Introduction to Thermal Energy Storage (TES) systems – How can these systems mitigate peak grid loads

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Introduction – Why (in a nut shell)?

- **29%** of the UK’s energy consumption used for DSH + DHW.
  - **69%** from gas and oil
  - Hence, **20%** of UK’s energy from gas and oil for DSH + DHW.
- Increasing amount of intermittent renewables on the grid (i.e Wind + Solar) which generate electricity (not heat directly).
- Can not guarantee renewable generation coincides with peak grid demand.
- Hence, the need for storage (to reduce grid peaks and utilise renewable generation) and the need for electrification of heat for DSH + DHW
- I will talk about ‘how’ we can potentially do this with TES.

TES - Introduction

- Thermal Energy Storage (TES) = Storage of heat (thermal energy) for use at a later time.
- Can be referred to as a thermal battery.
- This flexibility gives rise to the potential of grid balancing and reducing grid peak demand.
- TES systems typically are very flexible – energy sources can be direct electrical resistance, heat pump, Solar Thermal Collector (STC) etc.
- Typically TES is broken into 3 different technologies:
    - Sensible (STES)
    - Latent (LTES) or Phase Change Materials (PCM)
    - Thermochemical (TCES)
- Depending on the application a different TES technology may be more advantageous.
    - Storage duration
    - Power output
    - Energy density
    - Cost
    - Scale

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Sensible Thermal Energy Storage (STES)

- STES – use the heat capacity of a substance to store thermal energy.
- Typical example is a domestic hot water tank (heat up water = store thermal energy)
- Can be other material’s (i.e. rock, metals) depending on temperature range
- Energy density of water with a temperature difference of 25 °C = 105 J/g (29 kWh/m^3)
- **STES advantages**
- A developed technology (i.e. traditional DHWT)
- Can be cost effective – again if its water the cost of the energy storage medium is low
- Power output can be adapted – product of the heat exchanger design
- Can be used for large scale long term storage (large stratified water tanks)
- Energy storage efficiency can be high – function of heat losses from system
- **STES disadvantages**
- Relatively low energy density (typically ~29 kWh/m^3 for water)
- Short term energy storage at domestic scale – function of insulation.

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Latent Thermal Energy Storage (LTES/PCM)

- LTES or PCM
    - Takes advantages of the enthalpy involved with the phase transition of a material (i.e. melting)
    - An example is a wax – as the wax is heated it stores sensible energy.
    - Absorbs a relatively large amount of energy over a small temperature range when it transitions from a solid to liquid – This is the latent heat.
    - PCM's can be used for a broad range of temperatures. For domestic use typically can store around ~200 J/g of latent heat (plus the sensible heat).
- PCM advantages
    - Higher energy density than typical domestic hot water tank (around 2x) – compact system
    - Heat energy stored for longer period (relative to hot water tank).
    - Large power output over a small temperature band – ideal for instant hot water
    - Can be designed to be charged by different means (i.e. heat pump, direct electrical resistive heating, solar thermal system)
- PCM disadvantages
    - Technical difficulties - optimising charging and discharging heat transfer
    - Energy losses with time – less than but similar to a standard hot water tank.
    - Minimal systems on the market.

Thermochemical Energy Storage (TCES)

- TCES (ThermoChemical Energy Storage) takes advantage of the enthalpy involved with reversible chemical reactions.
- For domestic use this is typically a gas solid reaction. Gas = air with a water content which reacts with the solid sorbent releasing heat.
- To charge – heat for remove water. To discharge – add water to release heat.
- TCES advantages
  - High energy density – up to 10x of a traditional domestic hot water tank
  - Long term energy storage – potential for seasonal thermal energy storage (charge in the summer, release heat in the winter)
  - Potentially zero energy losses in energy stored as chemical potential
- TCES disadvantages
  - Currently no systems available on the market – predominately still in the R&D phase
  - Cycle stability can be problematic

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Mixergy – Smart STES system

- The Mixergy system is a domestic hot water tank which has a smart system.
- Can be charged by a range of sources (electricity, gas boiler, PV, STC, heat pump).

- In 2021 Mixergy announced a 1 MW frequency response service for National Grid.

