Thermal Systems R&I at Loughborough:
Thermal Energy Storage and Solar Thermal Systems

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The need for Energy Storage

Previous target (pre 2019) of 80% reduction in CO_2 emissions by 2050, new target net-zero greenhouse gas emissions.

The electricity supply can be decarbonised by the use of renewables, nuclear and CCS.

Nuclear is relatively inflexible in terms of generation.

Renewables are an intermittent supply with significant variation in output with time.

CCS reduces power plant efficiency and is not 100% effective.

Fossil plant with low utilisation/high cost may be required to meet peak electricity loads or when renewable generation is low.

Plans to electrify much of transport will increase generation requirements, flexibility in charging times may be limited due to user expectations.

If electricity supply is decarbonised, electrification of heat is a possible route to heat decarbonisation. Due to winter/summer load profiles this could exacerbate the need for low utilisation plant to meet peak demands.

Energy storage will become much more important with greatly increased storage capacities required.

Heat storage may have possible applications both in the demand side and electricity generation to reduce and meet peak loads.

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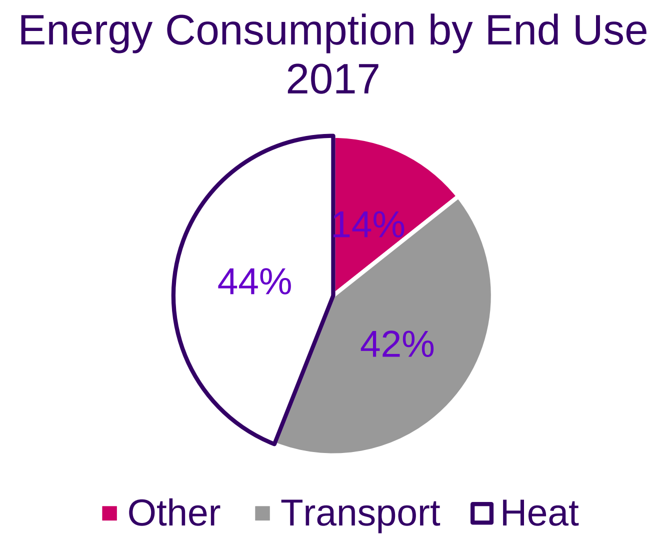
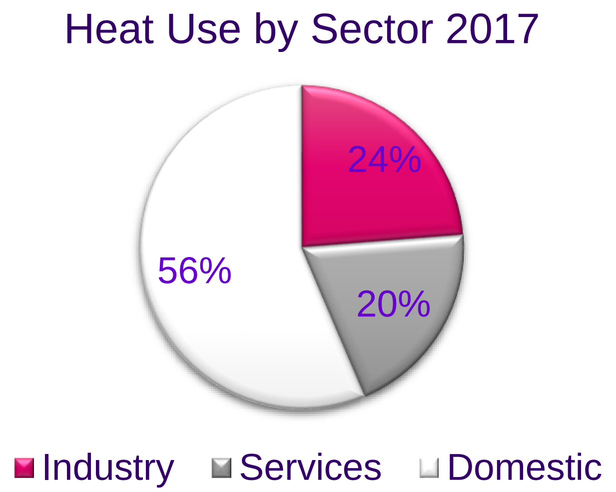
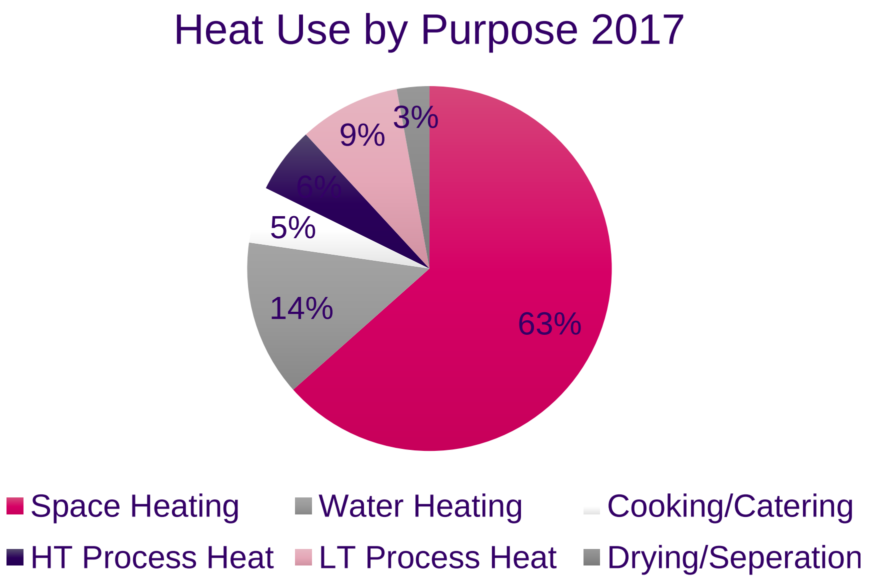
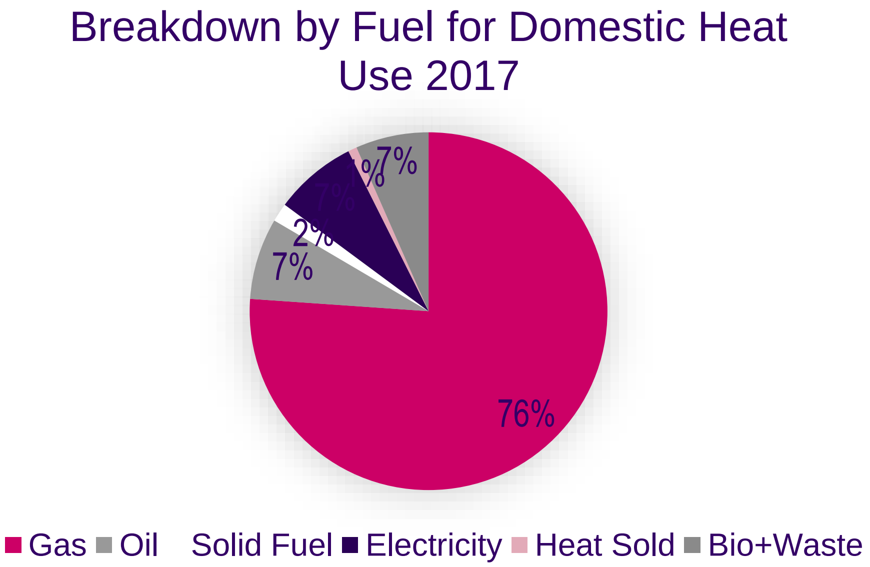
Decarbonisation of heat remains a significant challenge









