Energy Storage

Providing for a Low-Carbon Future

By Mark MacCracken, P.E., Member ASHRAE

The world's need to reduce its carbon emissions by reducing, in part, dependence on fossil fuel, will completely change the makeup of our electric delivery system. The reason is simple: fossil fuels are not just forms of energy; they are forms of *stored* energy. Coal is not hot until you light it. If we plan to replace fossil fuels with other forms of energy, such as wind power or solar, then we also need to replace the storage characteristic of fossil fuels.

Most natural or man-made systems use energy storage: food in our stomach, fuel in a car, and a battery in a cell phone. Conversely, the largest mechanical system ever created, our electric grid, has essentially no storage.[1] This unnatural design works only because of the storage inherent in fossil fuels, coupled with massive oversizing of equipment and complex controls to make the electric grid able to react instantaneously to any change in demand, any moment of the year. As we move toward a higher percentage of renewables (or nuclear) on the grid enormous[2,3] amounts of energy storage are necessary to make that energy dispatchable when we need it.

What does energy storage have to do with building HVAC systems and sustainability? Plenty! We can no longer rely on incremental improvements in component efficiencies as a method for creating better buildings. We must rely on a major shift to an integrated design process.

Bill Harrison, Presidential Member ASHRAE, recently showed a slide of eight major energy-efficiency factors in a building (for example, building orientation and building envelope), and pointed out that HVAC designers have no control over any of them. By continuing to design and construct buildings in the traditional linear process (architect, engineer, contractor), it is impossible to get to truly high performance buildings. If we are going to make even greater strides toward sustainability, this bigger picture view must extend past the building boundary and on to the grid. As long as a building is "grid connected," how and when the building uses power has large effects on society.

About the Author

Mark MacCracken, P.E., is president and CEO of Calmac Manufacturing in Fair Lawn, N.J. He is chair-elect of the U.S. Green Building Council.

One of those effects is the amount of oversizing of the grid. The U.S. had 1 trillion watts of electric generation in 2008. However, the average electric use was less than half of that.[4] This means we have twice as much generation as we need if we used electricity at a level rate year-round. The cause of this is the usage patterns of buildings.

Energy storage within buildings is certainly not new. Thousands of projects around the world have used thermal energy storage (TES) in the form of ice or chilled water, with hundreds of articles describing the advantages and justifications.[6,7] Even so, the use of storage has been relatively limited in comparison to the market size and potential. The move toward sustainability and renewable resources will completely change the potential value of TES in buildings, which should, if free market forces prevail, bring greater financial rewards to those who use thermal storage.

Energy Storage Types

A few different forms of energy storage exist including: potential, kinetic, chemical and thermal. One example of potential energy storage is pumped hydro (PH) where water is pumped up a mountain at night, and the next day the water flows down to run a turbine to create electricity. Other means for storing energy for electrical production include flywheels for kinetic energy, and some batteries for chemical energy.

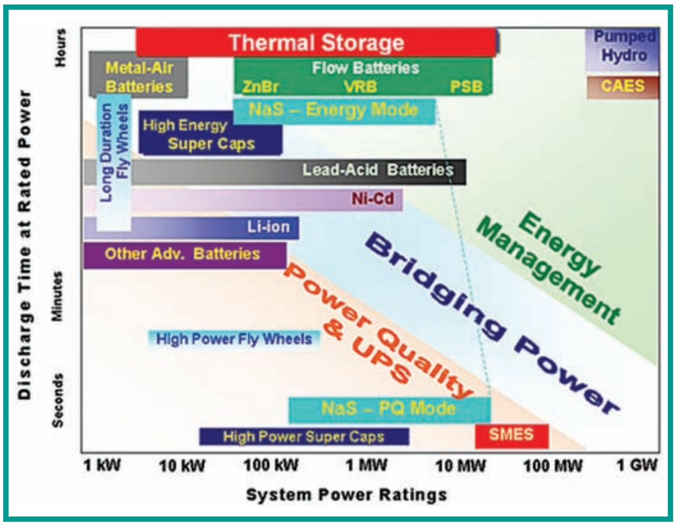

Figure 1: Different types of energy storage systems.[7]

Figure 1[7] shows the different types of energy storage and the size range of storage capacity versus the length of time of discharge for each type of storage system. The figure is divided into three general areas: the lower left is for power quality, the upper right for energy management/shifting and bridging power in between. (Some types of thermal storage are used on the "grid side" of the electric meter, but this article focuses on TES, a form of distributed energy storage.) The critical factors of any storage device are application (type and size), costs, cycle efficiency and longevity.

