in a major piece of equipment can return thousands of dollars per year in utility costs saving.

THINKING UNCONVENTIONALLY

Part of the “what if” thinking is focused on conventional loads in a facility. These are the items that every customer thinks about such as HVAC equipment, lighting, and the other typical energy use devices. There are many other items that should be considered, some of which are much less apparent.

Another portion of that thought process has focused on the data equipment in high density data centers, and what can be done to mitigate their energy use. The direct power usage of the equipment is subject to data loading, and is a likely candidate for a planned energy program, but the cooling equipment is considered by most to be one of the larger users of power within the data center.

There have been several studies performed to determine how best to increase the efficiency of the cooling system, but recently, some of the data equipment manufacturers and users have been studying the ability of the data equipment to deal with increased ambient temperature in the room. A general finding is that the equipment is able to operate reliably in a room with a higher ambient temperature, provided that airflow through the equipment is maintained at high enough levels to ensure proper heat dissipation.

In the real world, it is not uncommon to find the temperatures within the data equipment rooms to be held in the range of 65° F (18.3° C) to 68° F (20° C), and often even lower. Testing performed by certain manufacturers and end users indicates that the data equipment is able to operate reliably at temperatures as high as 85° F (29.4° C), provided the airflow is adequate. At roughly 78°F to 80° F (25.5° C to 26.6°), the cooling fans in the data equipment tend to increase speed, reducing the net saving in energy. The increase in fan speed gradually turns to a net decrease in efficiency. Utilizing these higher temperatures also requires that the redundancy of the cooling system is ensured in the event of the failure of one of the CRAC (computer room air conditioner) units, etc.

This brings about the discussion regarding the temperature requirements of the entire facility. Provided that the most critical equipment is capable of operating normally in a higher temperature, what are the other limiting factors that control the temperature requirements of a facility?

Many modern data facilities have relatively small staff requirements, and those people typically spend the majority of their time in the console or control room area. Even in office environments, the normal occupancy levels don’t require nearly the amount of environmental control, and therefore energy usage, as a typical small data center does. In those situations where there is a minimal amount of human occupation, or for limited amounts of time, why is the space being conditioned to a “comfort level” if there isn’t someone occupying it that needs to be comfortable?

Data equipment is sensitive to the humidity levels in the conditioned space, but appears to be not as sensitive to the temperature as many have thought. Other electronic equipment can reasonably tolerate higher temperatures as well, and are no different than the data equipment in their humidity tolerance. Why keep these data centers so cool? Holding these facilities at other than optimum temperatures required simply increases the amount of energy required to condition them.

Many facilities hold the equipment room where the UPS and battery are located at the same temperature as the critical areas of the data center. This is a practice inherited from “old school” data centers, and brought forward without a serious review in many cases. Many facilities have the UPS and battery located in the same space as the data equipment. Just as in the case of the data equipment, UPS modules are generally able to tolerate higher temperatures without any real issues. That isn’t to say that one should operate the UPS at temperatures of over 40°C (104°F), but there is certainly no reason to hold the equipment room at 20°C (68°F) either.

This practice of cooling the UPS module and battery below the standard operating temperatures is wasteful of energy, and does use increase the work load on the cooling equipment. This can cause increased maintenance and replacement costs over an extended period of time. As a data center is typically a 20 year capital investment, the reduction in repair or replacement can be considerable over the projected lifetime.

In a paper presented at Intelec 2005, Jim McDowall, of Saft America, Inc., and William G. Gates, Of FileScan LTD., presented a paper titled “Temperature up, Cost down: The influence of battery technology and thermal management in base stations”[1]. In that paper, the authors presented a very rational and well considered argument for raising the temperature in the cellular telephone base stations that they studied. The position of that paper was that temperatures in the equipment hut could be raised by 10°C, and the saving in energy cost would easily offset the increased cost of a nickel-cadmium or lithium technology battery over a lead-acid solution. Additional savings in maintenance and repair costs enhanced the basic energy cost savings significantly. In the time between 2005 and today, energy costs have continued to rise significantly. Some facility managers have started to question whether there is a case for the same increase in temperature providing an adequate financial benefit to offset the cost of replacing a lead-acid battery more frequently.

In one year, from 2005 to 2006, the average electricity cost per kilowatt-hour of commercial electrical power in the US rose by 9.1%[2]. That cost increase, coupled with the increase in demand of above 2.5% in the same one year period, could increase the amount spent on power by 22.75% per year. If this trend continues, the cost of the facility’s required electrical power could possibly double within the next 5 years, and that is if all other factors remain the same.

The US Energy Information Administration predicts that the use of energy will continue to increase at an average global rate of 2% per year for the next 50 years. This means that the consumption of energy will double within 50 years at current growth rates, and considering the rate of increase in the recent past, this growth rate is more likely to increase rather than stay constant.

