Thermal Energy Storage: Solution to Building Energy Efficiency and Load Management

CalPlug Workshop

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Motivation

The path of clean energy is clear

- Achieve 100% carbon pollution-free electricity by 2035
- Achieve net-zero carbon emissions by 2050

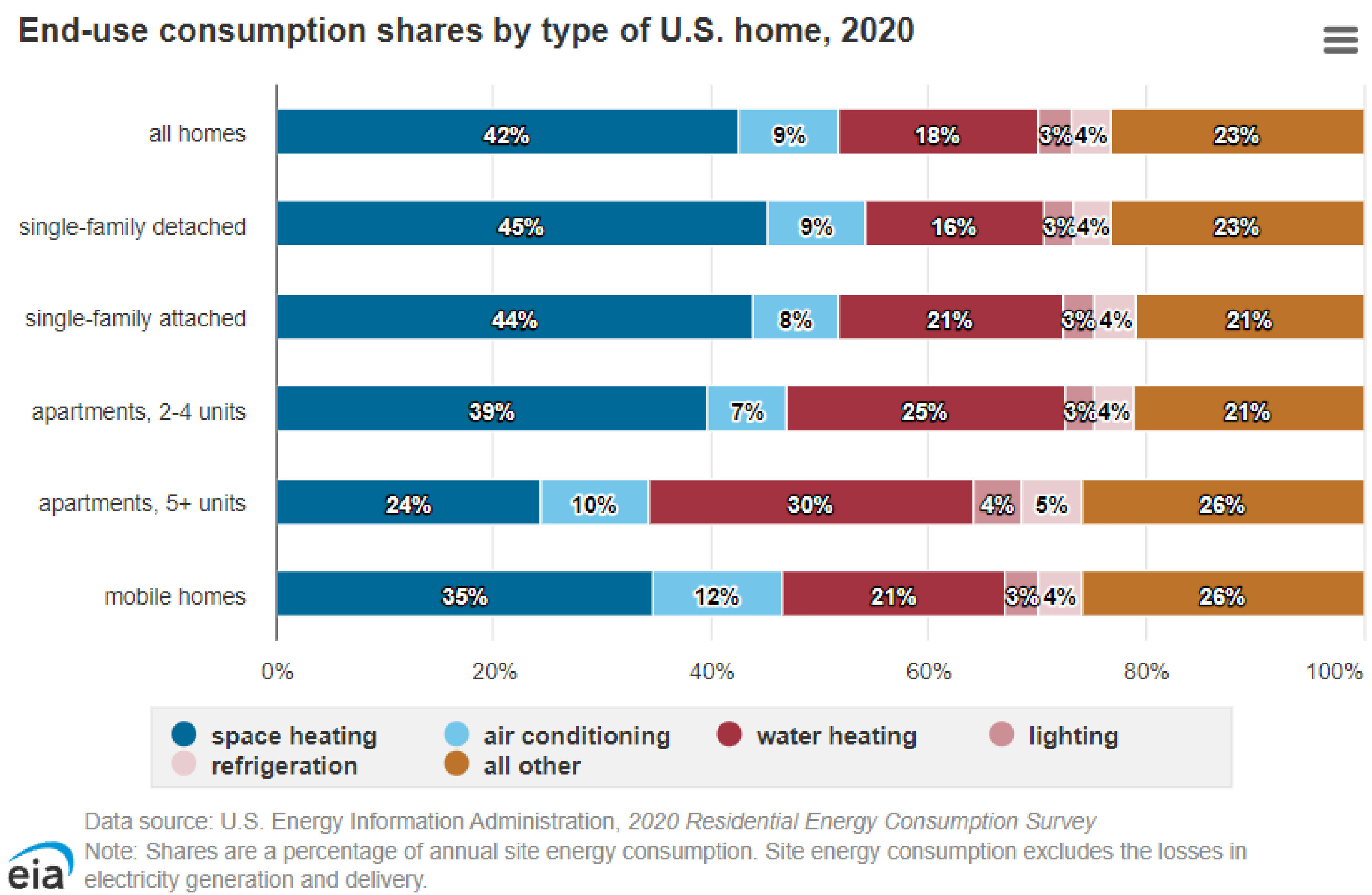
Building sectors account for 40% of energy use and associated greenhouse gas (GHG) emissions in the US.

Key: Decarbonation and electrification of buildings

Energy demand

Energy supply

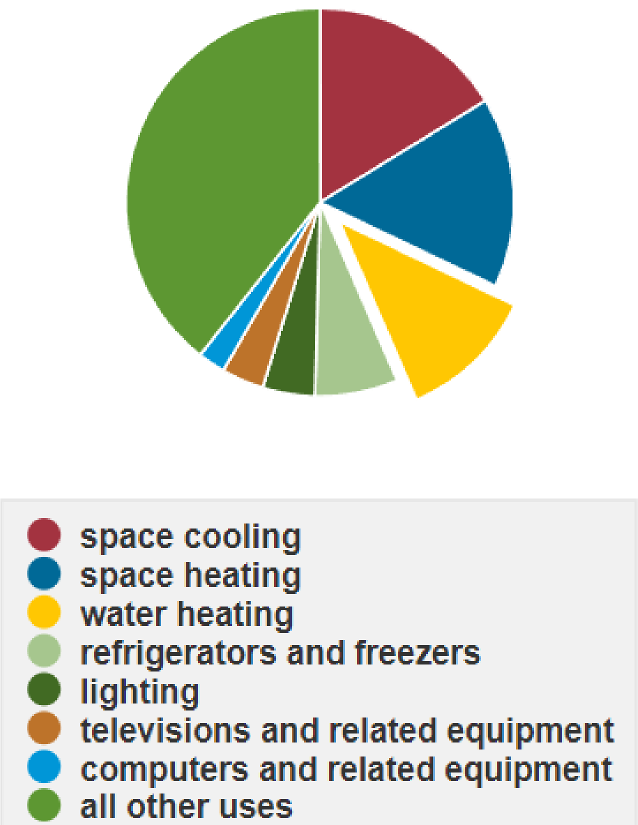
Background: energy demand



Most building energy consumption is used for space conditioning to provide a comfortable thermal environment

