ENERGY STORAGE:

A CRITICAL COMPONENT OF ENERGY CONSERVATION

BY ADAM MCMILLEN AND SEAN SMITH

Energy policy and efficiency standards such as ASHRAE 90.1 define requirements for buildings that save energy. However, a fundamental shift is happening in energy production that makes it critical that standards address more than energy reduction in buildings. Standards must also address the timing of when that energy is used because not all energy is created equally.

Energy producers must match production to the demand in real time. This forces producers into situations of high production cost at times of peak demand. If possible, energy producers want to load their lowest-cost energy production plants first. Then they ramp up higher cost plants as demand increases. Energy production cost is driven by both cost of fuel available to a plant and the efficiency of the plant. At peak, utilities must operate the highest-cost plants. Furthermore, transmission losses increase as more power is transmitted from the plants to the consumer at peak. Therefore, energy producers try to incentivize consumers and businesses to shift demand to the low-cost times through time of use (TOU) rates, demand charges, grid-enabled devices, and real-time pricing.

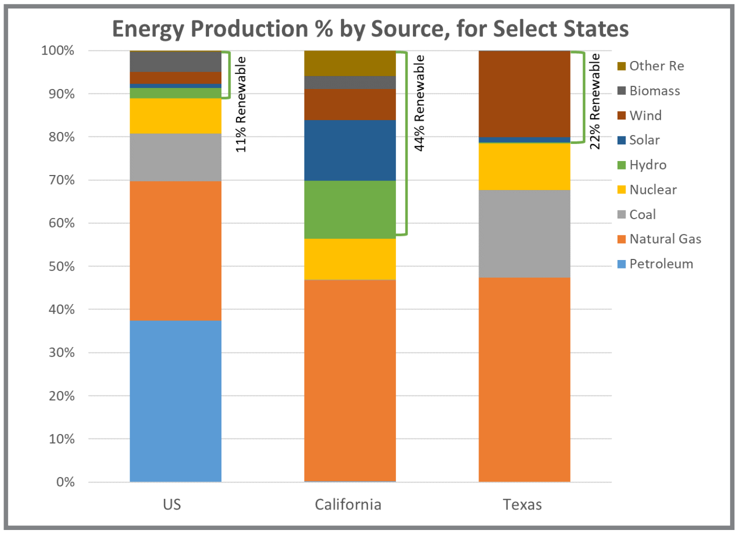


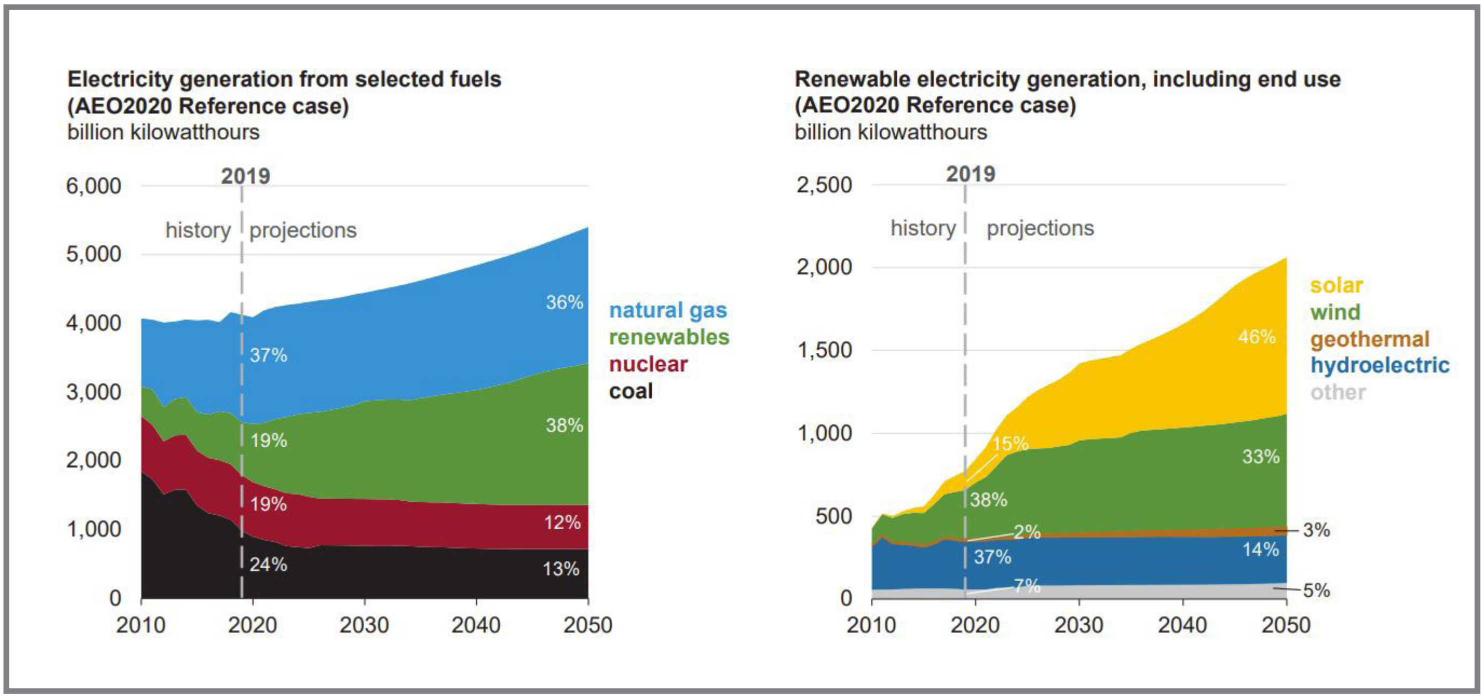
Figure 1: Energy Production % by Source for Selected States (© Sean Smith/Trane Technologies | Sources: Energy Information Administration, California Energy Commission, Dallas Observer)