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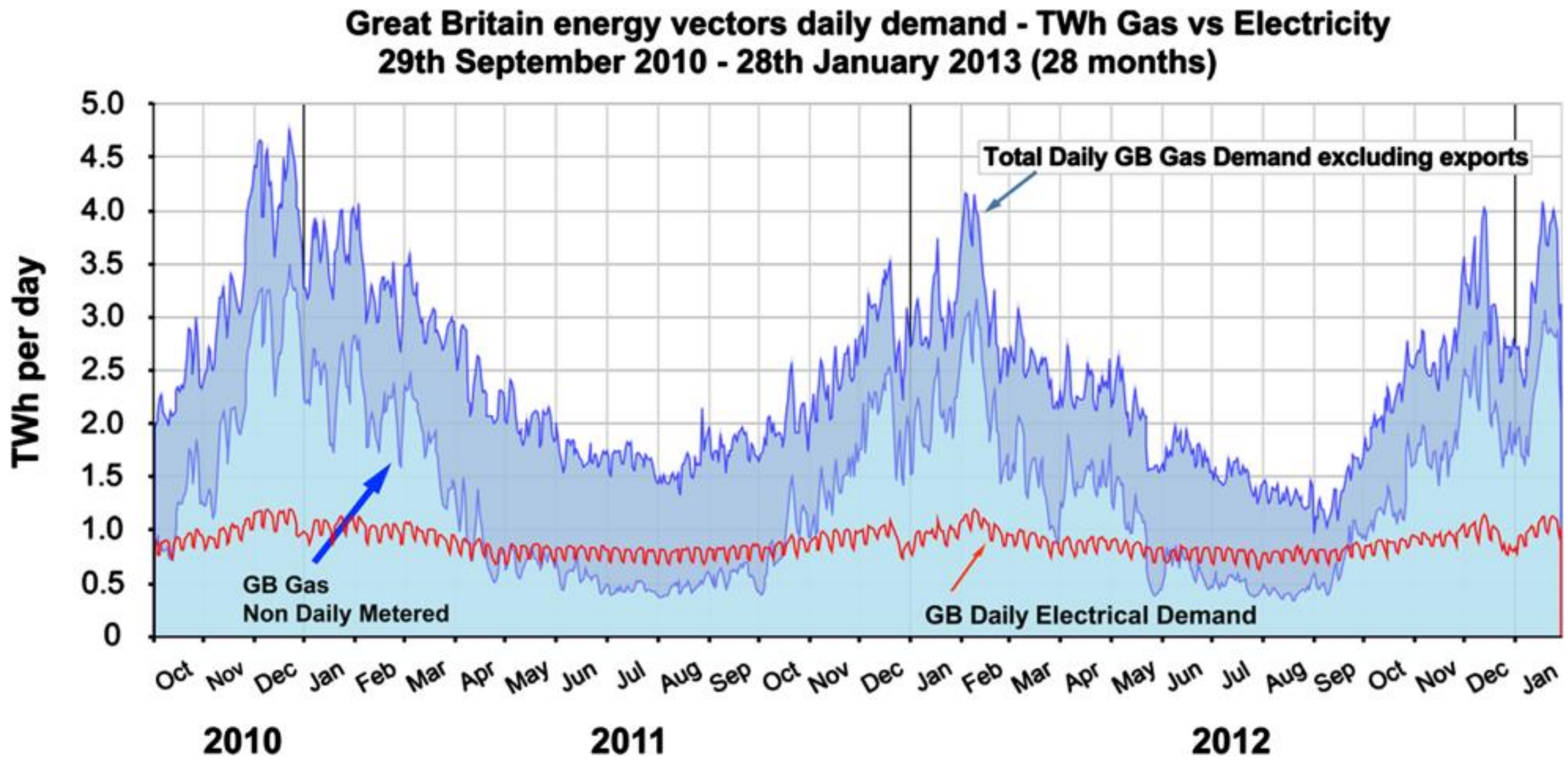
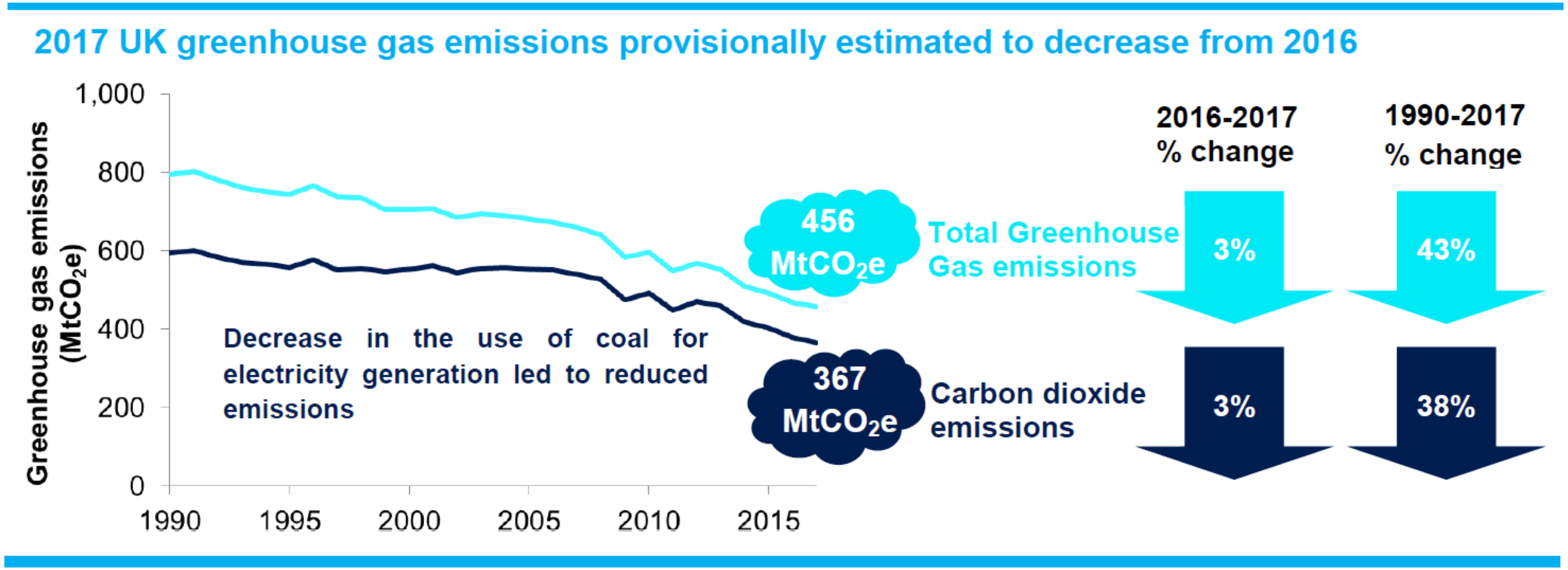


Wilson, I. G., Rennie, A. J., Ding, Y., Eames, P. C., Hall, P. J., & Kelly, N. J. (2013). Historical daily gas and electrical energy flows through Great Britain's transmission networks and the decarbonisation of domestic heat. *Energy Policy*, *61*, 301-305.

Progress in reducing Greenhouse Gas Emissions, Provisional figures for 2017



2017 UK GREENHOUSE GAS EMISSIONS, PROVISIONAL FIGURES,

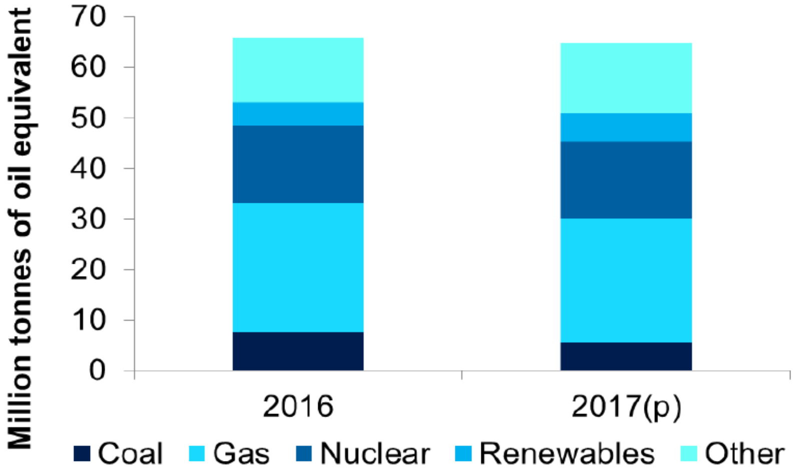
BEIS

Good progress in emissions reduction in some areas however transport and residential energy use are still challenges

The energy supply sector experienced the largest reduction in CO_2 emissions from 2016-2017

	2016-2017 % change	1990-2017 % change
Energy supply (including power sector)	↓ 8%	↓ 57%
Industrial process	↓ 1%	↓ 49%
Business	↔ 0%	↓ 41%
Transport	↔ 0%	↓ 1%
Residential	↓ 4%	↓ 18%
Public	↓ 3%	↓ 41%

Reduction in power sector CO_2 emissions driven by change in fuel mix for electricity generation in 2017, with less use of coal and more use of renewables



2017 UK GREENHOUSE GAS EMISSIONS,
PROVISIONAL FIGURES,
BEIS

Why thermal storage?