Applications

All of the various types (*Figure 1*) of storage will likely be needed to replace the storage of fossil fuels each in various applications as appropriate. Flywheels, capacitors and specialty chemical batteries can react instantaneously to provide ancillary services for regulating power quality (e.g., keeping 60 cycle power at 60 cycles). Sodium sulfur (NaS) batteries have been demonstrated[8] to provide bridging capacity in the two to four hour range. The solutions for storing large quantities of power for longer durations are pumped hydro, compressed air energy storage (CAES) and TES. Thermal energy storage is unique in that it is downstream of both the transmission and distribution systems and has relatively higher roundtrip efficiencies (addressed later).

Costs

Figure 2[7] compares storage technologies used in bridging power and/or energy management applications, and compares costs per kW output versus cost per kWh. The lower left hand quadrant is the lowest cost for both energy and capacity. The integrated thermal storage system is one of the most cost-effective storage options, and delivers benefits to both the transmission and distribution systems. Part of the reason for the large cost range is that when TES is integral to the design of a building cooling solution, other cooling equipment can be downsized or eliminated, reducing the overall capital equipment cost and, thereby, the cost per unit of TES. Naturally, as with all storage technologies, TES is designed for a specific purpose: peak load shifting of inductive motor loads used to provide cooling.

The important point here is that it is dramatically less expensive to store cooling than it is to store electrons to create cooling.

Cycle Efficiency

Perhaps the most dramatic differentiator for TES is its relatively high roundtrip cycle energy efficiency that ranges from 75% to 95%. As with any storage device, losses are associated with putting the energy in and removing it from the device (*Figure 3*). The thermal losses of ice storage systems on a daily basis are less than 1% with similar numbers for stratified water storage (so 99% thermal efficiency). Nonetheless, there is a wide range of cycle efficiencies shown for TES. That is because water storage can have cycle efficiency of 98%, simply because the lower ambient temperatures make the creation of the cooling more efficient at night, which makes up for the pumping power to transport the energy. This is true for air-cooled chillers making ice[9] since the drop in ambient temperature at night is about the same as the drop in evaporator temperatures to make ice.

For larger ice systems that use high efficiency water-cooled chillers, storage cycle efficiency, relative to nonstorage water-cooled chiller operation, may be about 25% lower, because the ambient wet-bulb temperature drops much less when compared to the drop in evaporator temperatures required to make ice. However, the overall absolute efficiency of a water-cooled chiller with storage will be better than an air-cooled chiller with storage.

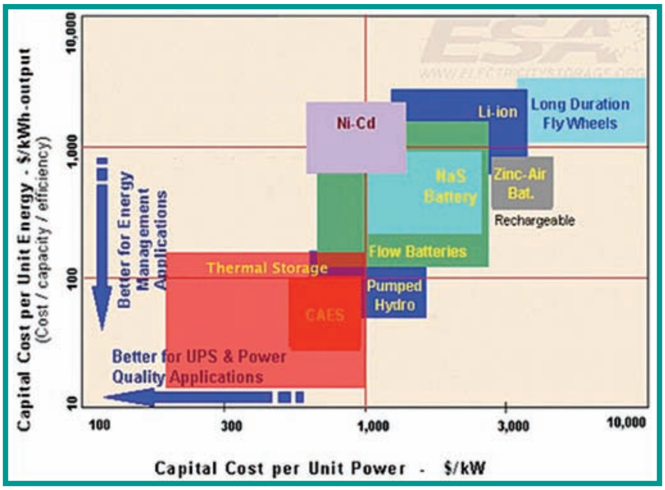

Figure 2: Energy storage system costs.[7]