Today some regions of the country are in a transition where renewable energy sources have become a significant portion of energy production (see Figure 1 above). Figure 2 shows how this is projected to grow through 2050, according to the U.S. Energy Information Administration. Some states have set goals for 100-percent clean energy production within this same timeframe. This is being driven by both de-carbonization efforts and the falling cost of solar PV and wind compared to fossil fuel generation facilities.

This progress, however, does come with some growing pains. For regions with a large penetration of renewables, some renewable energy sources produce energy when the underlying energy source, such as wind or solar, is available, not when it is needed. Therefore, renewable energy makes it difficult for energy producers to match load to demand. In some markets there is so much renewable energy production that production is curtailed due to lack of demand.

Figure 3 (next page) shows the daily curtailment of solar power in California for the year 2019. To be clear, these curtailments only represent 3% of the 2019 solar energy production, but the trends grow each year as more solar capacity is installed.

Figure 2: Projected Growth of Renewable Energy Production through 2050 (Source: U.S. Energy Information Administration, Annual Energy Outlook 2020) (public domain)


Electricity generation from selected fuels (AEO2020 Reference case)
billion kilowatthours

Renewable electricity generation, including end use (AEO2020 Reference case)
billion kilowatthours

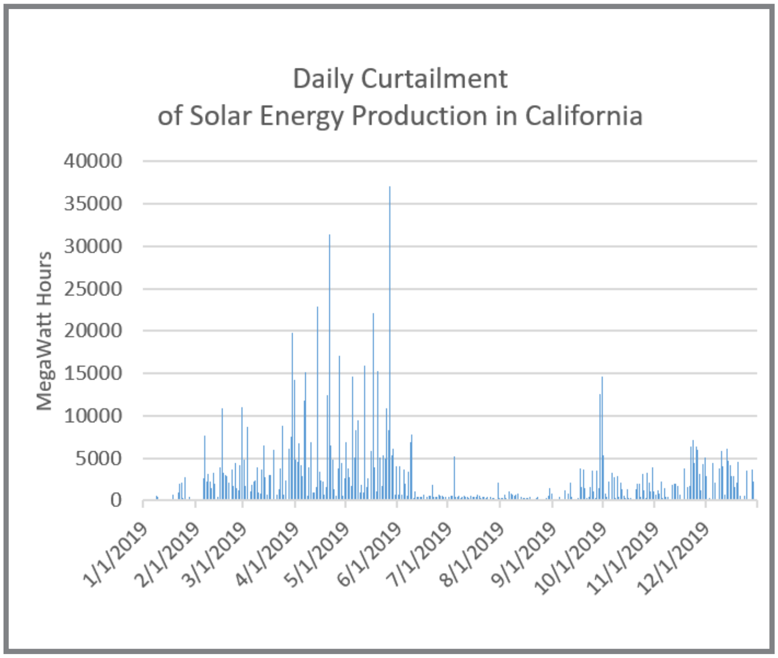


Figure 3. Curtailed renewable energy capacity in California in 2019 due to mismatch of production to demand. (© Sean Smith/Trane Technologies | Source: California Independent System Operator)

In the article, "**California has too much solar power. That might be good for ratepayers**," the Los Angeles Times reported that at around 1 p.m. May 27, 2019, "solar plant operators shut off a record total of about 4,700 megawatts of capacity at the same time — nearly 40% of the entire solar capacity installed on the California grid." This anomaly highlights the opportunity to use energy storage systems to bring demand and production together in time. Expanded use of TOU rates and even real-time pricing models may be used by energy producers to encourage consumers to help.

Another way to look at this is that not all energy saved is equal. For example, if a new code requirement saves energy in the middle of the night in east Texas, where wind turbines produce much more energy than is consumed, were the goals of energy savings realized? Did it improve economic resiliency or reduce demand on the international energy supply chain? Did that saved energy reduce the detrimental environmental effects of burning fossil fuels? No, it did not.

The same could be said for reducing energy usage during the sunniest part of the day in southern California, where solar power dominates production.

Several codes and standards encourage energy production on site. For example, in 2020 the **California Energy Commission** began requiring solar to be included in all new homes, and **ASHRAE 90.1** provides several exceptions to prescriptive requirements when the building has on-site renewable energy generation. If the energy generated by these on-site systems is not consumed on site, but put back into the grid, it can aggravate the problem.