- Potentially low cost
- Uses readily available materials
- Applicable over a wide range of different scales and applications

Storage of heat can find applications in areas including:-

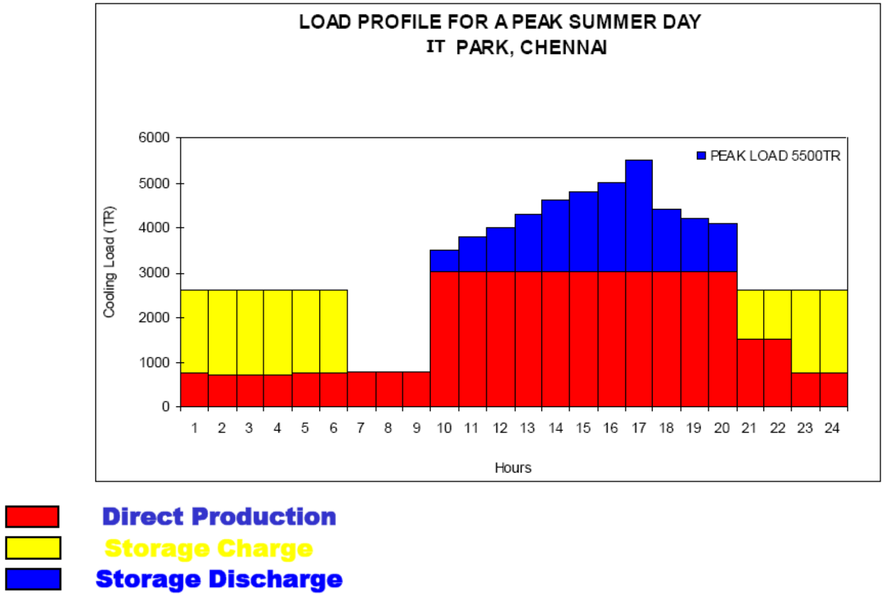
- a distributed form at a range of temperatures for demand side management by reducing peak heat/coolth loads
- large scale centralised high temperature applications for electrical generation by allowing thermal/nuclear plant to work at a continuous set optimum level, excess high temperature heat being stored efficiently for later electricity generation
- conversion of excess renewable generated electricity to high temperature heat for later electricity generation

TES can help address mismatch between heat (electricity) generation and load to improve energy efficiency and or plant utilisation/operation. (Time shifting and reduction in peak loads)

Specific Application Requirements

- Temperature,
- Load characteristics,
- Storage capacity required,
- Cycle characteristics, charge/discharge rate, time,
- Energy storage density,
- Round trip efficiency/parasitic heat loss,
- Materials requirements,
- Controls,
- Durability,
- Cost.

Source:- Cristopia



Thermal Storage Approaches

Sensible,

Latent,

Adsorption heat storage,

Thermo chemical reactions.

Increasing energy density

Characterisation and Test Facilities

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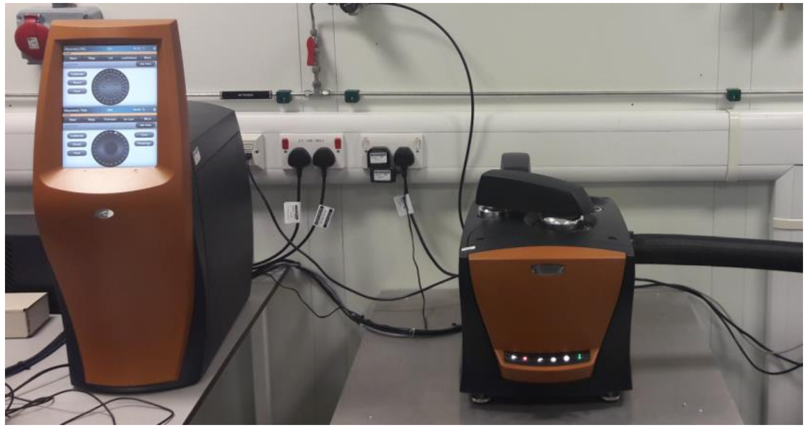
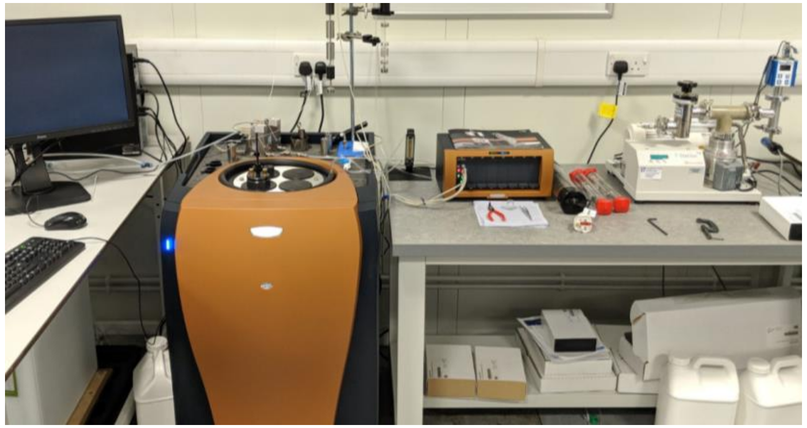


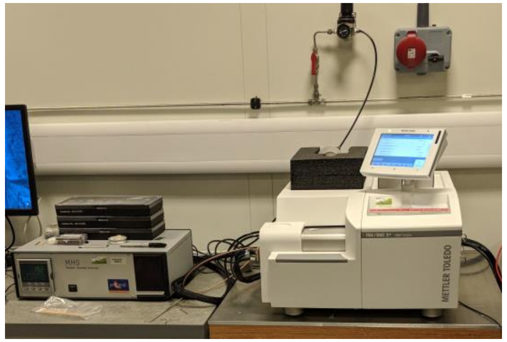


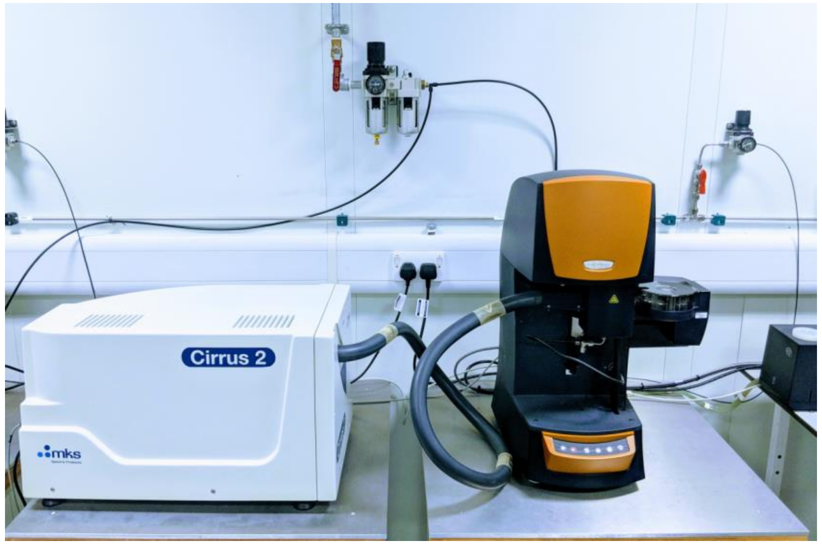
Material Properties

Multiple DSC systems for different temperature ranges, pressures, gas flows and sample sizes

Material Properties

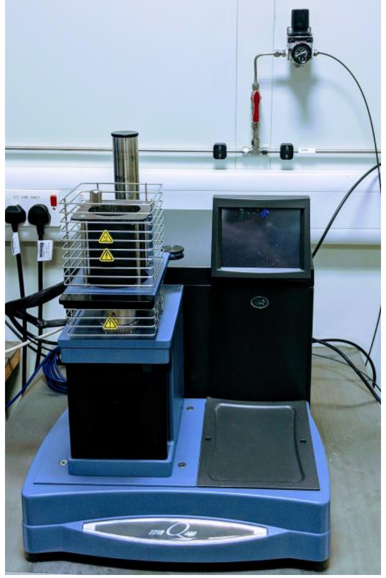
- DSC/TGA combination and TGAs for different pressures, temperatures and gas flows





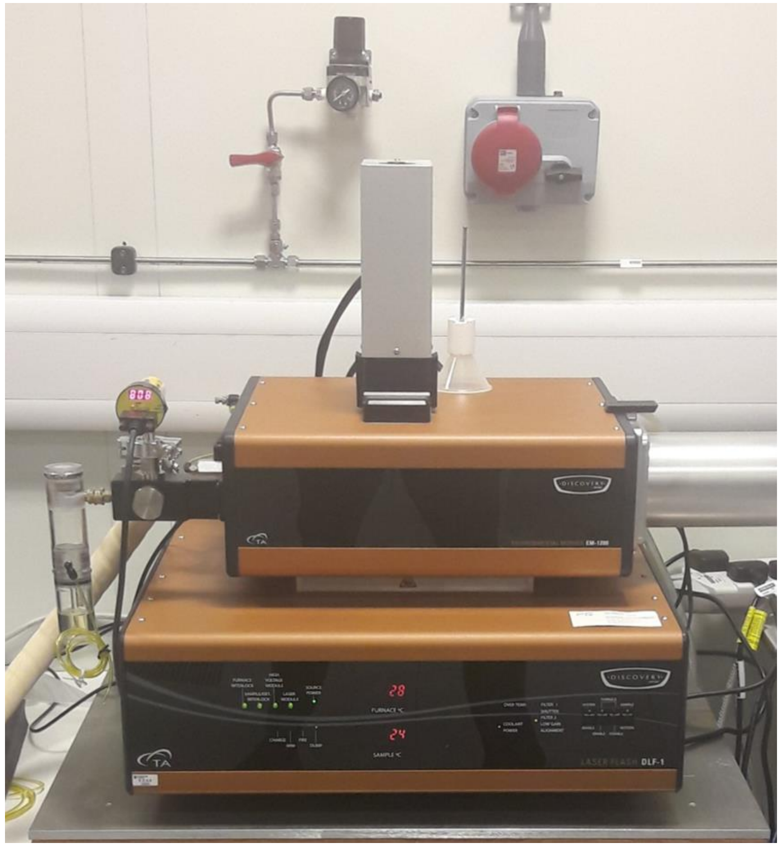
Material Properties.