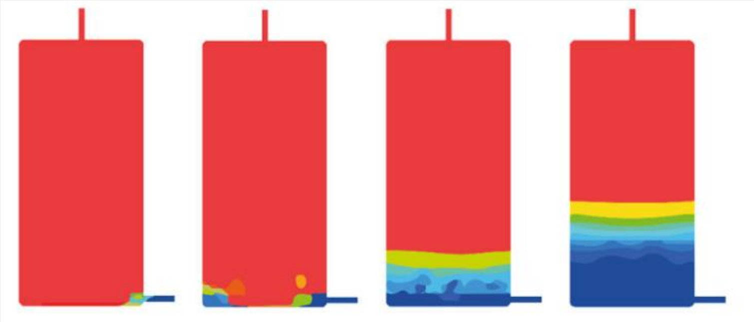
Image source: https://www.mixergy.co.uk/products/mixergy-tank/

30% more hot water from the same volume cylinder.

The inbuilt diffuser in the Mixergy tank prevents hot and cold water mixing, ensuring that the Mixergy tank delivers 30% more usable hot water for the same volume.

The diagram below compares what happens when you discharge 30% of a Mixergy cylinder vs. 30% of a conventional hot water cylinder:

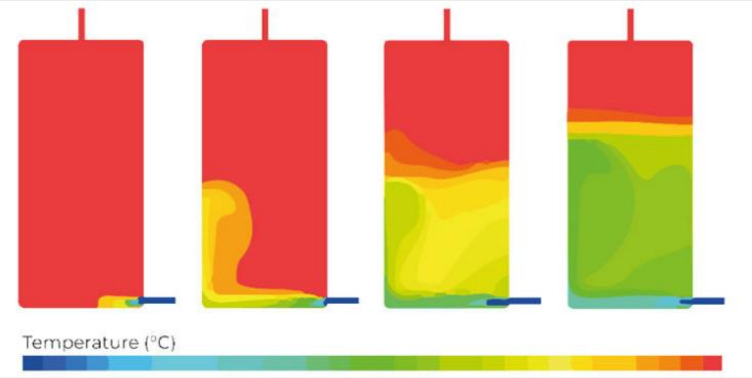
Mixergy cylinder (with an inlet diffuser):



60% hot water remains

30% cold water at bottom

Conventional cylinder (with no inlet diffuser):