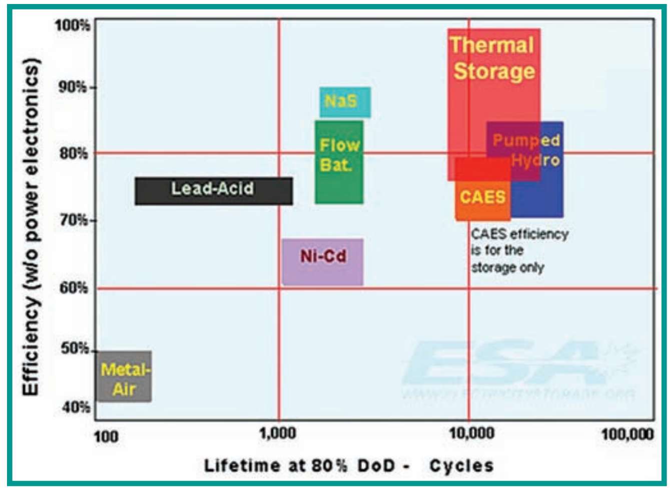

Figure 3: Cycle efficiencies and usable life expectance.[7]

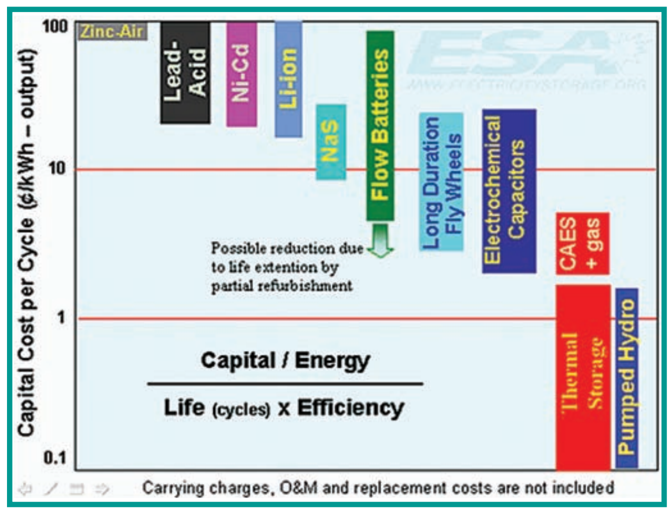

Figure 4: Total life costs of energy storage technologies.[7]

Longevity

The life of storage systems can be divided into two areas: storage media and equipment. In most chemical storage devices, there is degradation of the media. Currently, the most common chemical cell battery types that are sufficiently developed and available for use in large-scale storage systems are lithium ion, nickel cadmium, and lead acid. Each type has its own inherent set of traits as to preferred charging method, full discharge cycles, operational temperatures, cost to produce and limitations due to the hazardous nature of the material.

Regardless of type, each has a finite number of charge cycles due to some type of molecular degradation, which may be in the thousands, but each has a limit to its useful life. TES's that use eutectic salts also have limitations due to eventual chemical breakdown, normally a result of precipitation due to non-eutectic mixtures. TES's that use the sensible or latent energy of water are obviously perfectly stable. Equipment life for the rest of the storage system associated with the different storage media (e.g., containers, heat exchangers, pipes, pumps, etc.) are well documented on expected life and can be designed to outlive the storage media in most cases.

Combining the Attributes

Figure 4[7] combines the particular aspects of the different storage technologies to give a perspective on practicality for the different applications. Capital cost per unit of energy storage divided by the cycle life and cycle efficiency yield a cost per unit of output. The higher cost technologies are mainly ones that are used for power quality and bridging power, which are high value, less storage intensive applications. The energy management application is storage intensive, so the lowest cost technologies will have a major advantage in the marketplace.

Cool Storage Saves Generator Source Energy

Source energy, the fuel used at the power plants to create electricity, needs to be the real focus in the quest to reduce carbon. A strict focus on the electric meter on a building, and not source energy, is like looking at the odometer of a car to tell how much fuel you have used. It depends if it is city or highway driving, a Hummer or a Prius. If we look at how the cycle efficiency of different energy management types of storage affects the actual amount of source energy use when used for cooling, it becomes clear where storage should be located.