- Thermomechanical analyser, Dilatometer, Optical Dilitometer



Material Properties

Laser Flash, Hot Disk, Heat Flow Meter



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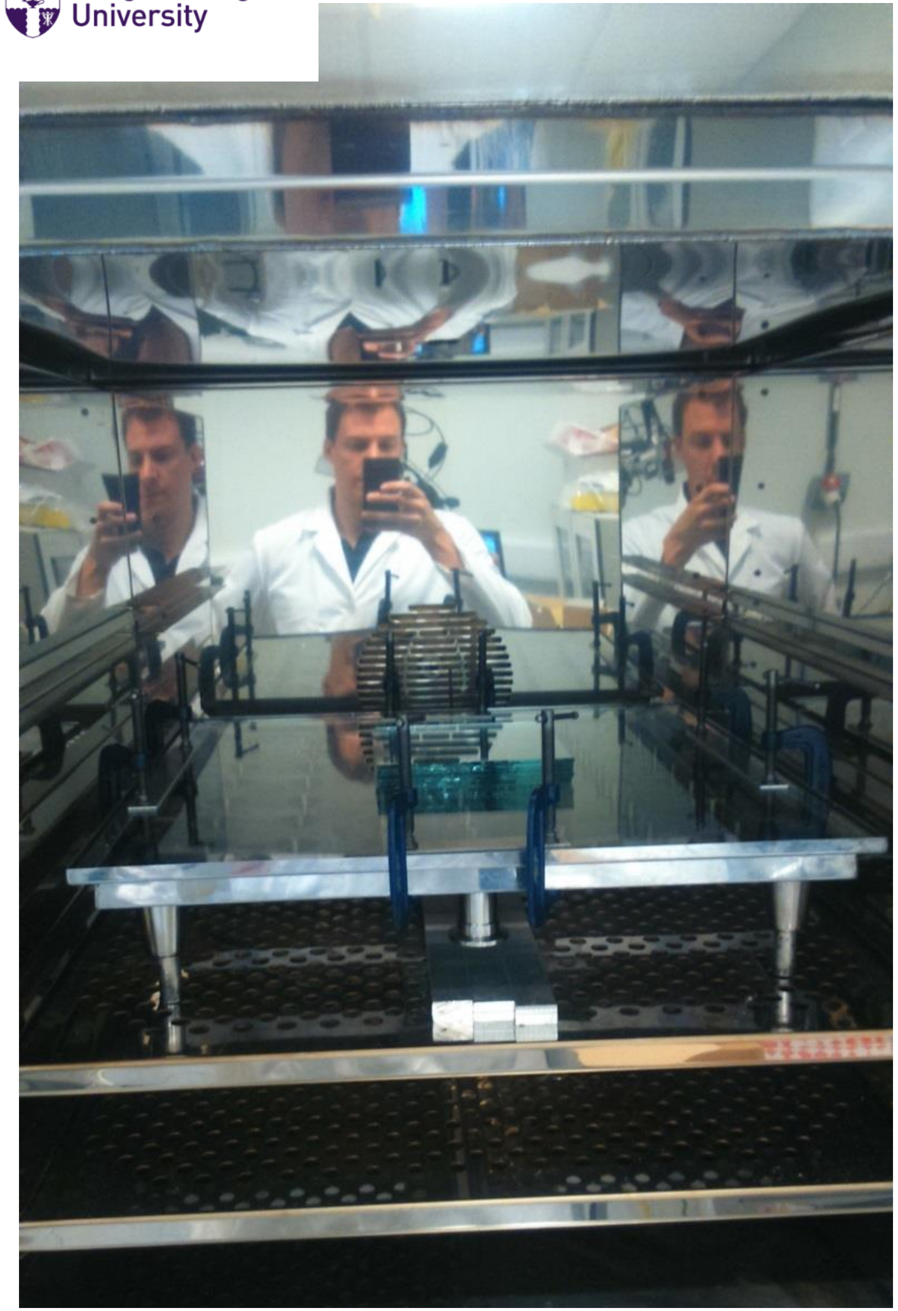
Material properties

- Bench Top Scanning Electron Microscope with attached Energy Dispersive X-ray Spectrometer, 3 D digital microscope,



Material Properties

Rheometer, FTIR Spectrometer and accessories, Gas Sorption Analyser.

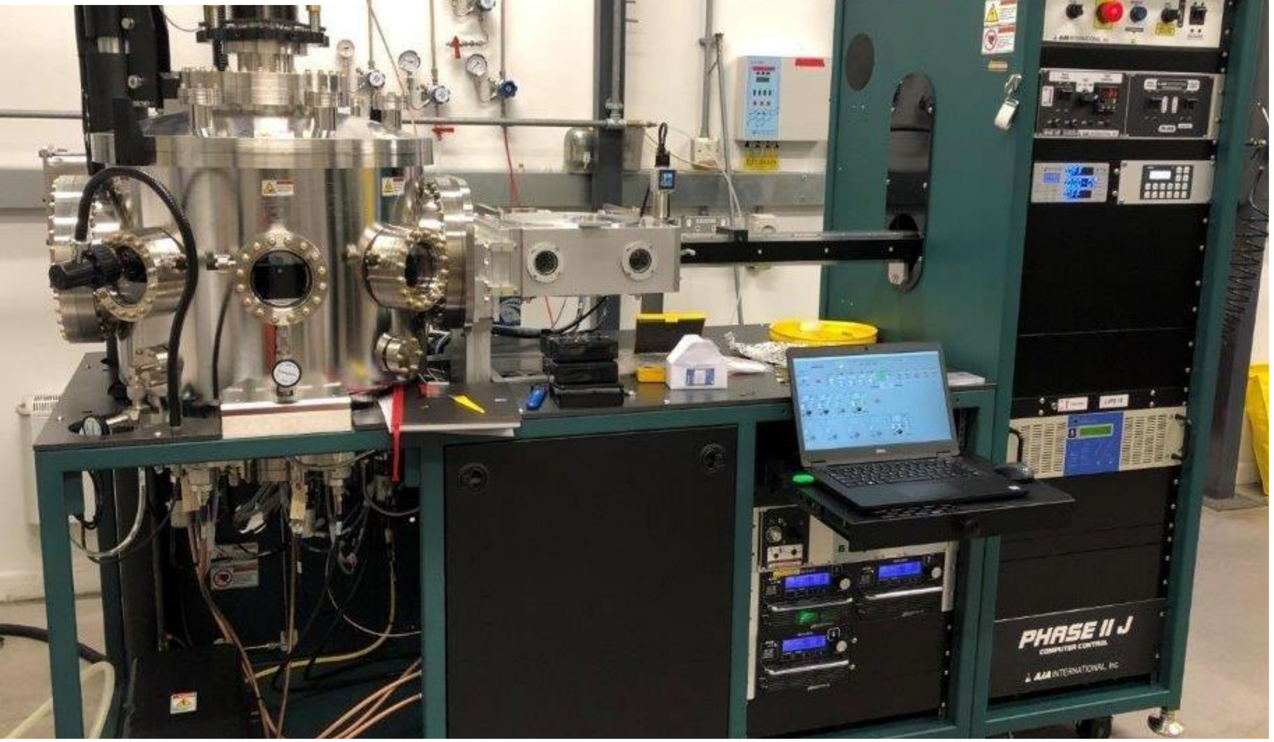


Prototype and material production. High temperature ovens, presses

Precision controlled heat sources for thermal storage characterisation

Fluid flow field and strain measurement

2D -3C PIV/LIF and DIC



Thin film surface deposition.