In its Congressional Report[3] in August of 2007, the US EPA estimated that the server and data center sector consumed approximately 61 billion kilowatt-hours (kWH), worth $4.5 billion, in 2006. This is approximately double the energy consumed by servers and data centers in the US during the year 2000, and could almost double again to more than 100 billion kilowatt-hours, worth $7.4 billion by 2011.

This report also states that “The peak load on the power grid from these servers and data centers is currently estimated to be approximately 7 gigawatts (GW), equivalent to the output of 15 baseload power plants. If current trends continue, this demand would rise to 12 GW by 2011, which would require an additional 10 power plants.” Another interesting point is that approximately 50% of the energy consumed by these datacenters is used for cooling and power infrastructure for supporting these systems.

It is precisely this energy that is consumed in cooling and power systems that is the focus of this paper. Any power consumed within the facility results in heat being created. This heat has to be removed, and is done so by expending more power. One of the recommended practices to reduce cooling requirements is to increase the target temperature of the room.

WHERE DO BATTERIES FIT IN?

In today’s data center environment, how do the batteries in a facility fit in to the efficiency equation? Is it worth considering tailoring an environment specifically for the battery system within the data center?

In today’s “green” philosophy, increasing the temperature in equipment and battery rooms can reduce power consumption, and therefore costs, by a significant dollar value. The exact cost saving will have to be calculated on an individual application basis due to the enormous variation in installed (or specified) equipment, cooling methods, and even the comfort level of the management team with the target temperature within the facility. Recent economic circumstances have caused many to rethink their capital expenditures, but even in challenging times, there are many opportunities for saving in both economic and environmental perspectives.

There is certainly some value to be added to the equation by the fact that virtually all battery technologies in use now are recyclable. Lithium technologies are almost 100% recyclable, lead acid technologies exceed 98% recyclable materials, and nickel-cadmium and nickel-metal hydride technologies are recyclable, although the heavy metal content complicates the process. The exact costs of each process may vary according to market fluctuations, but in general, it is less expensive to recycle any of these materials than it is to mine and extract new material. The cost benefit of recycling the battery is outside the scope of this paper, but should also be considered.

THE PROPOSAL

As was shown in the previously mentioned Intelec paper, the energy saving derived from raising the operating temperature of a facility may provide the financial return to pay the cost difference for a more advanced technology battery. If applied using the same methodology, this financial return should be sufficient to afford replacing lead-acid batteries (particularly the "10 year" VRLA) systems on a more frequent cycle. These batteries are typically deployed for a 4 to 5 year life expectancy. Despite the engineering community recommendations, this is the reality of the installed base.

It is a well understood phenomenon that the life of a lead-acid battery is directly related to the temperature of the environment in which it is stored and operated. For these lead-acid batteries, the standard storage and use temperature in North American is 77° F (25° C). The rule of thumb for VRLA batteries is that, for each 14.4° F (8° C) increase in temperature, the battery life is approximately halved. For vented lead-acid batteries, the rule of thumb is 18° F (10° C). Theoretically, raising the operating temperature by a few degrees will affect the life of the battery, but not to such a significant extent as to halve the life. There is a balance point at which the energy cost reduction of increasing the operating temperature of this environment is offset by the increased cost of battery replacement due to shortened life. This is the point that must be determined as the aim point, and at which the calculation of energy saving should be aimed. Depending on the equipment and battery type, this point could vary several degrees.

Provided that proper battery monitoring and evaluation is performed, and the data recorded and analyzed in order to detect trends that indicate deteriorating battery condition and potential early failure, these same battery systems could readily survive increased temperatures and still provide a viable service life. The precise degree of temperature increase will have to be balanced with the loss of life of the battery to determine where the cost/benefit ratio is at its optimum. There is no one magic number that will fit all installations or battery models, just as there is no one charger or inverter that is perfect for all installations.

With simple math, one can readily calculate that a saving of one or two percent in the power utilization for a system that uses hundreds of thousands of kilowatt-hours per year can return a significant financial incentive. If, by increasing the temperature by only a few degrees, a facility can reduce energy cost by several thousand dollars per year, while reducing the life of the battery by a reasonable percentage, there is a window of viable return within which a facility can demonstrate a positive financial return.

A data center with 100 racks of servers that require 10 kW per rack will draw 87,600,000 kWH per year. With an energy cost of $0.10 per kWH, that is $876,000 per year. Saving 2% of that would return $17,520 in revenue per year, or $70,080 in four years. That is enough of a saving to make increasing the room temperature a viable tradeoff.

A typical battery string for a UPS sized to serve this power requirement (1 MW) will contribute heat into the environment in addition to the heat contribution of the other operating equipment. Most VRLA battery installations are in the same space as the UPS, and as stated earlier, the UPS and batteries are held at the same temperature as the data center.