Therefore, to remain viable in the future, energy standards such as **ASHRAE 90.1** must fundamentally change how the standard addresses energy savings to include two measures. These standards must consider both energy savings and timing of that energy savings to coincide with the times when the energy savings achieves the underlying economic and environmental goals. Energy storage plays a key role in managing the timing. In some cases, energy storage systems will use more energy at the building. Therefore, standards need a way to make sure that the environmental benefits of matching demand to production outweigh the cost associated with higher energy usage. The authors contend that building analysis using TOU is an appropriate tool to evaluate the tradeoffs.

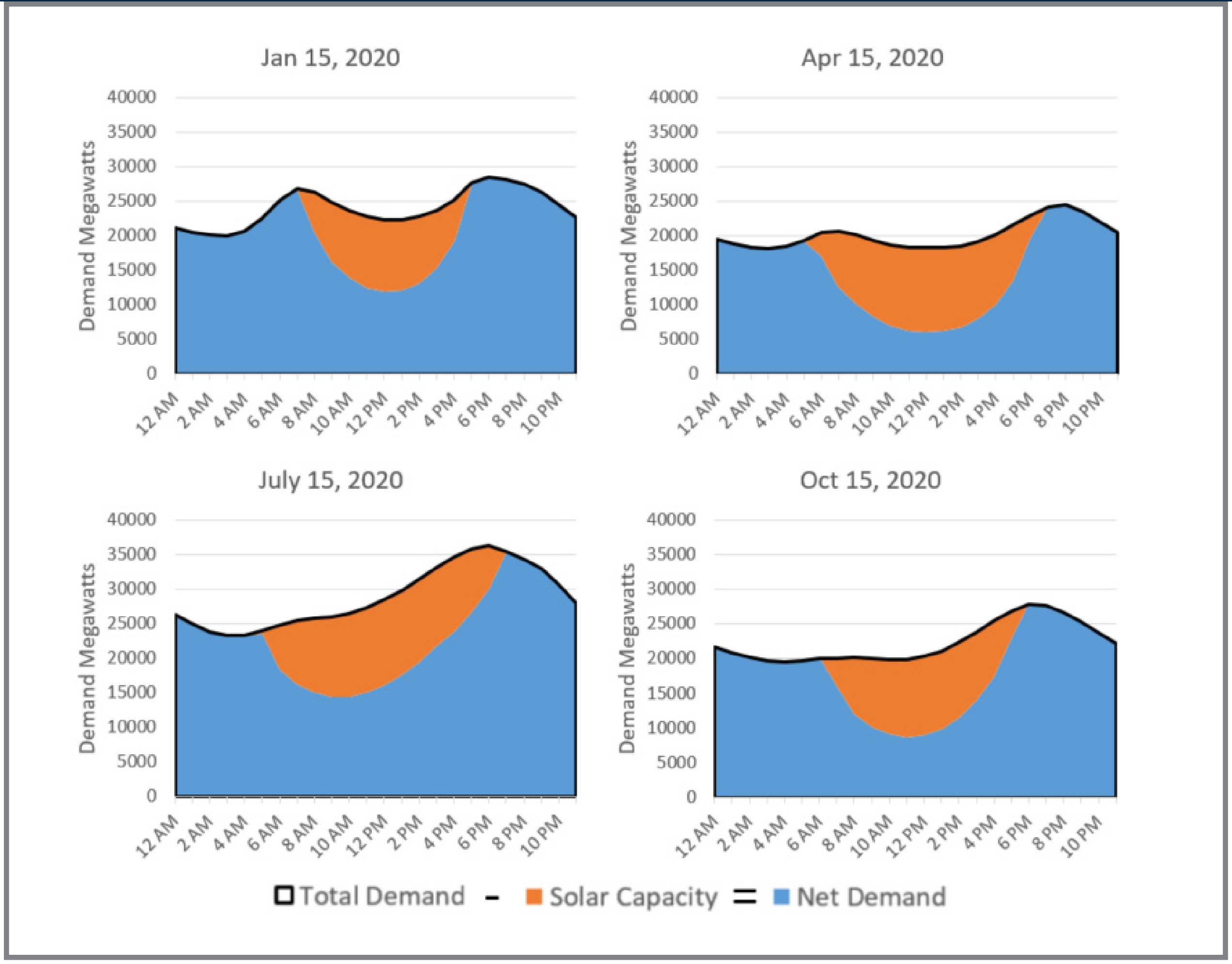


Figure 4: Energy Demand and Net Demand less Solar on select days in 2020. (© Sean Smith/Trane Technologies | Source: California Independent System Operator)

Time of use rates

One way that utilities try to match load to the lowest-cost power production is to use economic incentives such as TOU rates, demand charges, and demand response controls.

TOU rates are not new to building energy codes such as ASHRAE 90.1. Building design engineers are allowed to use TOU rates in their calculations to show energy cost savings when using the performance method in Appendix G.

What is new, however, is that for the first time the ASHRAE 90.1 committee has decided to allow TOU rates to be used to calculate energy cost savings associated with prescriptive requirements.

