Thermal Energy Storage in Commercial Buildings

State-of-the-Art Technologies and Practical Considerations for Implementation

Commercial Building Solutions to Achieve Ambitious Clean Energy Goals

There are 5.9 million commercial buildings in the United States,[1] totaling 96.4 billion square feet of floorspace and contributing to 18% of the nation's primary energy use.[2]

Space heating and cooling account for up to 40% of the energy used in commercial buildings.[1] Aligning this energy consumption with renewable energy generation through practical and viable energy storage solutions will be critical to achieving 100% clean energy by 2050.

Combining on-site renewable energy sources and thermal energy storage systems can lead to significant reductions in carbon emissions and operational costs for the building owner.

What is Thermal Energy Storage (TES)?

Thermal energy storage (TES) is one of several approaches to support the electrification and decarbonization of buildings. To electrify buildings efficiently, electrically powered heating, ventilation, and air conditioning (HVAC) equipment such as a heat pump can be integrated with TES systems. The TES acts as a "thermal battery:" a thermal storage material—such as ice/water, wax, salt, or sand—is heated or cooled (depending on the season) by the HVAC equipment to charge the TES. Later, the stored energy in the TES can be discharged to heat or cool the building, but with a much lower power requirement than if the HVAC system were running without the TES. This enables operating the HVAC system during periods when clean, renewable power is available and reducing the electric loads when renewable generation is not available or during peak load periods. Figure 1 shows an example of ice storage tanks connected with an HVAC system.

Benefits of Thermal Energy Storage Systems Integrated with On-Site Renewable Energy

- Cost-effective solution for heating and cooling
- Functions as a buffer for variable energy generation
- Maximizes the use of renewable energy
- No limits for exporting to utilities
- Added resiliency for temperature control and occupant comfort
- Integration with other Distributed Energy Resources

Figure 1. TES example: Ice tanks integrated with HVAC system. *Image by Trane.*

TES systems can lower peak energy demand and provide load shifting capabilities, reduce stress on the grid to avoid grid outages, make heating and cooling systems more resilient, and enable more cost-effective electrification of buildings without compromising occupant comfort. Figure 2 shows how storage can be employed to reduce peak loads and flatten the load curve, which can yield significant cost savings through lower peak demand charges and by using grid energy during lower cost off-peak periods.

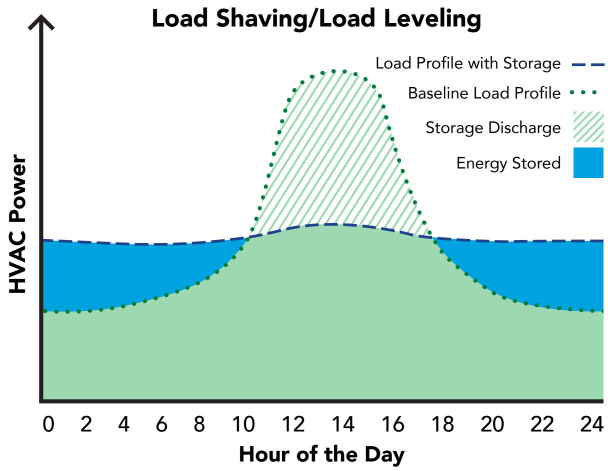

Figure 2. HVAC and energy storage load profiles.

Cutting-edge research in this field is developing new types of materials and control systems that can adjust when heating or cooling is generated, stored, and delivered to minimize costs and provide the greatest benefits to the grid. Advances in controls, standards, and integration pathways in buildings can make TES systems more affordable. Strategically integrated and appropriately sized systems also offer the opportunity to increase efficiency and achieve additional cost savings by allowing downsizing of HVAC equipment to handle average loads instead of peak loads.

Stor4Build
U.S. DEPARTMENT OF ENERGY

Stor4Build is a multi-laboratory consortium working to accelerate the development, optimization, and equitable deployment of cost-effective TES technologies. One of the consortium's many areas of research is the development of a software tool to quantify the benefits of storage.

Cost Benefits for Thermal Energy Storage

The costs associated with installation and operation of TES systems depend on a number of factors:

Climate

Storage for space cooling is more effective in very warm climates, while TES for space heating is more effective in cold climates.

Region

Certain locations or markets offer better economics for TES. For example, in utility areas with high demand charges or time-of-use electric rates, thermal storage can shift electricity use to lower cost periods or reduce a building's peak demand charges. Often, vendors have financial tools to estimate the energy/cost benefits of TES and provide detailed information about their system.

Incentives and Rebates

The Inflation Reduction Act enabled unprecedented incentives for clean energy and decarbonization technologies. Look for state and federal opportunities as well as utility incentives and rebates to improve financial feasibility.