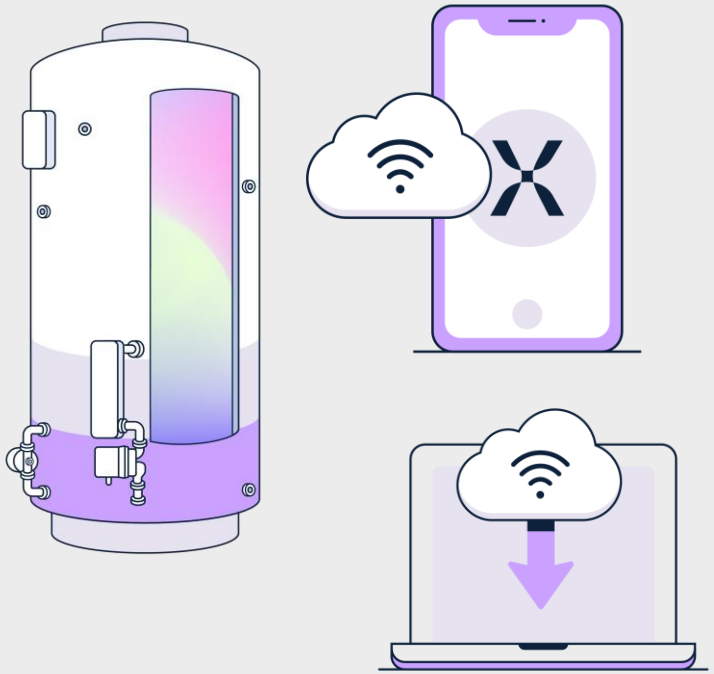
30% hot water remains

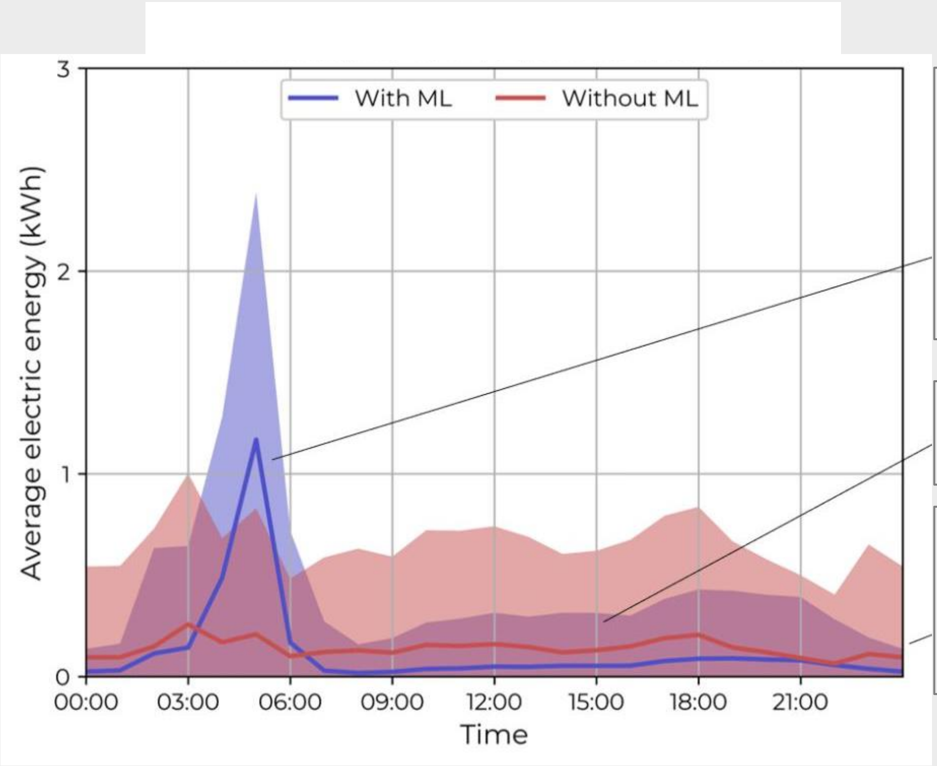
60% diluted water at bottom

Machine learning to meet your home's hot water schedule.

Machine learning adapts your water heating schedule to meet your household's specific needs.

Tests demonstrate that Mixergy tanks using machine learning (ML) capability can provide additional savings of around £55 per year (a 40% reduction) on water heating compared to the same tank operating with user controls only.





The implementation of machine learning shifted energy consumption into the off-peak period, meaning that a significant proportion of the energy consumed was delivered at a significantly lower price.

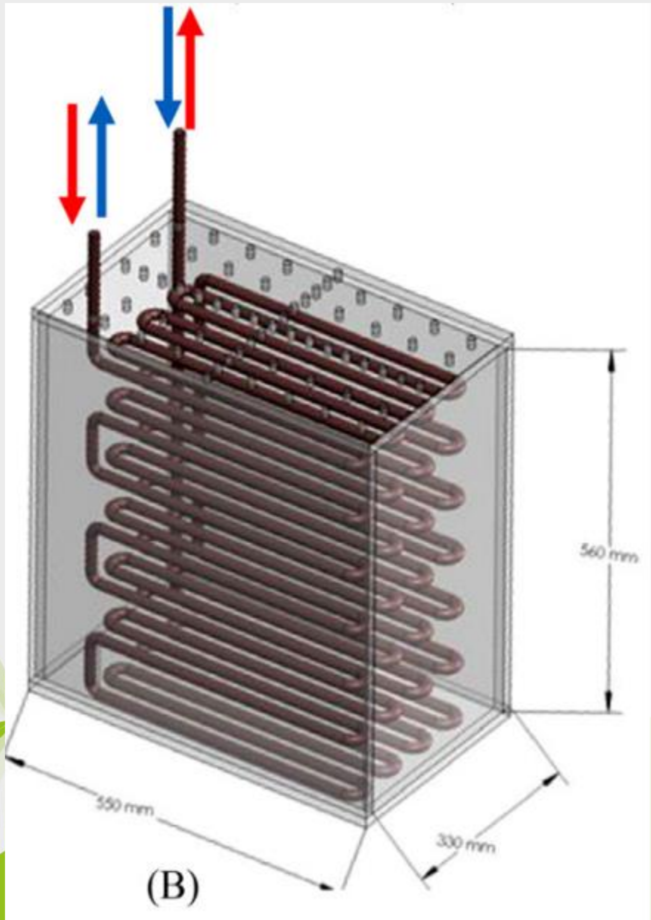
Tank has learned that 45% of capacity sufficient for the rest of the day