Figure 4 shows the demand and net demand less solar energy production for electrical energy in California for select days in 2020. As the sun goes down at night, solar generation drops off significantly and ultimately stops altogether – at the same time demand increases as consumers come home from work, turn up the air conditioning, cook meals, turn on lighting, and enjoy evening entertainment. Since renewable sources are not available, non-renewable energy plants must be fired up to meet the peak demand.

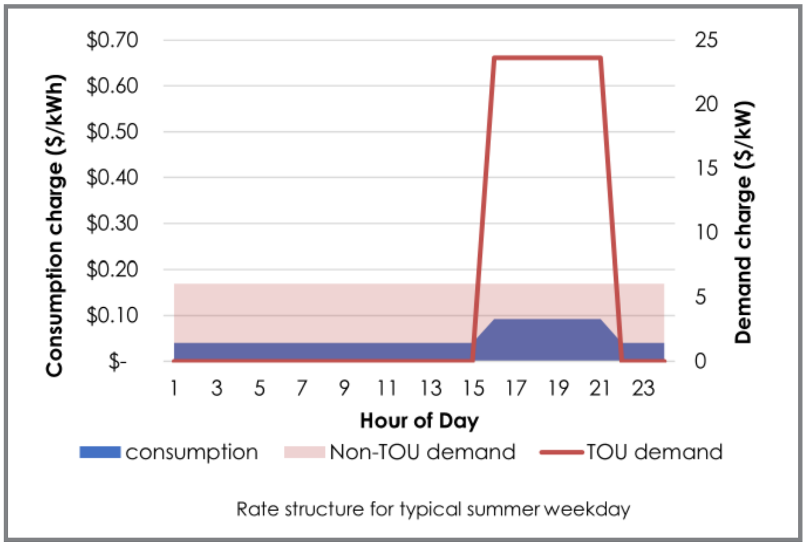


Figure 5: Sample utility rate structure for typical summer weekday. (© IMEG Corp.)