TES Technologies on the Market and in Development

A range of technologies are currently available:

- **Ice Storage with Central Chiller**

  Provides greater energy density than chilled water, enabling a smaller footprint

  Allows TES to be used in space-constrained situations

- **Ice Storage in rooftop unit (RTU)**

  Simplified solution for integrated storage with RTUs, if additional space in mechanical rooms is not available

- **Chilled or Hot Water Storage**

  Large tanks are often used in district or campus-scale HVAC systems

Smaller tanks can be used for individual buildings, if sufficient space is available

- **Ceramic Brick Heating Storage System**

  Coupled with electric heating, can offer consistent comfort while enabling load shifting and reduced peak demands

- **Phase Change Storage for Commercial Refrigeration Systems**

  Enables load shifting in large commercial refrigeration systems and improved temperature stability

- **PCM Ceiling Panels/Passive Storage**

  PCM integration in the building envelope increases thermal mass and can improve temperature stability

  Supports improved occupant comfort and less frequent HVAC system cycling

- **Heat Pump Water Heater (HPWH)**

  HPWHs provide efficient water heating for both residential and commercial buildings

  Are often configured to receive utility or aggregator signals to support demand management for peak load reduction.

New technologies are under development and will soon be on the market. Current research to advance this field includes:

- Alternative materials for storage, including thermochemical materials and salt hydrate phase change materials, that can dramatically increase the duration of storage, reduce TES system size, and reduce costs
- Advanced controls to optimally manage charging and discharging of TES systems
- More efficient heat exchangers designed for heat transfer with phase change materials to increase storage efficiency and charge/discharge rates
- Thermal storage for defrosting HVAC equipment
- Desiccant-based TES and dehumidification storage
- Rooftop units with novel phase change materials

Why Now?

Existing and anticipated carbon emission regulations require new and existing commercial buildings to be designed, built, and operated with low- or zero-carbon technologies. For example, in August 2023, Colorado's Air Quality Control Commission[3] established new energy performance standards for buildings 50,000 square feet and larger to reduce energy use and greenhouse gas pollution.

Additionally, the overall energy demand for heating and cooling in commercial buildings is expected to increase in the coming years. And, as the shift to energy-efficient electric heating technologies will offset carbon emissions, the transition could create new instances of peak energy demand during cold weather if energy storage solutions are not utilized.

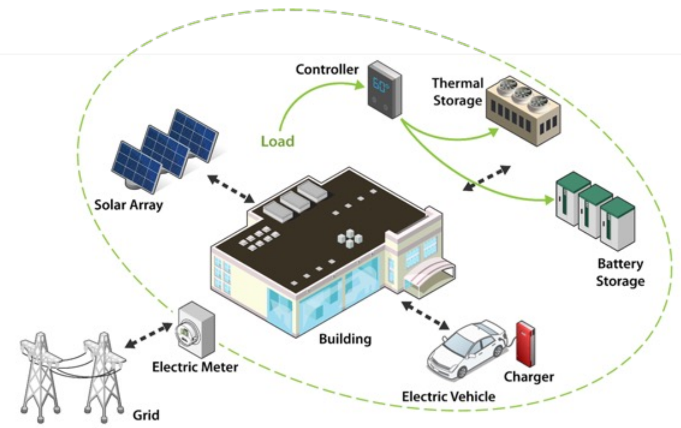

Figure 3. TES may be combined with other behind-the-meter technologies to maximize building electrification benefits. *Image by NREL.*

Practical Considerations for TES Installation

- **Behind-the-Meter Strategies**

  TES can be deployed in parallel with other behind-the-meter distributed energy resources, such as onsite renewable generation, to maximize the potential use of renewable energy to decrease curtailment, increase cost benefits, alleviate the need for grid infrastructure upgrades, and reduce carbon emissions.

- **Space Requirements**

  As technology evolves, TES systems are becoming smaller and more flexible to reduce the space required in a commercial building. Newer systems can distribute the storage materials among several smaller containers to reduce the footprint and fit into otherwise unused spaces.[4]

- **System Sizing**

  TES systems can in many cases reduce the required capacity (and cost) of chillers and heat pumps used in large commercial buildings. While the TES is discharging, it effectively provides additional capacity that can be combined with that of the HVAC equipment to satisfy peak heating and/or cooling loads.

- **Installation**

  An experienced contractor familiar with TES systems should be used for design and installation.

- **Integration with Existing Equipment**

  For retrofits, integrating the TES into existing equipment can be challenging or require upgrades or overhaul of some components. A system must be selected that is compatible with the HVAC mechanical system used in the building. For example, central chillers and RTU systems require different approaches.

- **Additional Equipment:**

  Integrating a TES system in a commercial building may require new or changes to existing chillers, hardware, plumbing, and more. When using ice storage, a new chiller may be required to reach the temperature required to freeze water. Additional plumbing may also be needed to connect the components, which may require further sensors and pumps.

- **Control Strategy**

  A control strategy must be designed and programmed for the intended goals of a new TES system (e.g., minimizing cost, operating in conjunction with renewable energy generation, or reducing peak demand). Customized predictive controls using modeled data can be developed to consider weather, variable utility costs, and optimal performance. TES system vendors can help understand the needs and how to integrate existing controls with TES.

Tax Incentives

The Inflation Reduction Act (IRA) is a game changer for de-risking of TES systems. Benefits of TES systems for commercial buildings include:

- Up to 40% Investment Tax Credit for most thermal energy storage systems
- Systems include tanks, piping, TES-charging chiller, glycol, heat exchanger, controls, pumps, concrete pad, and more
- Exemption for prevailing wage if < 1 MW
- Tax exempt organizations can obtain direct payment from IRS
- An installation project can qualify for utility rebates for additional cost reduction
- Thermal energy storage can qualify for demand response programs to provide additional revenue streams
- IRA funds are available through September 30, 2031.[5]

References

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