Innovation in Renewable and Sustainable Cooling

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REnewable Energy for Future UK Net-Zero Cooling (REEF-UKC)
Webinar Series – Episode 4

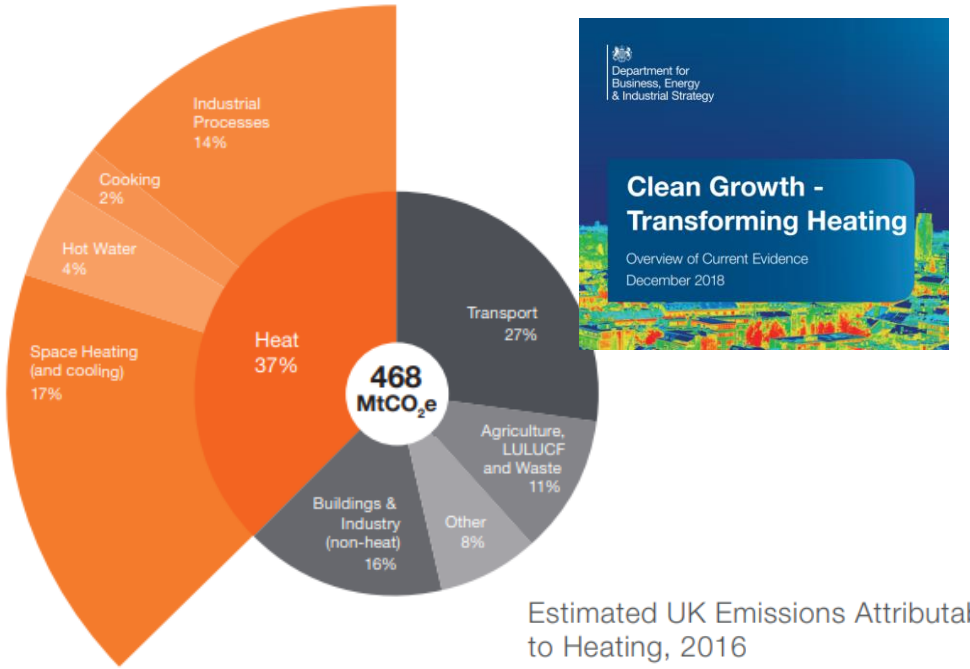
Outline

- **Motivation**
- **Flex-Cool-Store**
  - **Cooling Technologies**
- **PBIAA The SWITCH to Net Zero Buildings**
  - **Ground-Source Heat Pump Systems**
- **UKIERI/SPARC Project**
  - **PCM-based Heat Exchanger for HVAC Systems**
- **Concluding Remarks**

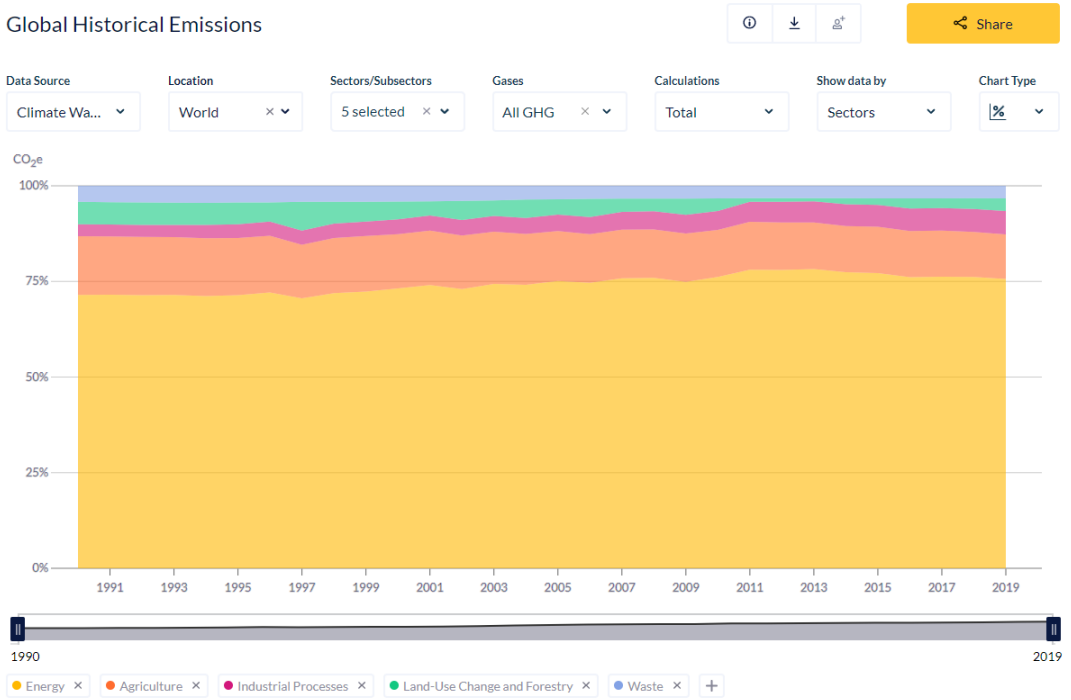
Motivation

https://www.climatewatchdata.org/

- **Decarbonisation of energy is a major endeavour**
  - **Mitigating climate change** through a **reduction of GHG emissions** is necessary.
  - **Major contributor to emissions: >**2/3 of the total global emissions.
  - **Significant progress in the electricity sector**, but more muted in other areas.