Sputter and dip coating

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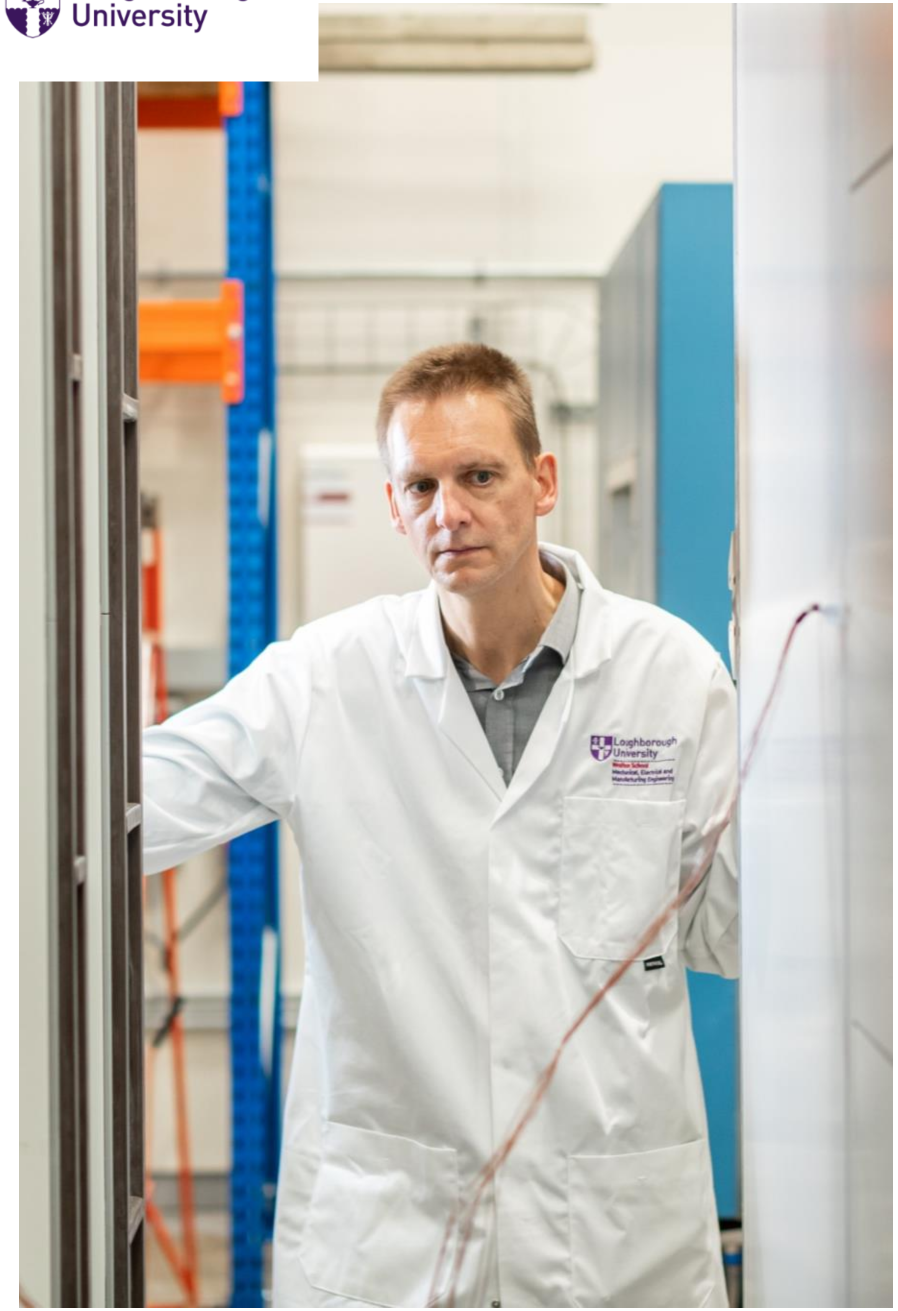

Window and façade element testing

Hot box calorimetry, outdoor test cells

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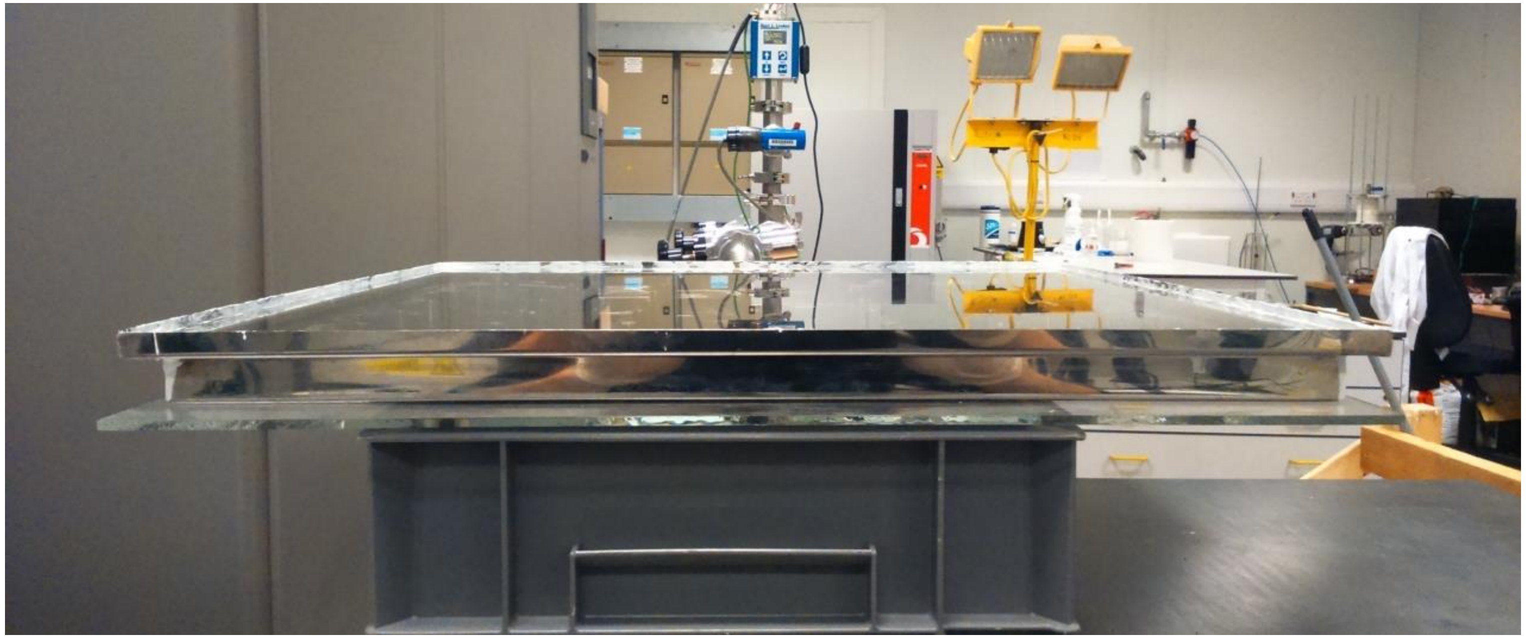
Thermal storage system test loops



Vacuum Insulation, vacuum glazing, vacuum flat plate collectors

Ongoing research includes

- PCM based thermal store development at a range of temperatures for different applications including domestic space heating, hot water provision, low/medium temperature heat applications.
- High temperature sensible heat storage materials/systems development and characterisation.
- Thermochemical heat storage materials characterisation and prototype system design and characterisation
- Enhanced high temperature building envelope integrated vacuum flat plate solar collector development
- Advanced low heat loss glazing development
- Solar thermal façade systems for building retrofit
- Modelling of low temperature district heat networks and assessment of thermal storage options
- Thin film coating development to improve solar collector performance

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R&D

(Fundamental Research)

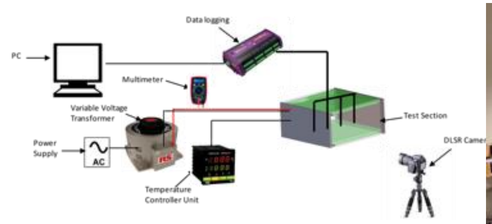
Pilot plant and real test

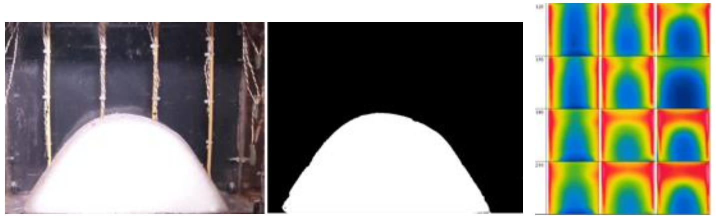
(Applied Research)