Background: energy demand

U.S. residential sector electricity consumption by major end uses, 2022

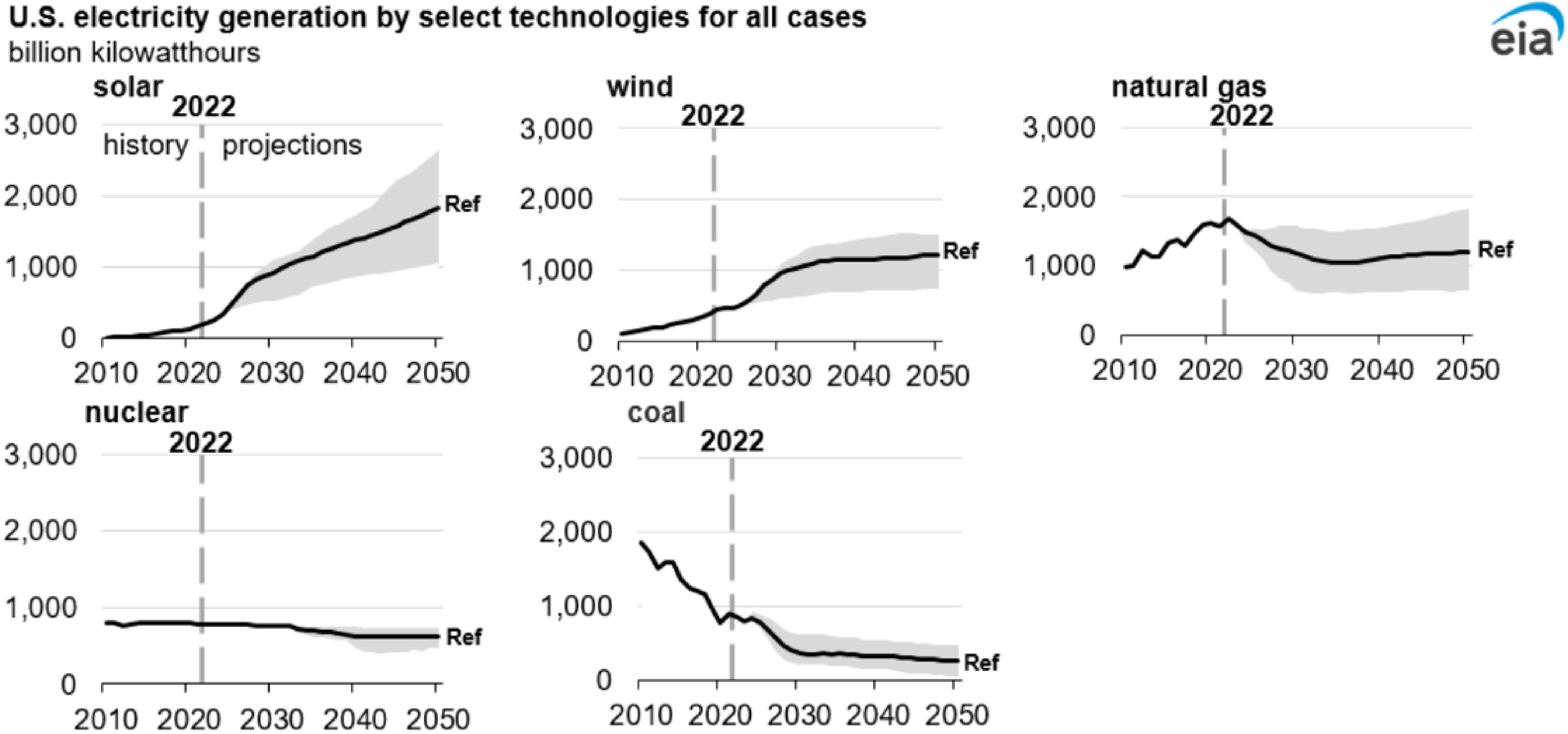


Top 4 electricity consumption in residential buildings:

1. Spacing cooling
2. Spacing heating
3. Water heating
4. Refrigeration

More than 50% of electricity consumption in buildings is to meet thermal loads.
Easy to shift!!