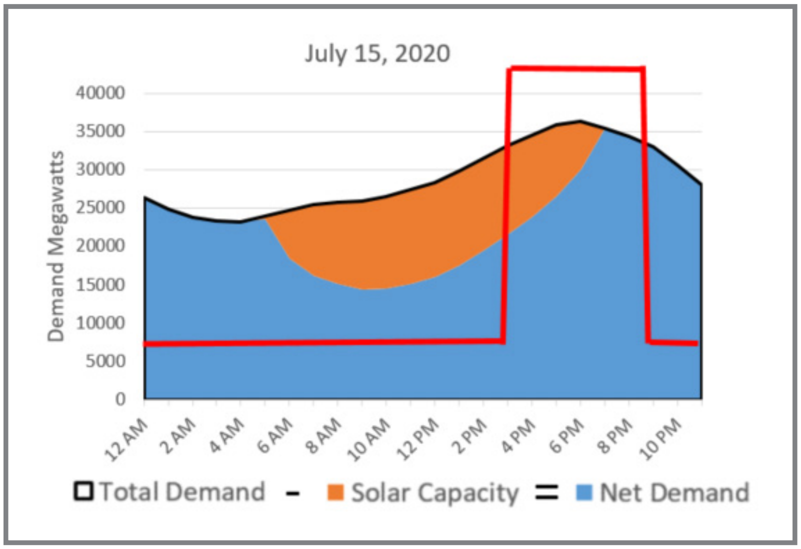


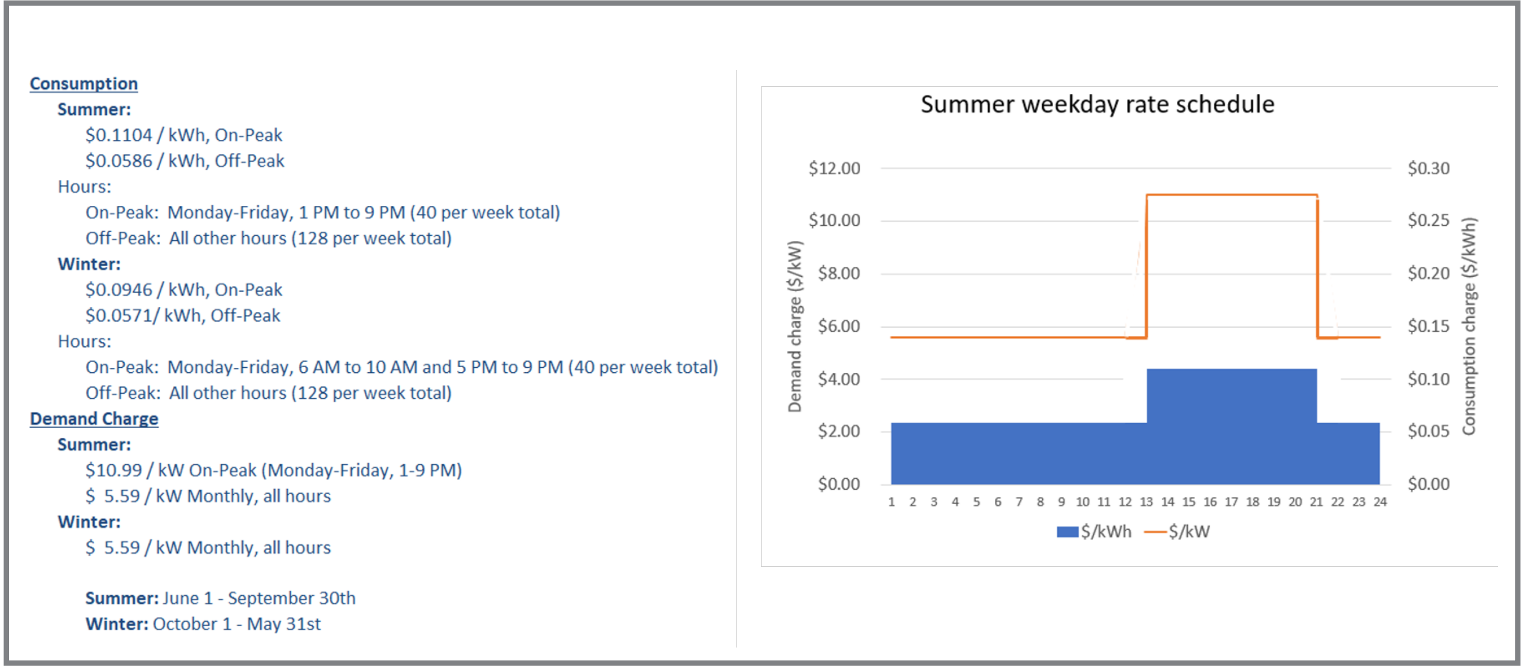
Figure 6: Demand charge peak coinciding with demand data. (© Sean Smith/Trane Technologies |Sources: California Independent System Operator, ASHRAE RP 1607)

Some utilities institute demand charges during this peak – as shown in Figure 5 – to incentivize the consumer to curtail demand and to recover their costs. To further illustrate this point, Figure 6 shows this same peak demand charge overlaid with the July 15 data from Figure 4 (previous page).

One solution to benefit both the consumer and the utility is to shift load from high-demand time period to low-demand time period using energy storage systems.

One option for shifting this load in a warm climate is chilled water storage. Consider a 300,000 square-foot healthcare facility with high cooling loads in a southern climate. It has 1,000 tons of peak cooling and anticipated energy costs of $750,000 per year. This facility has the utility rate structure shown in Figure 7 (next page) that was recently adopted by ASHRAE 90.1 to represent a representative time of use schedule. The figure outlines this schedule for a summer weekday, showing that demand charges and consumption charges approximately double during an eight-hour period in the afternoon/early evening.

An example baseline hourly cooling load profile for this facility, without storage, is shown in Figure 8 (next page). A typical design approach in line with current prescriptive requirements of 90.1 would look to optimize the chilled water plant efficiency to coincide with this load profile. It would look at envelope improvements, chiller efficiency/sizing, cooling tower optimization, pumping etc. In this new framework that includes a time of use rate



Consumption

Summer:

$0.1104 / kWh, On-Peak

$0.0586 / kWh, Off-Peak

Hours:

On-Peak: Monday-Friday, 1 PM to 9 PM (40 per week total)

Off-Peak: All other hours (128 per week total)

Winter:

$0.0946 / kWh, On-Peak

$0.0571/ kWh, Off-Peak

Hours:

On-Peak: Monday-Friday, 6 AM to 10 AM and 5 PM to 9 PM (40 per week total)

Off-Peak: All other hours (128 per week total)

Demand Charge

Summer:

$10.99 / kW On-Peak (Monday-Friday, 1-9 PM)

$ 5.59 / kW Monthly, all hours

Winter:

$ 5.59 / kW Monthly, all hours

Summer: June 1 - September 30th

Winter: October 1 - May 31st

Figure 7: ASHRAE 90.1-adopted time-of-use electricity rate schedule. (© IMEG Corp.)

schedule, we can now also consider the impact of shifting the peak cooling load to an off-peak period to realize annual energy cost savings.

While an energy model would typically be used to analyze savings from this load shift, we will keep our analysis in a "full load hours" framework to simplify a discussion that demonstrates the benefits. We first size the chilled water storage tank to reduce the peak load by about half to 500 tons for all hours during the demand window as shown in Figure 8. This now establishes three operational periods shown in Figure 9 (next page): charging, follow load, and discharge. For this load profile and storage goal, we realize the need to shift about 3,000 ton hours from the peak to the off-peak period.

At 100 gallons of chilled water storage per ton hour of load, this gives us a 300,000-gallon tank. If we then assume a 10-hour charging period, we need to produce 300 tons of chilled water during each hour of the charging period as shown in the figure. This stored chilled water would then discharge about 3,000 ton hours of chilled water load at a rate to keep the peak kW as low as possible during the on-peak period (~500 tons in this case).