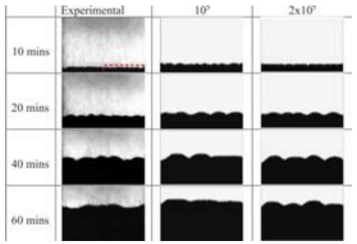
Commercialization of product

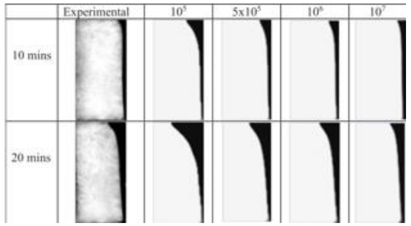
Design → Develop → Validate

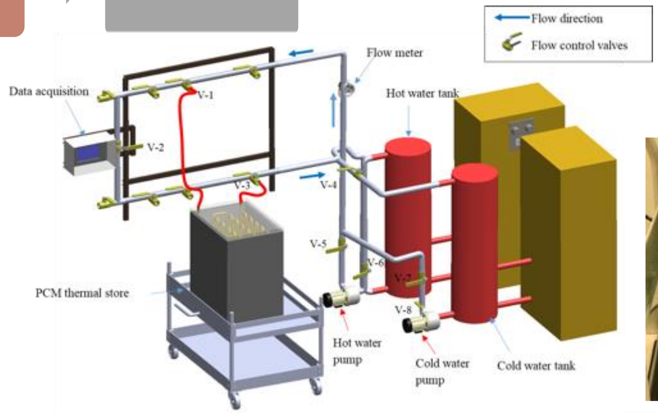
(-20°C ↔ 200°C)