Figure 5 shows two scenarios for energy storage used for cooling buildings: one scenario has the storage on the grid side with PH, and one scenario uses TES (cool) at the building. Assuming a heat rate of 8,900 Btu/kWh (2.6 kW/kWh) for the power plant, which is a reasonable number for baseload operation, that translates into a 38% efficiency (3414/8900) for the plant. For the PH system, energy is stored by pumping water up a mountain, which is retrieved the next day with 70% (field data) cycle efficiency. After including daytime transmission and distribution losses, the final power efficiency at the building is 23.5% of source energy, or we could say an "effective" heat rate of 14,500 Btu/kWh. Therefore, assuming 0.9 kWh per ton-hour of cooling, a ton-hour of cooling costs 13,000 Btus. If we follow the same logic for cool storage at the site, the numbers are 38% for generation and slightly better transmission and distribution efficiencies at night, yielding 35.4% to the site. At 1.0 kW per ton (89% cycle efficiency) TES will have an effective heat rate of 9,650 Btu/kW, which is 35% better on energy. An analysis with compressed air energy storage (CAES) will yield similar results. Finally, to relate it back to renewables, which is the premise for the need for storage in the first place, a wind farm would have to generate 1.45 kWh of electricity to create a ton-hour of cooling during the day if using pumped hydro storage, compared to 1.07 kWh/ton-hour for thermal storage at the site. So clearly, of the storage technologies that meet a reasonable cost criteria (TES, HP and CAES), the most *energy* efficient storage system for cooling buildings is TES at the site, and not on the grid.

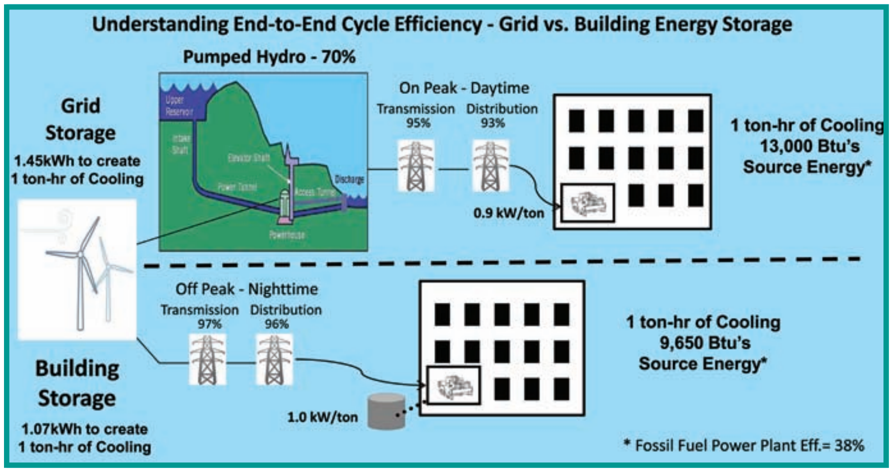

Figure 5: Energy storage and source energy for cooling.

The Renewable Link

The main two sources of renewable energy that are most looked to for future sources of clean power are solar and wind and neither of these can be counted on to be there when the grid needs them. Data from across the various electric grids around the U.S. shows that wind speeds are stronger mainly at night. *Figure 6*[10] shows the output of a wind farm in California during the hottest week of 2006. The nine days of cycles show that wind speed varies, but more importantly, is that when the electric utility was hitting its peak (red diamonds on graph) they were getting less than 25% of its wind generation capacity. *Figure 7* shows similar results[11] for other regional grids around the country.

However, too much wind also can be a big issue. Imagine megawatts of wind capacity having to be immediately curtailed when wind speeds get too high. Bridging power, either fossil fuel or grid-side electric storage must almost immediately make up the difference. At a recent energy storage meeting, an ISO dispatcher put up a graph he described as the "day from hell" that had four such events occur within 24 hours.

Although solar's availability generally coincides with higher utility loads, it normally will have peak output at noon, whereas most grids peak three to six hours later. In addition the unpredictability of cloud cover further complicates the issue. Results from the National Renewable Energy Laboratory's (NREL) monitoring of photovoltaic (PV) projects across the country show that, although large PV systems on buildings can greatly reduce kWh purchased from the grid, the peak load of the building is not reduced compared to non-PV buildings.[12] Therefore, to be ready for the unpredictable loss of solar or wind capacity, the grid must have more "spinning reserves," which are generators running at lower than design capacity (and lower efficiency) to be ready, whether they are needed or not. Solar and wind, because of the lack of storage, have some carbon emissions associated with them (when considered from the big picture perspective) and need backup.

The final complication comes from having an abundance of wind energy, but at the wrong time. In west Texas, where 6,000 MW of wind has been installed, 12% of all the hours last year had a wholesale price of *zero* or less[13] (the utility will pay you to take the power); and 6,000 MW is only a small fraction of the wind power that is planned to be installed by 2020. Historically, not only has the cost of nighttime electricity been one-half of the price of daytime power, it is the only source of energy that has stayed flat or decreased in the past 40 years.[14] So for building owners, history would indicate the storing of nighttime power on site is the strongest way to stabilize future energy costs, and more wind will only strengthen that trend.