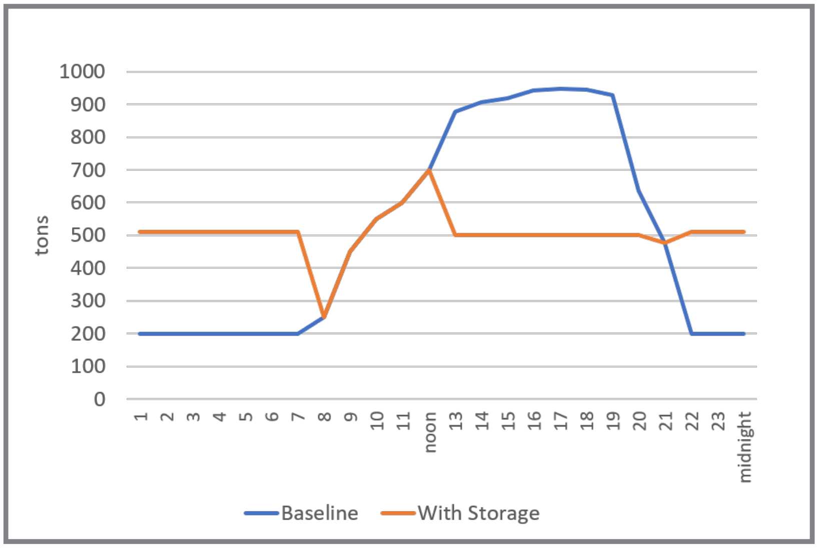


Figure 8: Example hourly chilled water plant load profile without storage (baseline) and with storage. (© IMEG Corp.)

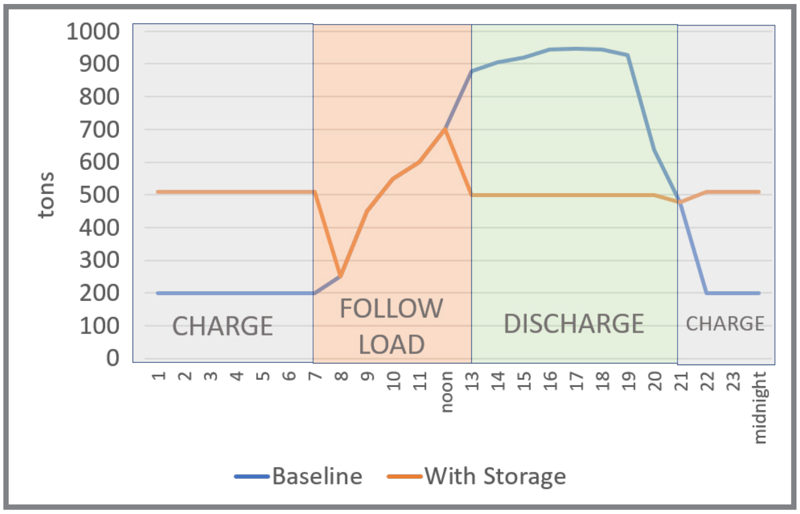


Figure 9: Three operational periods of thermal storage scenario. (© IMEG Corp.)

With these new load profiles established, we convert the plant from cooling tonnage to kW by assuming a 0.8 kW/ton chilled water plant (chiller, primary pumps, cooling tower, and condenser water pumps) efficiency to establish the electrical load profile for each scenario. For simplicity, we assume this same efficiency for the entire 24-hour period. Table 1 (next page) and Figure 10 (next page) outline the kWh and kW load shift under this scenario for a typical day.

The savings in energy consumption occur each day, five days per week, by shifting the chilled water production to the lower-rate period. The savings in demand come each month by shifting 358 kW demand away from the peak demand period each day. Note that in addition to the peak demand charge reduction, the "all hours" demand charge reduction coincides with the peak demand. While it is a lower rate than the demand charge, this example did realize a monthly savings of $1,023 from this

ASHRAE 90.1:

Reducing energy use for 45 years

ASHRAE Standard 90.1 was created in response to the 1970s global energy crisis with the goal to reduce dependence on international supply for energy.

Over the intervening years, society has benefited from a building energy standard that reduced energy usage by over 50 percent from the minimum requirements established in 1975 to the most recent requirements in 2019.

In the intervening years, it has also become clear that energy conservation produced a positive impact on the environment through reduction in demand for power plants and reduced consumption of fossil fuels.

The positive environmental impact of conservation is just as critical to society as the original purpose of achieving economic resiliency that birthed the standard.