Background: energy supply

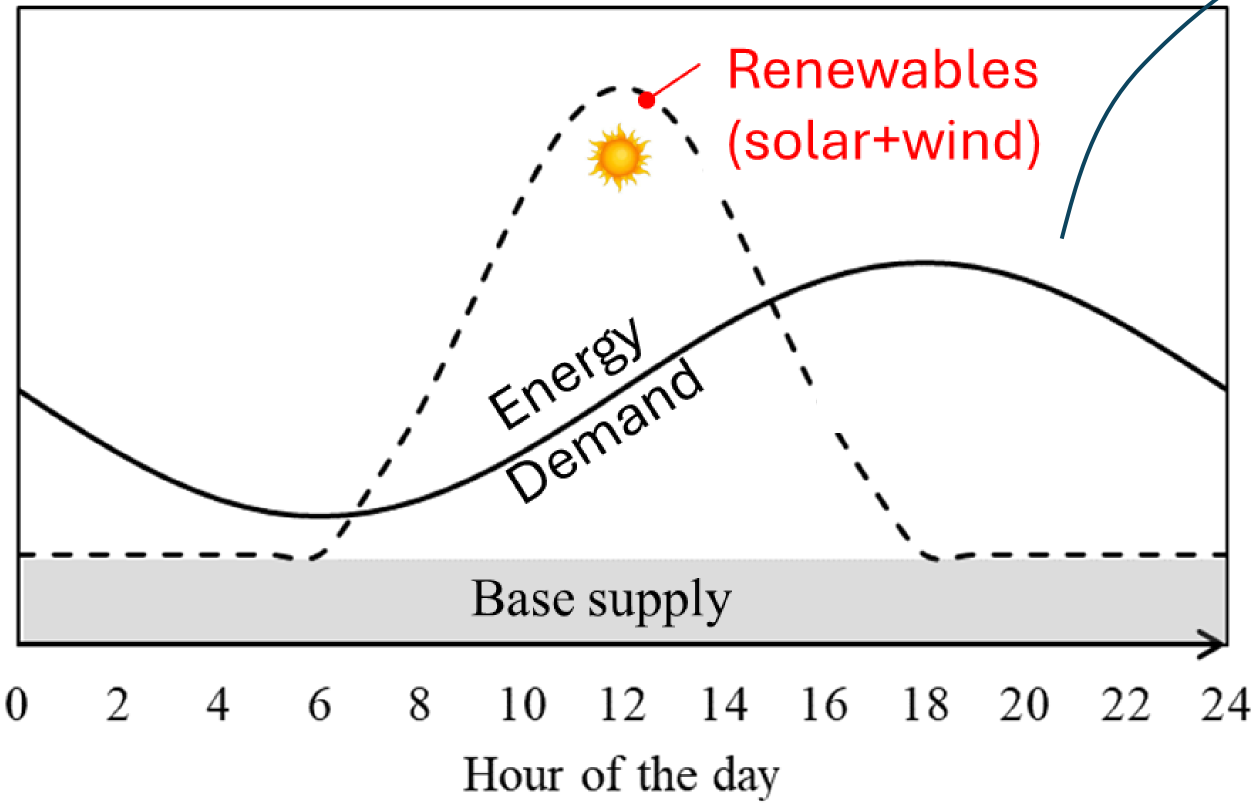


Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases. Ref=Reference case.

The electrification process will rely more on renewables which replace traditional fossil fuels