The following study provides a look at what the potential returns are, based only on increasing the temperature of the room containing the UPS and battery. This does not include any data for the remainder of the data center. This is only for compressor demand, and as such takes in a very tightly limited scope.

DIRECT EXPANSION (DX) COMPUTER ROOM AIR CONDITIONER (CRAC) OPERATING COST ANALYSIS

The Load:

The Batteries and UPS are assumed to occupy the same controlled space within a building housing a Data Center. This space is further assumed to be an interior room within the building and as such isolated from solar loads and operating as a separate environmentally controlled zone.

The primary load is a 1MW double conversion UPS with an assumed electrical efficiency of 93% (η_{EL}) operating at a steady load level of 80% (LD).

$$Q_{UPS}[\text{BTU/Hr}] = (1-\eta_{EL}) * 1\text{MW} * \text{LD} * 3.412\ [\text{BTU/W·Hr}] = 191{,}072\ [\text{BTU/Hr}]$$

The secondary load within this space is the heat released during battery charging. Only the float mode is considered. The battery heat release from I^2R losses during charge recovery after discharge is about 2 times the float mode. However, it is transient and of relatively short duration. Therefore recovery after discharge does not have significant implication on annual cooling energy consumption and has been neglected in this evaluation.

Current during float charge is assumed to be 500 [mA] per string section at a voltage of 540 [V]. There are a total of (8) string sections each with a quantity of (40) 12 volt, 100 Ah batteries.

$$Q_{BatFlt} \text{ [BTU/Hr]} = 500 \text{ [mA]} * 540 \text{ [V]} * 8 * 3.412 \text{ [BTU/W·Hr]} = 7{,}370 \text{ [BTU/Hr]}$$

The combined thermal load on the UPS/Battery Room is assumed to be the sum of the above two values, for a total of 198,442 [BTU/Hr].

The Cooling System:
The cooling system for this space is assumed be (2) 10 Ton CRAC each moving 6,000 CFM with a total fan static pressure of 2.5 [”WC]. Each air-conditioner is assumed to have (2) scroll compressors using R134a as the refrigerant. The indoor evaporator fan power is assumed to be 3.5 kW for each of the air-conditioners.

$$Q_{Fan} \text{ [BTU/Hr]} = 2 * 3.5 \text{ [kW]} * 3412 \text{ [BTU/W·Hr]} = 23{,}884 \text{ [BTU/Hr]}$$

The total heat needing to be addressed by the cooling refrigeration system is therefore 222,326 [BTU/Hr], this is the net cooling effect needed by the compressor based vapor compression refrigeration system.

Compressor capacity and power consumption are highly influenced by both saturated evaporating temperature and saturated condensing temperature. For a given design and component selection both evaporating and condensing temperatures are effected by conditioned space temperature and out-door dry bulb temperature.

Compressor power and capacity have been calculated using AHRI 10 Coefficient Compressor Model[4] for each of the (22) bin conditions in Table 1 at both the 90°F and 72°F room conditions. An assumed saturated evaporator temperature of 55° and 37°F has been used for the two different room conditions of 90°F and 72°F respectively.

Design and components for the cooling system are assumed to be identical in both room conditions, with room temperature having a linear effect on the needed saturated evaporator temperature. The cooling process is also been assumed to remain sensible, no dehumidification of the conditioned space.

In actuality the evaporator coil could be optimized for the 72°F room condition allowing significantly higher saturated evaporating temperatures, and greater efficiency. However, the same higher performance coil for lower temperature room conditions would likely result in compressor overload if used to sustain cooling at the 90°F room condition.

The saturated condensing temperature was allowed to float as a function of ambient temperature plus 15°F TD, but constrained to a minimum value of 95°F.