By shifting the water heating to off-peak periods, the average hot water bill was reduced from £135 to £80 per annum.

PCM system – published research prototype

- Limited commercially available PCM systems on the market (i.e. Sunamp) – Toby may speak to this.
- Research team at CREST developed, tested and published data on a prototype PCM system.
- The system demonstrated was 0.1 m^3 in volume, with an energy density of **54-56 kWh/m^3** (dependant on charge conditions) – around twice the energy density of a hot water tank.
- System charged between **60 – 70 °C**.
- Phase change temperature = **42 – 43 °C** – Temperature where **218 J/g** energy stored.

- Scaled power output of 10 kWh system
  - Peak input power = 30.3 kW
  - Power input after 20 minutes = 3.7 kW
  - Power output after 10 minutes = 10.1 kW
  - Power output after 20 minutes = 4.4 kW



Ref for image and study : Fadl, M., Mahon, D., & Eames, P. C. (2021). Thermal performance analysis of compact thermal energy storage unit- An experimental study. *International Journal of Heat and Mass Transfer*, *173*, 121262. https://doi.org/10.1016/j.ijheatmasstransfer.2021.121262

Interseasonal TCES – published experimental research

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- Published research of a novel domestic TCES material for domestic use developed and tested at CREST.
- Charging temperature = **150 °C**
- Specific energy density = **702 J/g** (195 kWh/1,000 kg) – (>6x DHWT)
- Volumetric energy density = **415 MJ/m^3** (115 kWh/m^3)
- Peak power output scaled value = **30 kW** for a 1,000 kg system. – Energy output can be controlled
- Performance = **85%** = Energy stored as chemical potential.
- Charging input power (scaled for 1 m^3 system) = **64 kW** (controllable to match available energy)

Study Ref: D. Mahon, G. Claudio, and P. Eames, “A study of novel high performance and energy dense zeolite composite materials for domestic interseasonal thermochemical energy storage,” *Energy Procedia*, no. August, pp. 22–25, 2018.