Energy demand vs. supply

Comparison of hourly energy consumption and supply by renewables

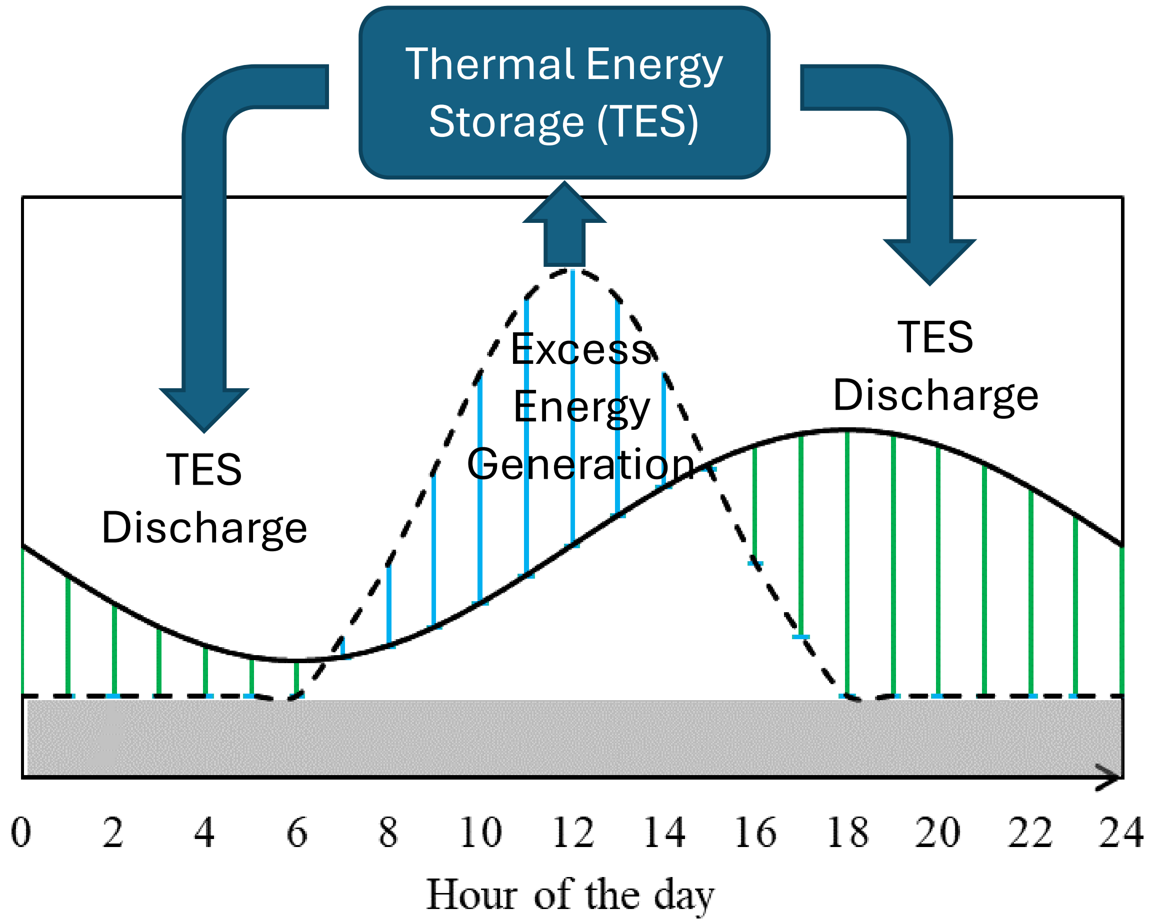


Peak Energy Demand in the Evening

Supply and Demand Mismatch

Solution:
Thermal Energy Storage

Energy demand vs. supply



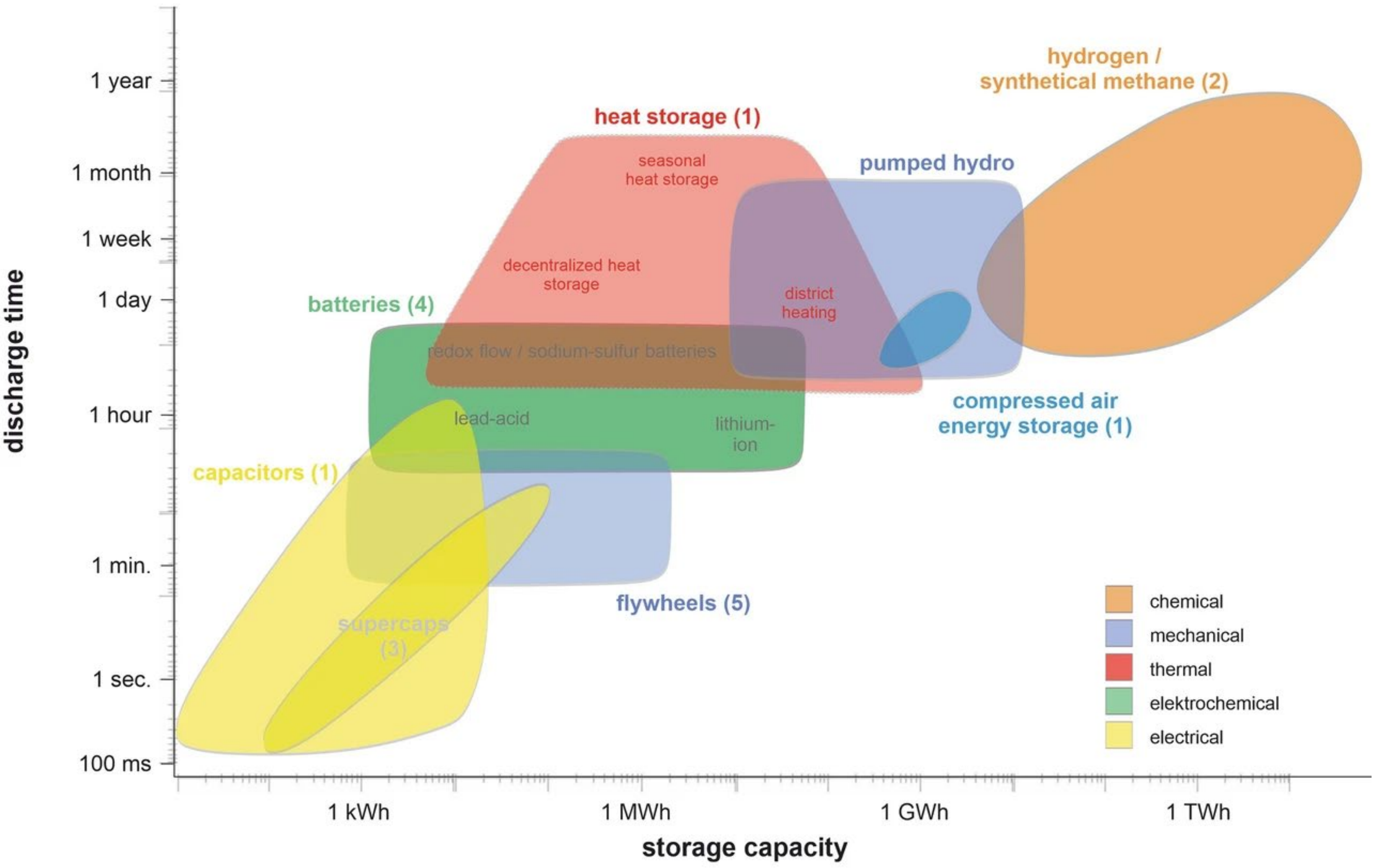
Charge of TES:

- Energy supply > Energy demand
- During off-peak hours or when renewable energy is excessive

Discharge of TES:

- Energy supply < Energy demand
- During peak hours

Why thermal energy storage?



- Provide long-term energy storage solution with high storage capacity
- Mitigating intermittency of renewable energy sources
- Operation flexibility (take advantage of low energy rates and reduce peak demand)
- Lower cost alternative than electric batteries
- Directly improve thermal comfort of occupants

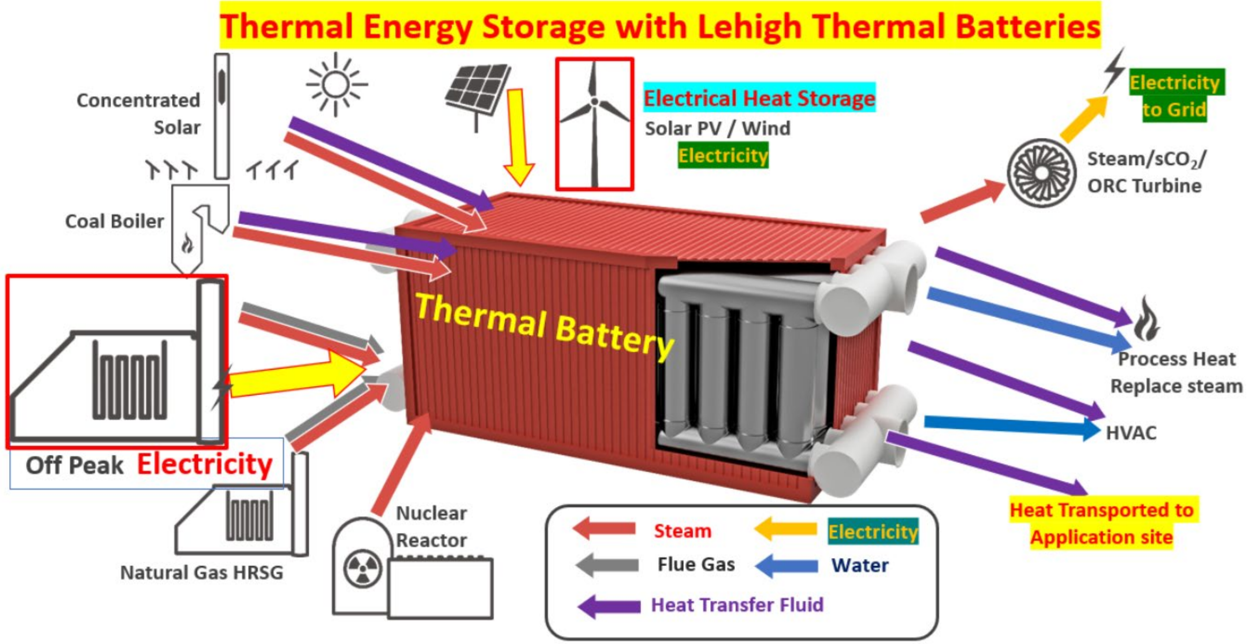
Types of TES technology

	Sensible Heat Storage		Latent Heat Storage	Thermochemical Storage
Type of storage media:	Solid media	Liquid media	Phase change material	Chemical Compound
Energy storage approach:	Energy stored by directly increasing media temperature		Energy stored in latent heat during phase transition of media	Energy stored in enthalpy through reversible chemical reactions