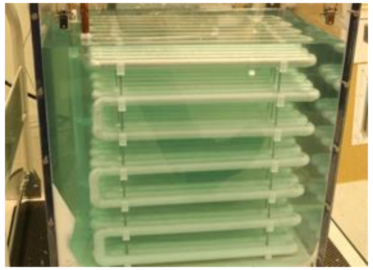




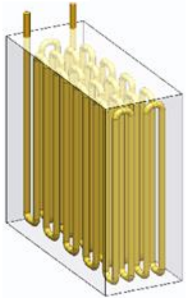


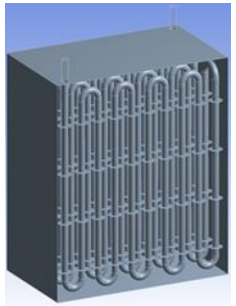


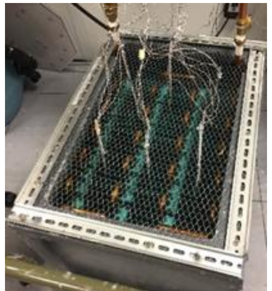


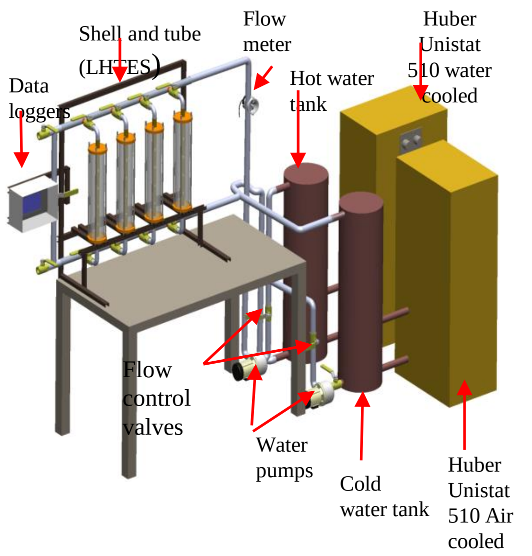


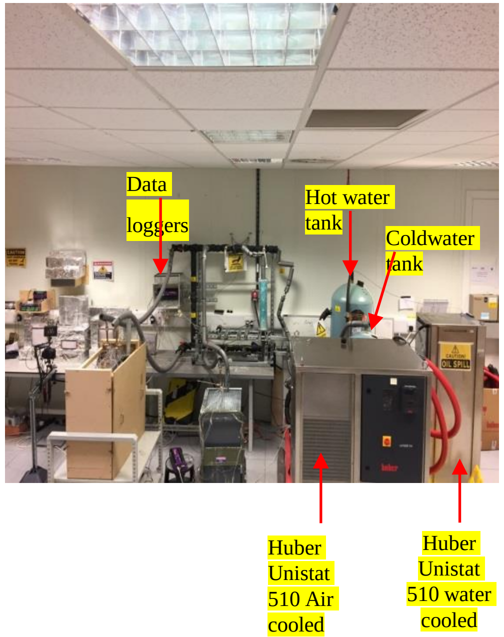
Working with industry

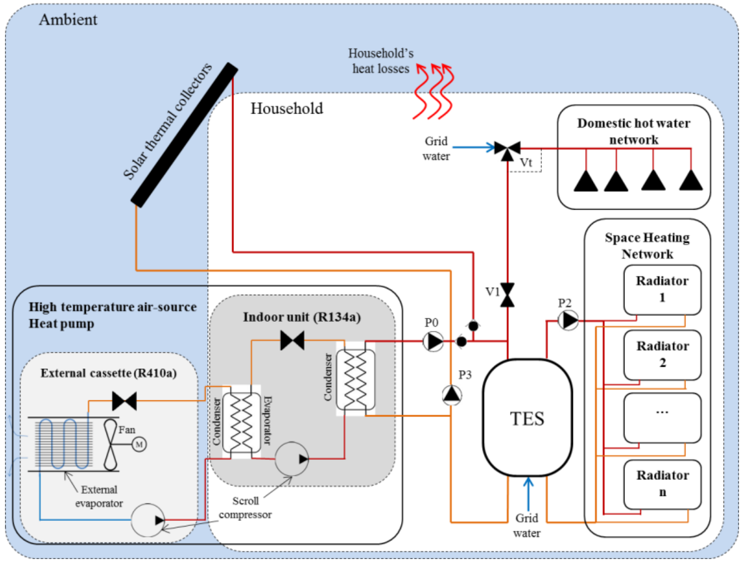




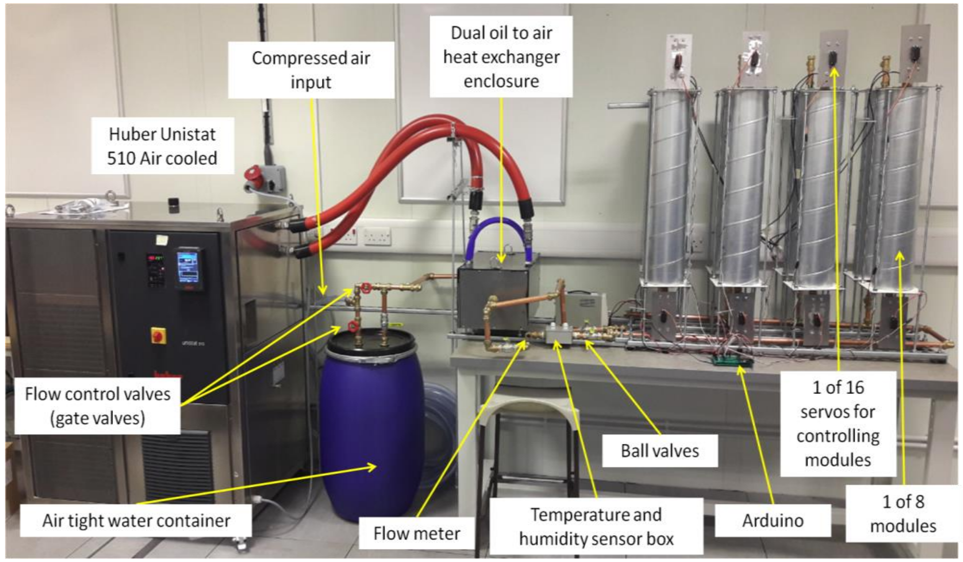


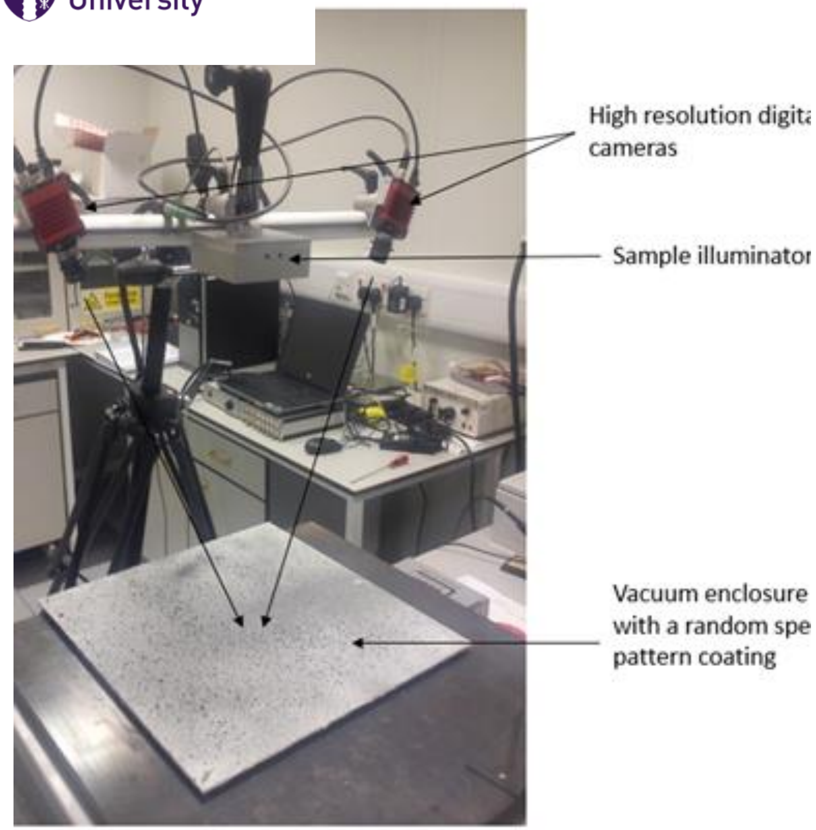


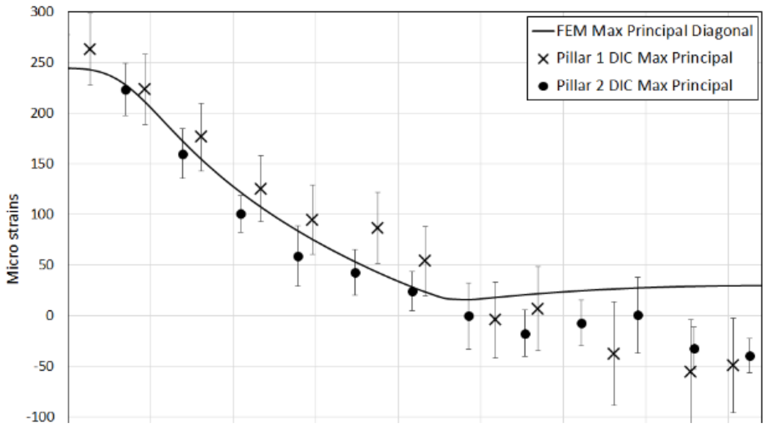


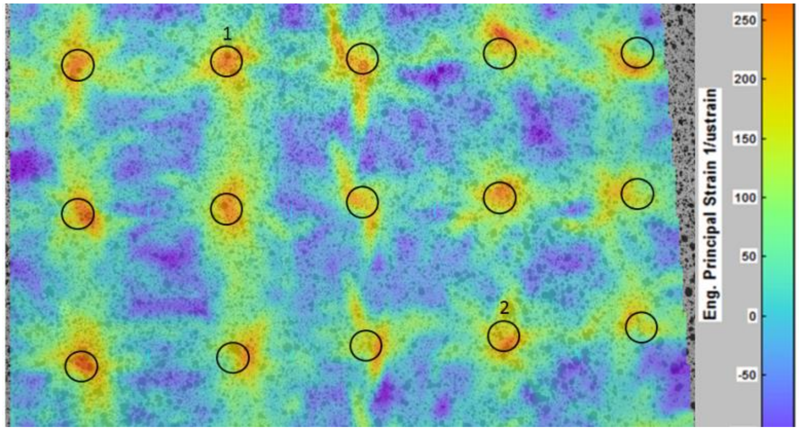


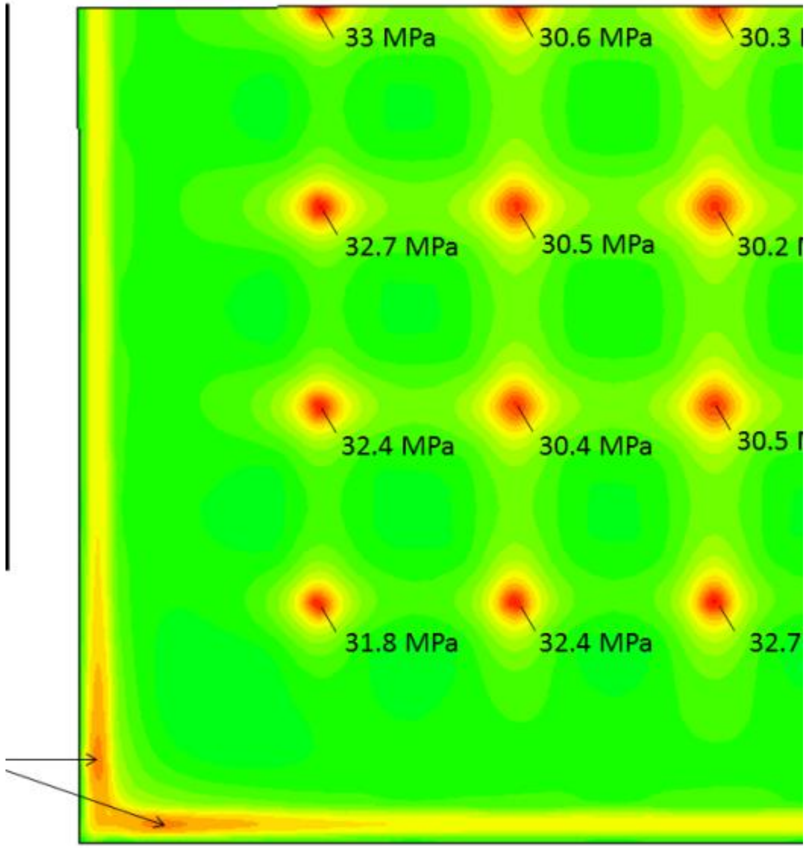
Examples of recent thermal storage work

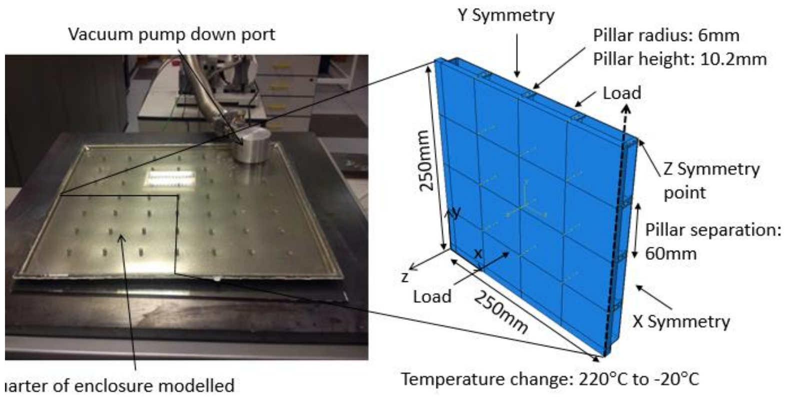








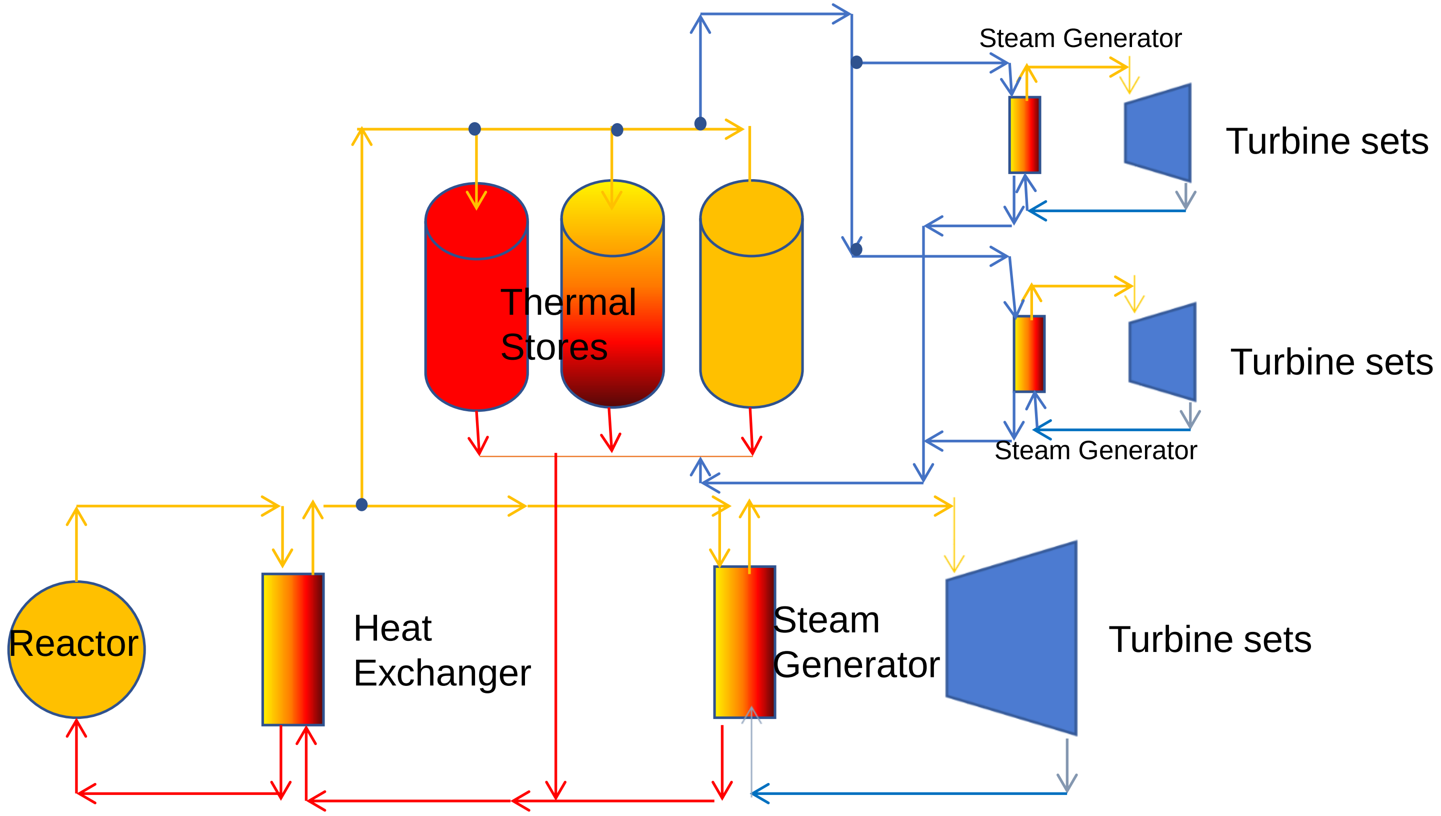




Comparison of FE model predictions and experimentally measured strains using DIC

High Temperature Storage for Flexible Nuclear Generation The Proposed Approach

Heat generated by a nuclear reactor can either be used to directly generate steam for power generation or be used to charge a store /stores for generation of steam at a latter time giving great flexibility in terms of generation capacity.



Nuclear with high temperature thermal storage

The thermal store is charged at times of low electrical load or when electricity from renewables is in excess and would be shed.

At times of peak load or reduction in renewable generation the thermal store is used to provide additional electricity generation capacity by the addition of an additional turbine set.

Due to the direct storage of thermal energy rather than using electricity to generate heat/coolth storage efficiency will be very high and electricity from storage will be produced with a similar efficiency to that of a standard nuclear plant.

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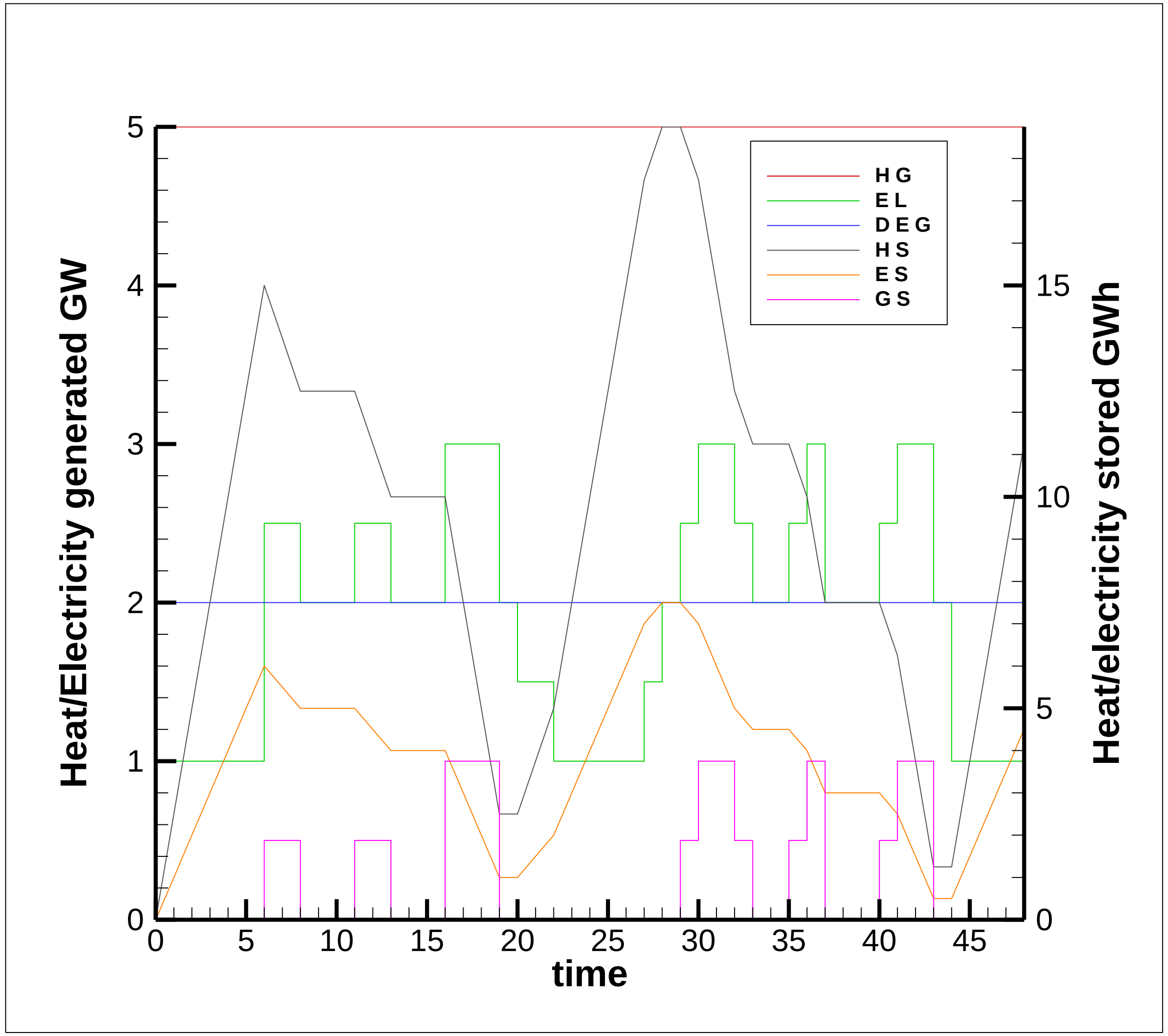
The potential flexibility afforded by adding 20GWh of heat storage to a 2GWe Nuclear plant

H G = Heat Generated
E L = Electrical Load Provided
D E G = Direct Electrical Generation
H S = Heat Stored