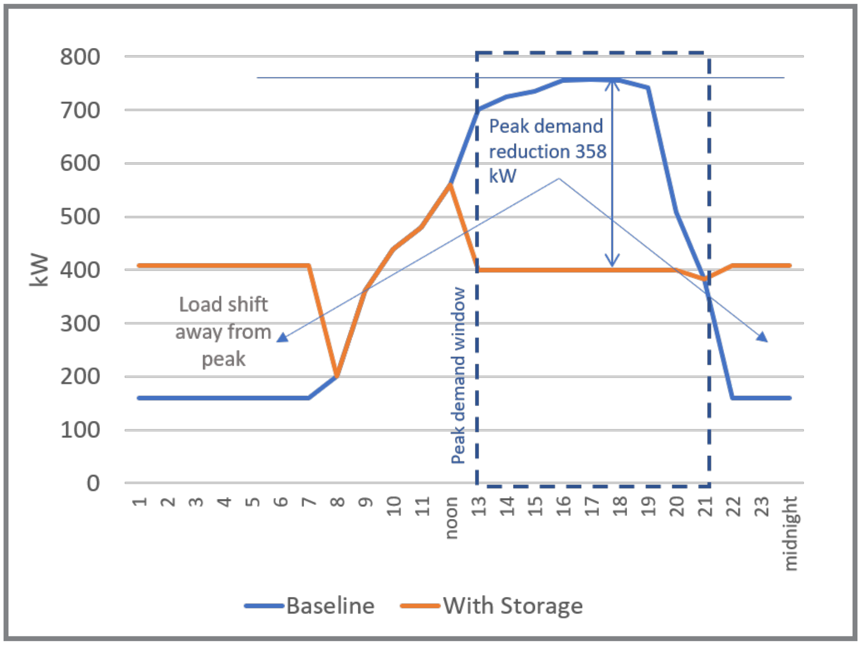
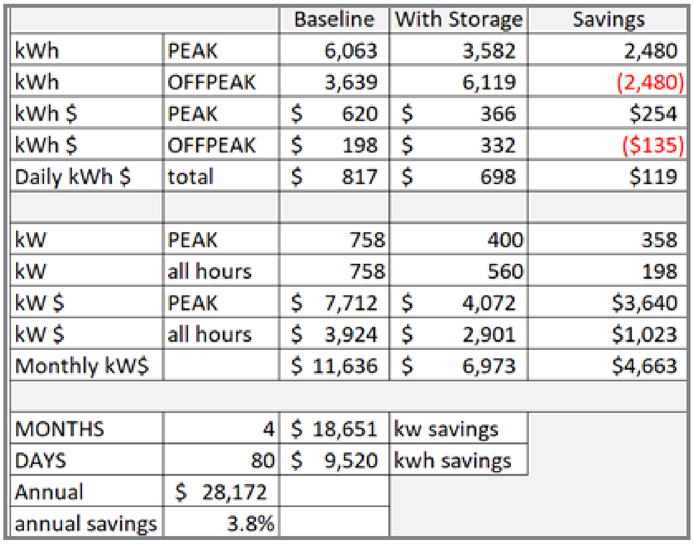


Figure 10: New demand profile and peak demand reduction. (© IMEG Corp.)

Table 1: Energy and energy cost savings from thermal storage example. (© IMEG Corp.)



		Baseline	With Storage	Savings
kWh	PEAK	6,063	3,582	2,480
kWh	OFFPEAK	3,639	6,119	(2,480)
kWh $	PEAK	$ 620	$ 366	$254
kWh $	OFFPEAK	$ 198	$ 332	($135)
Daily kWh $	total	$ 817	$ 698	$119
kW	PEAK	758	400	358
kW	all hours	758	560	198
kW $	PEAK	$ 7,712	$ 4,072	$3,640
kW $	all hours	$ 3,924	$ 2,901	$1,023
Monthly kW$		$ 11,636	$ 6,973	$4,663
MONTHS	4	$ 18,651	kw savings	
DAYS	80	$ 9,520	kwh savings	
Annual	$ 28,172			
annual savings	3.8%			

reduction as well. The sizing and timing of the storage does require careful balancing to keep demand relatively flat and not spike in the off-peak period and take away from the overall savings.

If we assume this daily and monthly savings equally across the four-month summer period of this example, high-level analysis shows about $30,412 savings in energy costs per year using thermal energy storage. There would also be savings available for the other eight months of the year, but we limited this example to summer only. In an integrated design scenario, this annual savings would be coupled with first-cost savings in other areas being served by the chilled water tank.

Energy storage projects often reduce installed cooling plant capacity since part of the load is being served by the tank. If 300 tons could be removed in our example at $2,500 per ton, this would realize a first cost reduction of $750,000 to help fund the install of the tank. For projects with backup generator required, chilled water storage often allows a reduction in generator size, providing additional first-cost benefit.

This example demonstrates an approach to energy cost savings using the ASHRAE 90.1 adopted time of use rate. TOU rates vary across the country; some regions have higher demand charges for a shorter time window that would realize much higher savings. The goal is to shift the load from a more critical five-hour window (4 to 9 p.m.) when the load is increasing and solar PV generation is declining. In this scenario, the facility could shift that load to the night period as shown in the ASHRAE TOU example (Figure 7, page 6) or shift it to the period when excess solar PV energy is available.

That decision could be made on a cost basis if rates are lower during a period of excess solar PV. It could also be made on a carbon basis if the grid mix during the day with excess solar PV has lower carbon content than the grid mix at night when no solar PV is available.

Classifications of storage systems

At the core, there are four types of energy storage (Table 2): long-term load shift, short-term load shift, long-term energy shift, and short-term energy shift. Notice that the electrical energy storage systems require energy to be converted from electrical energy to another form, resulting in conversion losses consistent with the third law of thermodynamics.