Conclusions

For decades the "storage" characteristic of fossil fuels has made it possible for electricity to be available, when we need it, to meet peak loads that are essentially double the average electric load.[1] Fortunately, what is causing the huge peaks for energy from the grid is also the least expensive and most energy-efficient form to store, which is cooling. All forms of energy storage are needed to move toward a modernized grid. While adding grid-side storage will help solve a host of power quality, bridging capacity and availability issues, cool thermal storage created off-peak and stored at the site, can address over 30%[15] of the peak power issues while saving building owner's money.

References

1. EIA. 2010. "Electric Power Annual 2008." U.S. Energy Information Administration.

2. California Independent System Operators Corporation. 2007. *Integration of Renewable Resources*.

3. Berry, G. 2009. "Present and future electricity storage for intermittent renewables." The 10-50 Solution: Technologies and Policies for a Low-Carbon Future. The Pew Center.

4. EIA. 2000. "Electric Power Annual 2000" (with data from 2008). U.S. Energy Information Administration.

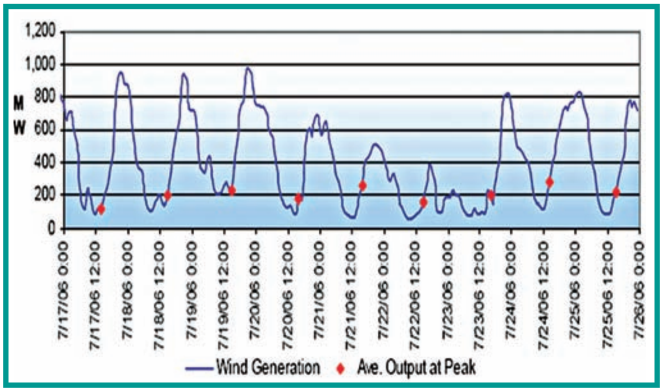

Figure 6: Design week wind generation output.

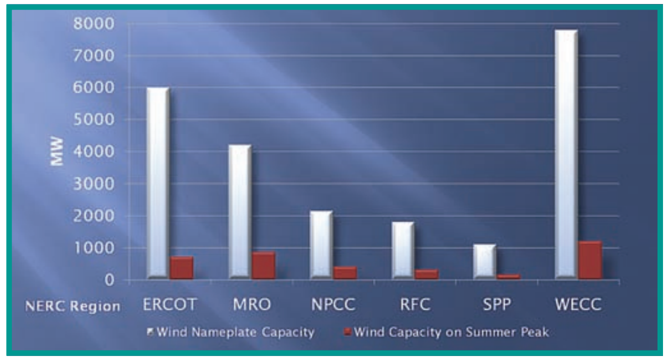

Figure 7: Storage bolsters variable wind resources. (Wind data from North American Electric Reliability Corporation, six of eight regions.)

5. Potter, R.A., D.P. Weitzel, D.J. King, and D.D. Boettner. 1995. "ASHRAE RP-766: Study of operational experience with thermal storage systems." *ASHRAE Transactions* 101(2):549–557.

6. O'Neal, E. 1996. "Thermal storage systems provide comfort and energy efficiency." *ASHRAE Journal* 38(4).

7. Electricity Storage Association (with Thermal Storage data added by author). 2010 www.electricitystorage.org/ESA/technologies.

8. Priore, S. 2002. News Release, "AEP Dedicates First Use of Stationary Sodium Sulfur Battery." American Electric Power Co., Inc.

9. MacCracken, M. 2003. "Thermal energy storage myths." *ASHRAE Journal* 45(9).

10. California ISO. 2007. "2007 Summer Loads and Resources Operations Assessment."

11. NERC. 2008 Summer Reliability Assessment. May 2008.

12. Crawley, D., S. Pless, P. Torcellini. 2009. "Getting to net zero." *ASHRAE Journal* 51(9).

13. Fahey, J. 2009. "Wind power's weird effect." *Forbes Magazine*, Sept. 7.

14. Foster, C. 2008. Personal conversation with EEI consultant, Chuck Foster.

15. EPRI. Commercial Cool Storage–Reduced Cooling Costs with Off-Peak Electricity.●