E S = Equivalent Electricity Stored
G S = Electricity Generated from Storage
Turbine Sets 500MWe

In a future with Nuclear and Renewables, heat storage linked to Nuclear could provide large scale low cost energy storage helping balance variable renewable generation to meet variable demand profiles.



How large do stores need to be for large scale power generation?

- The Andasol Concentrating Solar Thermal Power system uses a molten salt storage system of around 14,000 m^3 in volume which stores approximately 1 GWh_t or 375MWhe working between 390 and 290˚C.
- If such a store worked between 490 and 290˚C the stored energy available would be approximately twice this, thus a store of 18,667 m^3 could provide a GWh_e storage, that is a cube of side 26.5m would store around 1/9 of the energy available from Dinorwic, the UK’s largest pumped storage facility.
- To store a TWh_e the volume required is 18,667,000 m^3 Although sounding large this volume is provided by stores 20m high over an area equivalent to 131 football pitches.

Concluding Remarks

Lab facilities have been established that allow a wide range of thermal energy storage material properties to be measured and allow prototype thermal storage systems to be developed and tested.

The potential applications for thermal energy storage, if at sufficiently low cost are very large and are likely to increase significantly with the move to more intermittent energy sources and the new zero greenhouse gas emissions target.

Innovative building envelope systems can help reduce building energy loads and generate electricity and heat. It is essential however for rapid large-scale impact that they are suitable for both new build and retrofit applications.

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Acknowledgement

- Funders:- UK Research Councils, Innovate UK, EU, Industry.
- Staff:- Academic colleagues, RAs, PhD & MSc Students, Technician and Admin.
- The meeting organisers for inviting me to speak.