Key research focus of TES

- **Optimization and manufacturing of storage materials**
- **Modeling and analysis**
- **System optimization and integration**
- **Commercialization**

Lehigh Concrete Thermal Energy Storage System



Basic elements
Storage media: Concrete cylinders/blocks
Heat exchanger: Thermosiphon
Heat transfer fluid
Heating source: High-temperature air

Key research focus of TES

Optimization and manufacturing of storage materials

How could storage media effect performance of TES?

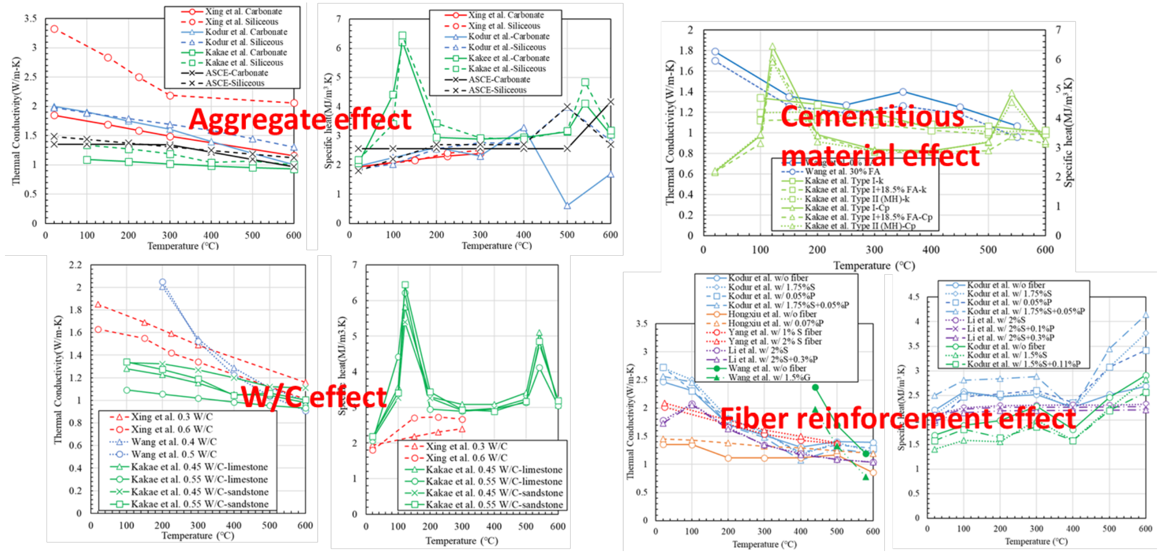
	Storage capacity	Efficiency of discharging
Governing equation:	$E_{stored} = Cp \cdot m \cdot dT(+\Delta h \cdot m)$	$Q_{conduction} = -k \cdot A \cdot \frac{dT}{dx}$
Governing material property:	Specific heat (and latent heat)	Thermal conductivity

Key research focus of TES

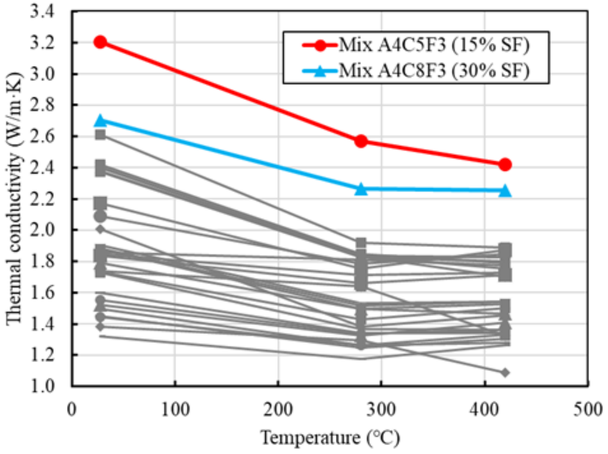
Optimization and manufacturing of storage materials

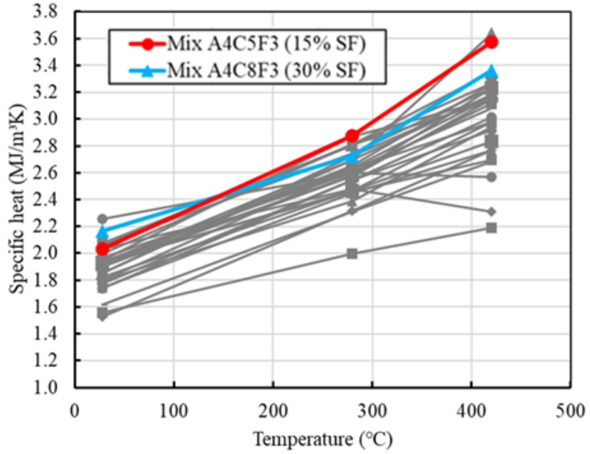
(Example: material characterization of concrete as storage media for sensible heat storage)