ASHRAE 90.1 energy storage working group is focused on short-term storage types 2 and 4. The three goals of a good short-term storage system are:

1. Maximize use of renewable energy sources
2. Match load to production such that the net demand curve shown in Figure 4 (page 4) is flattened
3. Minimize conversion losses (also known as round trip losses)

This will result in the lowest total energy cost by reducing the need for high-cost and less environmentally friendly energy production methods to satisfy peak loads.

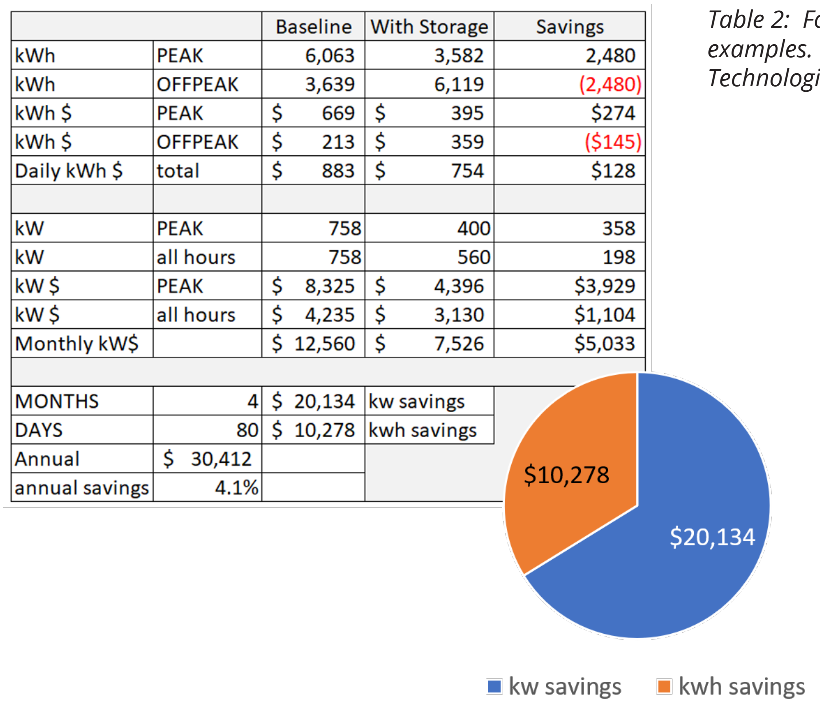


Table 2: Four types of storage with examples. (© Sean Smith/Trane Technologies)

		Baseline	With Storage	Savings
kWh	PEAK	6,063	3,582	2,480
kWh	OFFPEAK	3,639	6,119	(2,480)
kWh $	PEAK	$ 669	$ 395	$274
kWh $	OFFPEAK	$ 213	$ 359	($145)
Daily kWh $	total	$ 883	$ 754	$128
kW	PEAK	758	400	358
kW	all hours	758	560	198
kW $	PEAK	$ 8,325	$ 4,396	$3,929
kW $	all hours	$ 4,235	$ 3,130	$1,104
Monthly kW$		$ 12,560	$ 7,526	$5,033
MONTHS	4	$ 20,134	kw savings	
DAYS	80	$ 10,278	kwh savings	
Annual	$ 30,412			
annual savings	4.1%			

The ability of energy storage systems to meet these goals depends upon several factors including selection and application. For example: a compressed air system, due to the complexity of the plant, is likely to be applied at the utility. Batteries can be effectively applied to a building that has on-site electrical power generation if the power cannot be consumed immediately. Water and ice storage can be applied to many chilled water systems, providing redundancy as well as storage benefits. ASHRAE published the second edition of the **Design Guide for Cool Thermal Storage** in 2019 and **Guideline 21 Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications** in 2018 to help practitioners evaluate and apply these systems.

Energy storage in efficiency standards such as ASHRAE 90.1

The purpose statement for ASHRAE 90.1 is: To establish the minimum energy efficiency requirements of buildings other than low-rise residential buildings for

a. Design, construction, and a plan for operation and maintenance; and
b. Utilization of on-site, renewable energy resources.

To further this purpose the standard committee established an energy storage working group to investigate where storage should be part of the total energy savings solution in the code. Some issues under investigation include:

1. Establish round-trip efficiency requirements for storage equipment
2. Establish storage requirements related to on-site renewable energy production to ensure that the energy produced is used on site
3. Establish requirements to use energy storage systems that save energy and/or energy cost

Conclusion

Building standards such as ASHRAE 90.1 have a role to play to encourage use of renewable energy. Establishing requirements for energy storage supports the original intent of the standard and can lead to a more environmentally friendly electrical grid.

ABOUT THE AUTHORS

Adam McMillen, PE, LEED AP BD+C, is Director of Sustainability for IMEG Corp. He leads the firm's high-performance building design and project sustainability efforts and builds industry relationships that positively impact the built environment.
Contact: Adam.M.McMillen@imegcorp.com.

Sean A. Smith is Chief Engineer for Trane Technologies. He has been an ASHRAE member since 2013 and currently leads the Energy Storage Working group for the ASHRAE 90.1 committee.
Contact: SSean@Trane.com