Table 1 Bin Data Saint Louis, MO

		Bin	Ambient		90°F Room Temperature, 55°F ET				72°F Room Temperature, 37°F ET			
		J	DB, °F	Hrs/Yr	Demand	W	BTU/HR	kWH	Demand	W	BTU/HR	kWH
No Econ		1	**97**	**31**	2.52	5327	88265	416	3.58	5196	62066	577
		2	**92**	**196**	2.44	5061	90974	2424	3.47	4913	64096	3340
		3	**87**	**345**	2.38	4816	93609	3946	3.36	4647	66077	5395
Elevated Economizer Hours 90°F		4	**82**	**495**	2.31	4590	96167	5253	3.27	4400	68005	7120
		5	**77**	**597**	2.29	4506	97167	6155	3.23	4306	68760	8311
		6	**72**	**931**	2.29	4506	97167	9598	3.23	4306	68760	12961
		7	**67**	**742**	2.29	4506	97167	7649	3.23	4306	68760	10330
	Normal Economizer Hours 72°F	8	**62**	**664**	2.29	4506	97167	6845	3.23	4306	68760	9244
		9	**57**	**569**	2.29	4506	97167	5866	3.23	4306	68760	7921
		11	**52**	**629**	2.29	4506	97167	6484	3.23	4306	68760	8757
		12	**47**	**527**	2.29	4506	97167	5433	3.23	4306	68760	7337
		13	**42**	**672**	2.29	4506	97167	6928	3.23	4306	68760	9355
		14	**37**	**883**	2.29	4506	97167	9103	3.23	4306	68760	12293
		15	**32**	**716**	2.29	4506	97167	7381	3.23	4306	68760	9968
		16	**27**	**313**	2.29	4506	97167	3227	3.23	4306	68760	4357
		17	**22**	**147**	2.29	4506	97167	1515	3.23	4306	68760	2046
		18	**17**	**158**	2.29	4506	97167	1629	3.23	4306	68760	2200
		19	**12**	**80**	2.29	4506	97167	825	3.23	4306	68760	1114
		20	**7**	**25**	2.29	4506	97167	258	3.23	4306	68760	348
		21	**2**	**30**	2.29	4506	97167	309	3.23	4306	68760	418
		22	**-3**	**10**	2.29	4506	97167	103	3.23	4306	68760	139
Straight DX Operation, Total kWH/Year								**91,347**				**123,530**
Economizer/DX Operation, Total kWH/Year								**6,786**				**48,033**

Compressor demand (cooling load 222,326 [BTU/Hr] / compressor capacity [BTU/Hr] is the number of compressors needed to support the total heat load in the UPS/Battery room at the specific operating condition. The demand factor is multiplied by the annual operating hours at the specific condition and the power requirement for this operating point. The product being the annual energy [kW·Hr] for the particular temperature bin under evaluation, bins are then summed together yielding the annual compressor energy required for the particular room temperature.

$$E_{Comp} = \sum_{j=1}^{n} (demand_J * power_J * hours_J)$$

[kW·Hr/Year]

The system was further evaluated with an air-side economizer mode. Economizer operation was limited to outdoor ambient temperatures of 8°F or more below the desired room condition. The lightly shaded green area of Table 1 represent annual hours compressor operation would not be required with a room condition of 72°F and the darker shaded green area of Table 1 represents additional annual hours compressor operation would not be required with a room condition of 90°F. The yellow area of the chart represents hours that mechanical cooling would be required for both room conditions.

Table 2 Summary Annual Savings

90° F vs 72° F Room Savings Per Year		
System Type	**kWH**	**$**
Straight DX	32,182	$3,218
DX w/ Air Economizer	41,247	$4,125

Table 2 is a summary of the annual energy difference between the two rooms for compressor operation at the two different temperatures. This table includes values for both straight DX cooling and air economizer combined with DX cooling.

The straight DX cooling system would have an annual compressor energy demand difference of 32,182 kW·Hr/Year for a savings of $3,218.

The economizer version would have an annual compressor energy demand difference of 41,247 kW·Hr/Year for a savings of $4,125.

Then annual evaporator fan energy demand would be considered equal in both cases and is therefore not considered in the comparison.

SUMMARY

Based on this study, it can be concluded that the return for energy saving using the battery and UPS alone can be a small but quite measurable dollar amount. If the UPS and battery are located within the critical conditioned space, the return can be dramatically higher. Any additional efficiency increases in any of the related systems (UPS, chiller, CRAC or other air handling equipment, etc.) will only increase the energy saving.

The actual heat contribution of the battery itself to the compressor demand is extremely small. This fact indicates that having a separately conditioned space, regulated specifically to meet the requirements of the battery is a viable way to reduce the overall energy consumption of facilities where the UPS and data equipment share a common environment. Where the UPS and battery are collocated, but separate from the data equipment, regulating that space to a temperature that is optimized for the battery will not significantly affect annual operating costs.

If a facility manager wishes to explore the possibilities of temperature management benefit regarding the battery, the Arhenius Equation can be used for simple modeling and initial estimates of projected battery life. Specific testing and data gathering should be utilized to record all of the available information regarding the state of the battery, and establish a graphic representation of the critical battery parameters for the purpose of plotting the battery's life cycle against the known performance of the same battery installed in industry standard systems.

As in every other financially governed endeavor, the cost/benefit ratio has to be analyzed, and the determination made on an individual site application basis whether or not the savings realized by raising the operating temperature will outweigh the cost of more frequent battery replacement. Because there is no standard charging equipment or utilization equipment, the effects of the individual connected apparatus will have to be studied on a case by case basis to determine what the approximated frequency of replacement will be, and then a comparison made to the potential cost savings.

REFERENCES

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