Study matrix with different concrete constituents

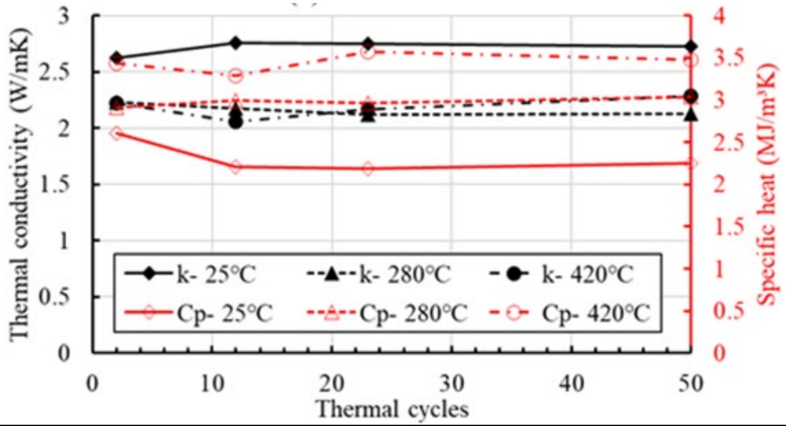


Optimized thermal properties





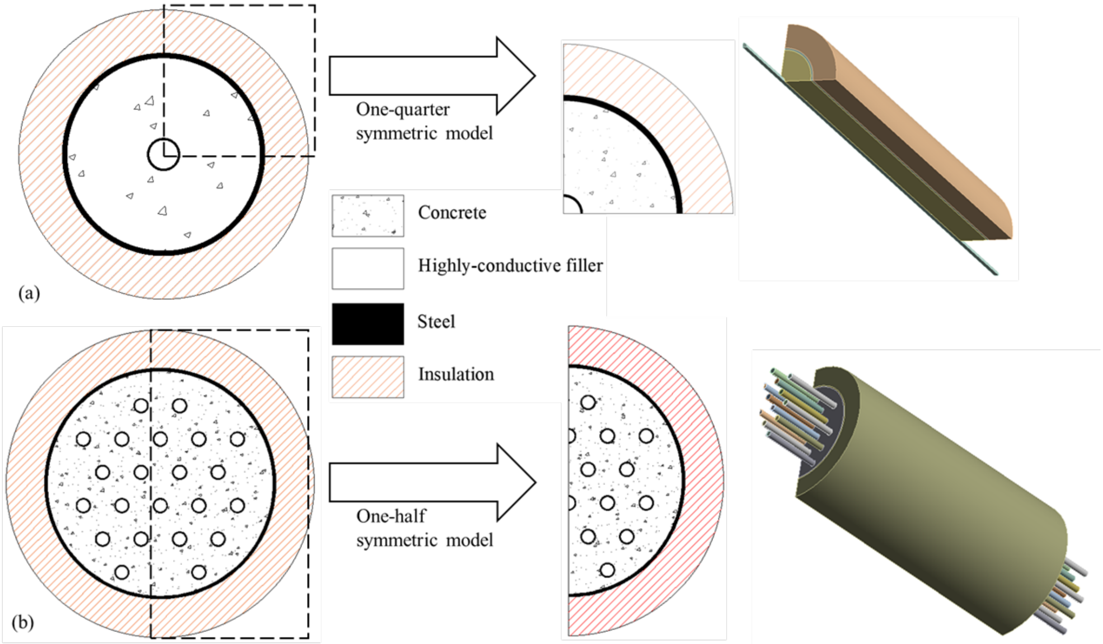
Enhanced temperature resistance

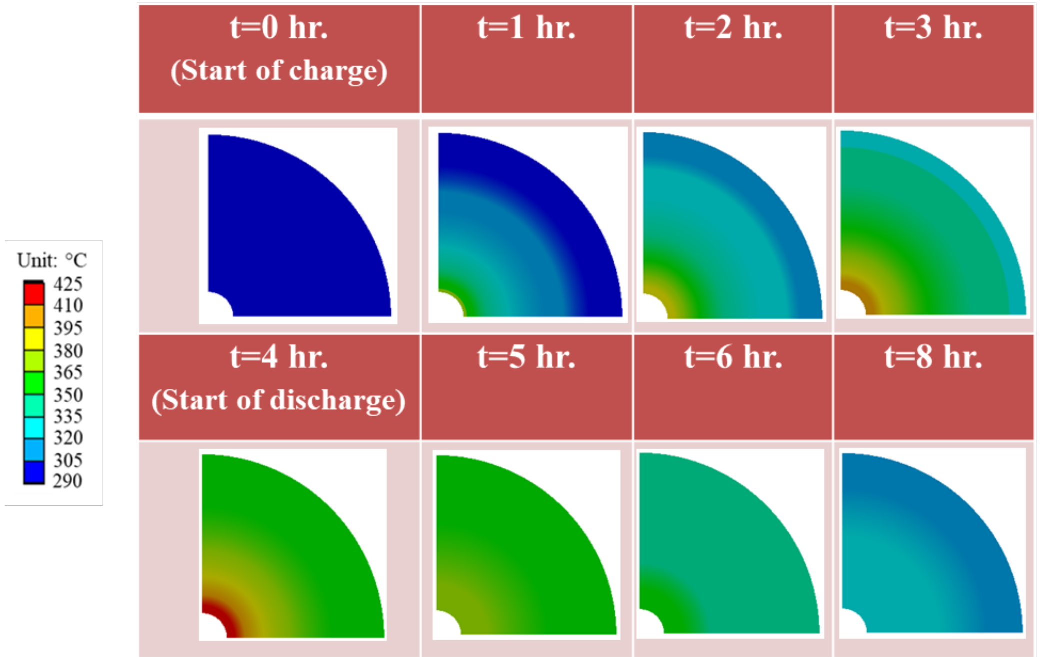


Key research focus of TES

Modeling and analysis

- Establish thermal modeling to predict TES performance with different scales and materials, under different operating conditions
- Develop numerical tools to predict benefits of TES implementation and integration with renewable energy sources.