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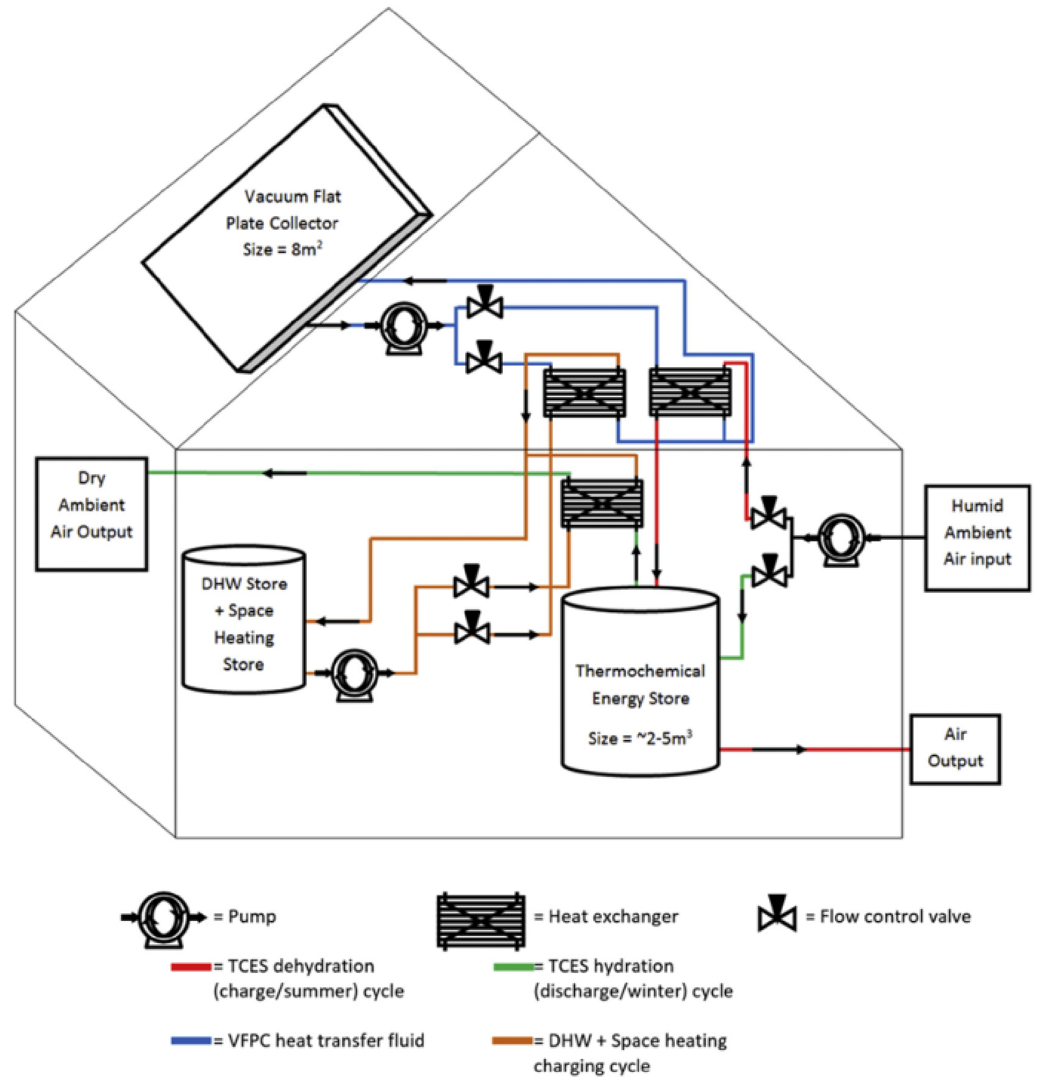
Interseasonal TCES – published feasibility study

- Study looked at several different TCES systems charged with different solar thermal collector systems
- Charged over the 3 summer months discharged over winter.
  - Mitigate seasonal mismatch between thermal energy supply and demand
- Only 1 charge/discharge cycle per year.
- System cost (OPEX + CAPEX) / energy stored = **5.1 pence/kWh** (best cost found)
- Yearly energy production ~**4,500 kWh/year** = best system with a Vacuum Flat Plate Collector (VFPC)



Study Ref: D. Mahon, P. Henshall, G. Claudio, and P. Eames, "Feasibility study of MgSO 4 + zeolite based composite thermochemical energy stores charged by vacuum flat plate solar thermal collectors for seasonal thermal energy storage," *Renew. Energy*, vol. 145, pp. 1799–1807, 2020.

Thank you

I hope this presentation has outlined different TES technologies and how they may be applicable for different grid peak shifting activities.

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References:

- Mixergy Image source: https://www.mixergy.co.uk/products/mixergy-tank/
- PCM ref: Fadl, M., Mahon, D., & Eames, P. C. (2021). Thermal performance analysis of compact thermal energy storage unit- An experimental study. *International Journal of Heat and Mass Transfer*, *173*, 121262. https://doi.org/10.1016/j.ijheatmasstransfer.2021.121262
- TCES ref: D. Mahon, G. Claudio, and P. Eames, “A study of novel high performance and energy dense zeolite composite materials for domestic interseasonal thermochemical energy storage,” *Energy Procedia*, no. August, pp. 22–25, 2018.
- TCES feasibility study: D. Mahon, P. Henshall, G. Claudio, and P. Eames, “Feasibility study of MgSO 4 + zeolite based composite thermochemical energy stores charged by vacuum flat plate solar thermal collectors for seasonal thermal energy storage,” *Renew. Energy*, vol. 145, pp. 1799–1807, 2020.

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