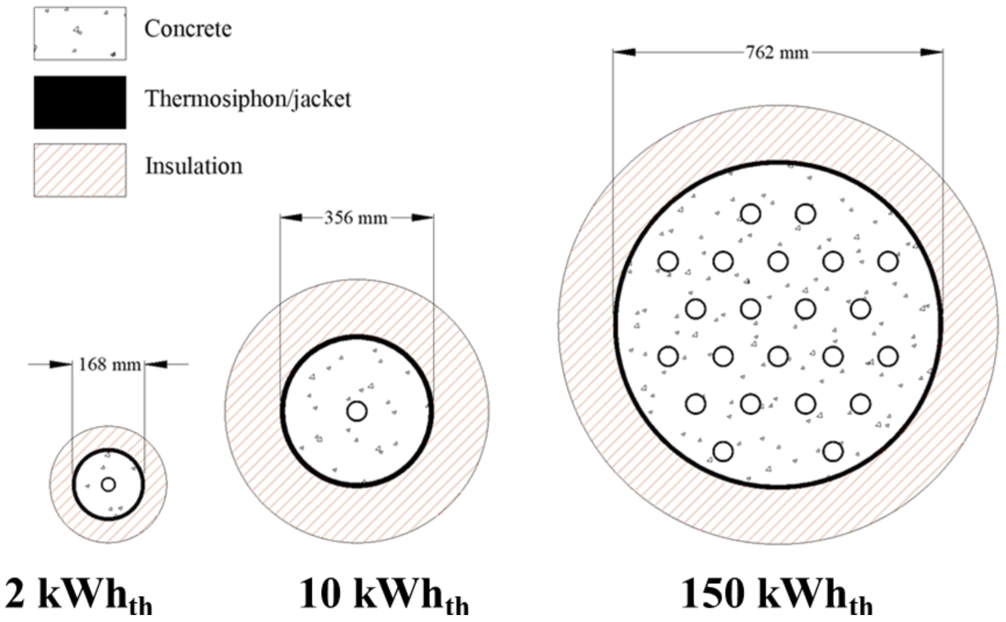




Key research focus of TES

System optimization and integration

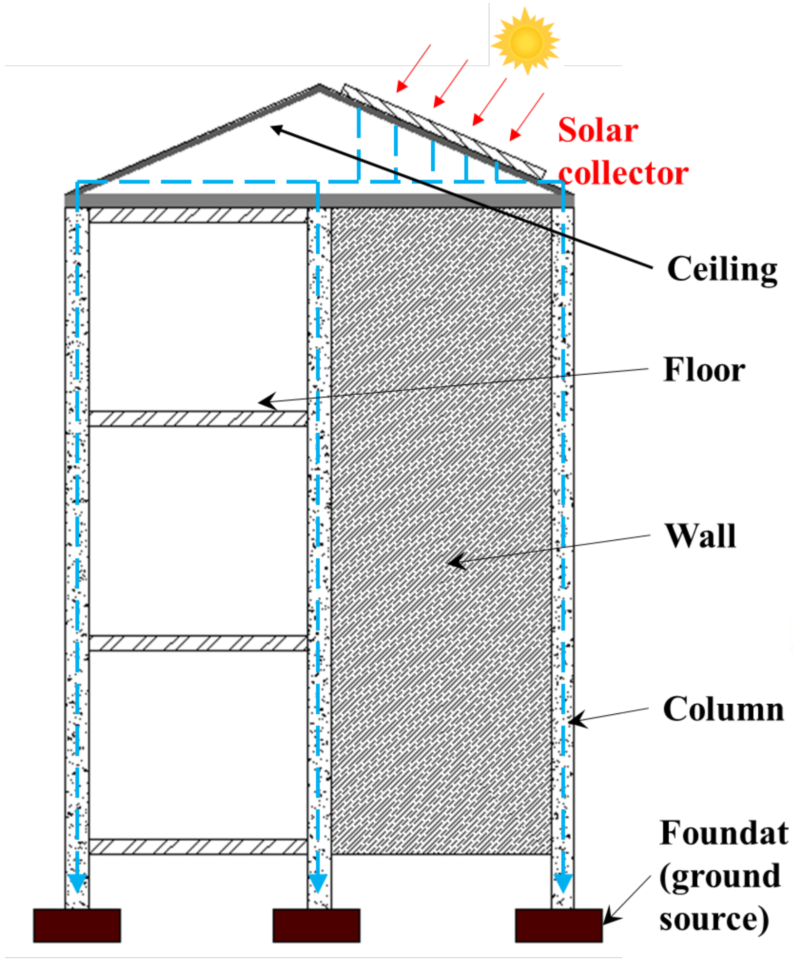
- Scale up ability to fabricate and manufacture materials and components.
- Develop cost-effective configurations for simpler TES integration in building and industrial applications.



	Volume (m³)	Operation Range (°C)	Charge + Discharge Duration (hour)	Actual Energy Storage (kWh_{th})	Charge %	Energy density (kWh_{th}/m^3)	Charge Rate ($kWh_{th}/m^3 \cdot hr$)
$2kWh_{th}$ TC-TES	0.0264	300-380	4 + 6	1.584	79.2	60.00	15.00
$10kWh_{th}$ TC-TES	0.2088	220-340	6 + 4	10.070	100.7	48.23	8.04
$150kWh_{th}$ TC-TES	0.9057	210-380	10 + 6	137.506	91.7	151.83	15.13

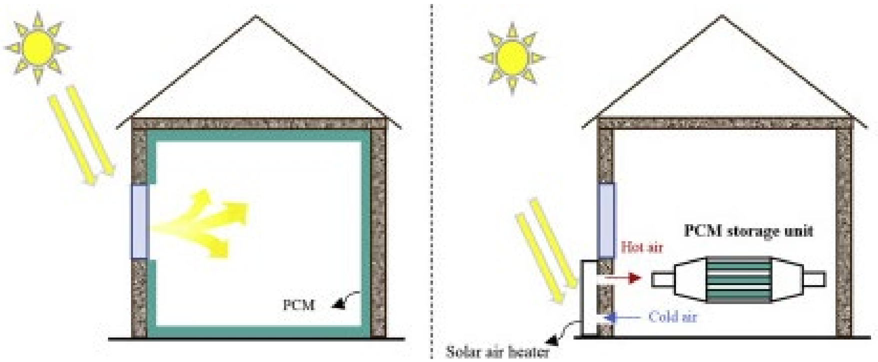
Key research focus of TES

System optimization and integration: On-site TES in buildings

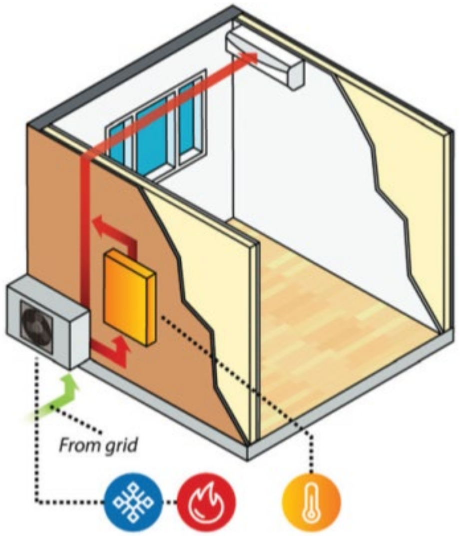


Integration with building envelope

- **Passive systems**
- **Active systems**



Integration with building thermal equipment

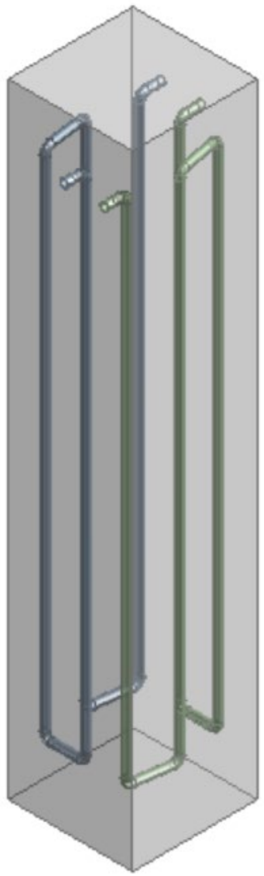


TES integrated HVAC system

Key research focus of TES

System optimization and integration: On-site TES in buildings

(Example: Concrete energy column - an active TES system)

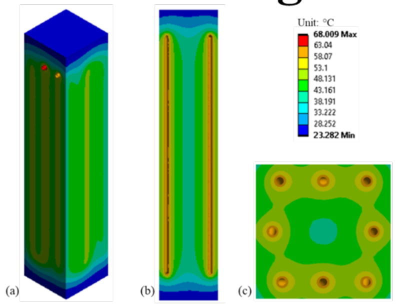


Storage media: Concrete column

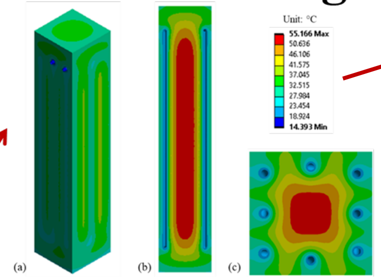
Heat exchanger: Steel pipes

Working fluid: Water

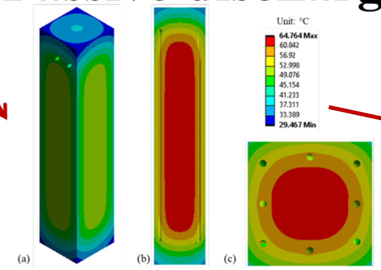
Active charge



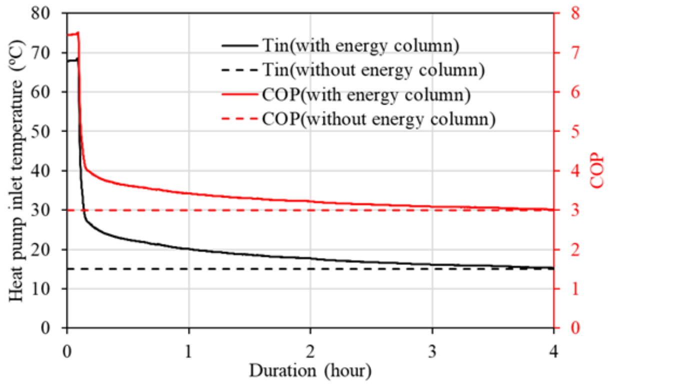
Active discharge



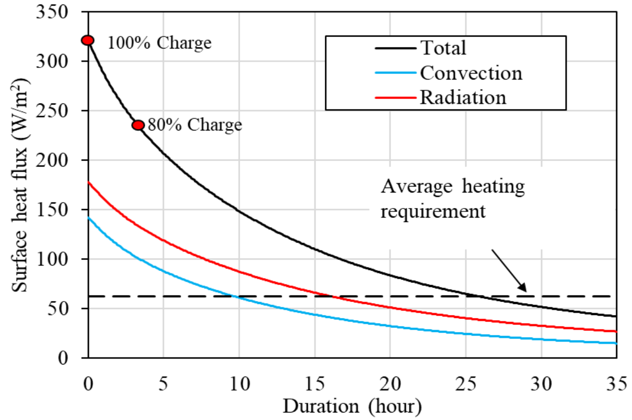
Passive discharge



Heat pump efficiency improvement



Natural indoor thermal regulator



Key research focus of TES

Commercialization

Develop a strategic plan that will enable commercial success for TES products and systems.

- Identify pathways to scale the adoption of equitable and clean TES systems in buildings.
- Identify market and policy barriers to allow for an equitable adoption of building storage technologies in all communities.
- Understand current codes and standards and determine needs to optimize the storage technologies to enable their safe adoption in buildings.

Research barriers on TES in buildings

- **Cost**

Expensive PCMs, integration cost into building sectors

- **Material discovery**

Characterization on current materials, design of novel (PCM) materials

- **Integration**

Adequate space in buildings, other form of renewables

- **Operation**

The operation of TES can only be seasonal, or be limited in a narrow temperature range.

- **Round-trip efficiency**

Ensure no extra energy lost or gained from the ambient

- **Lifetime**

Material degradation, appropriate maintenance protocols

- **Testing and design standards**

Testing protocols and design standards to increase adoption of the technologies

Questions and comments are welcomed

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