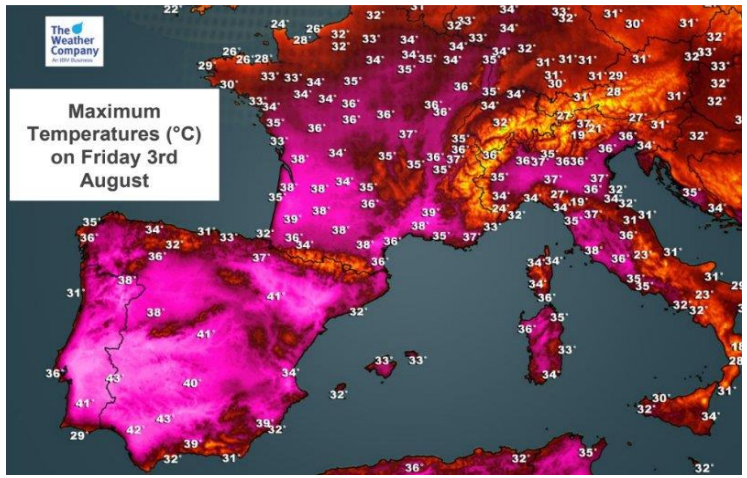
Estimated UK Emissions Attributable to Heating, 2016

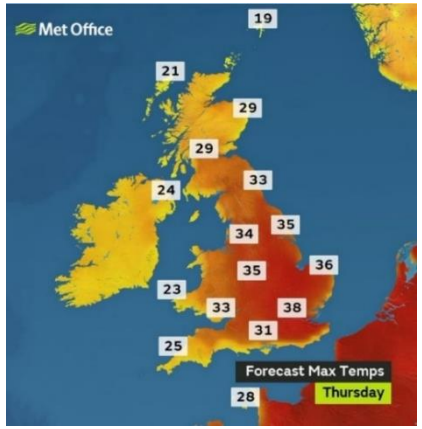


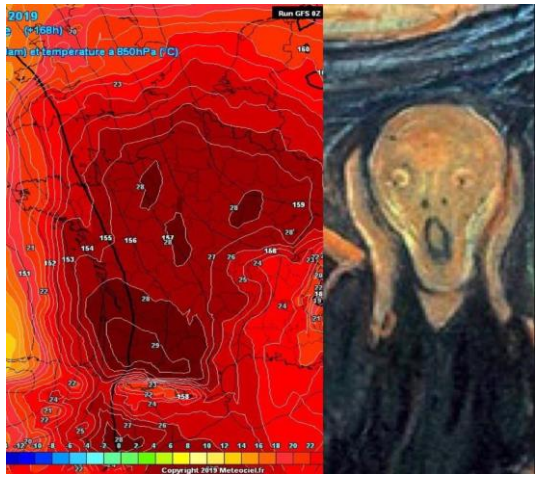
- **In the UK**, **heating** accounts for >1/3 of the emissions.
- **Cooling** has been mostly **overlooked** by policy.
- **Heatwaves** will drive an increase for **cooling** services:
  - Uptake of 18m units or air conditioning systems in households by 2050.
  - +39 GW of peak electricity demand on a typical summer weekend day.
  - Summer electricity demand is changing...

Motivation (2)

Heatwaves have been **intense** and **frequent** lately, with **cooling demand** in cities **increasing** due to the unusual weather.







How to **quantify** **cooling demand?** What does this mean to the **electricity system**? Which **technologies** can be used to meet **cooling demand?**

Flex-Cool-Store: Overview and Objectives

- **Flex-Cool-Store** investigated the impacts of a **growth** in **UK cooling demand**.

- **Objectives:**

  1. Understanding **cooling demand** considering **technical and socio-economic factors**.
  2. Quantifying the **impacts** of an increased **cooling demand** on electricity networks.
  3. Investigating the **flexibility provision** to the electrical power system from integrating **cooling technologies and storage**.

- **Key aspects:**

  - Investigation of prospective **cooling demand and cooling infrastructure**.
  - **Interdisciplinary approach** to address **cooling decarbonisation**.

Cooling Demand

➢ Modelling UK cooling demand (*existing datasets restricted to non-domestic buildings)

- Literature review on UK households.
- Weather projections obtained from **UK Climate Projections (UKCP)** database.
- Use of **IES VE** for modelling radiation.
- Modelling of **a community** and **multiple dwellings**.
- Prediction of **future cooling demand** for UK households using **UKCP data** and **AI-based methods**.

Individual dwellings:

- **IES VE** model was verified against a published literature.
- Using **IES VE** multiple dwelling types were modelled based on a literature review including constructions, location and orientations.
- Generation of **dwelling-level cooling demand** datasets.

Community-level:

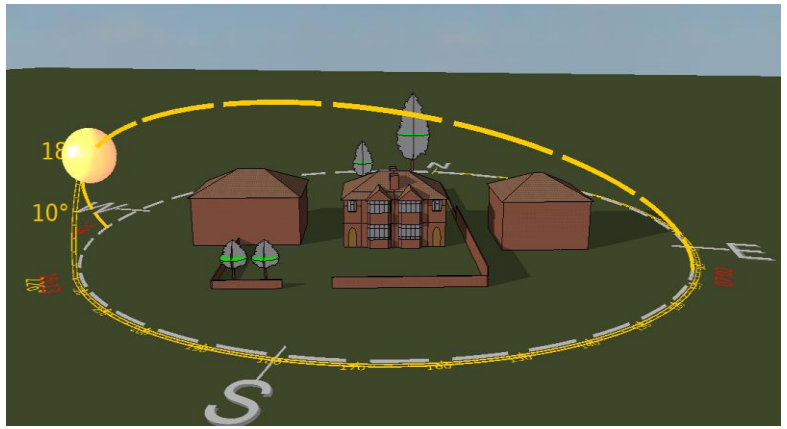
- A community-level **cooling demand** estimator was developed in **Modelica**.
- Thermal circuits were implemented in each house for variable indoor temperature consideration.
- Generation of **community-level cooling demand** datasets.

Cooling Demand for Individual Dwellings

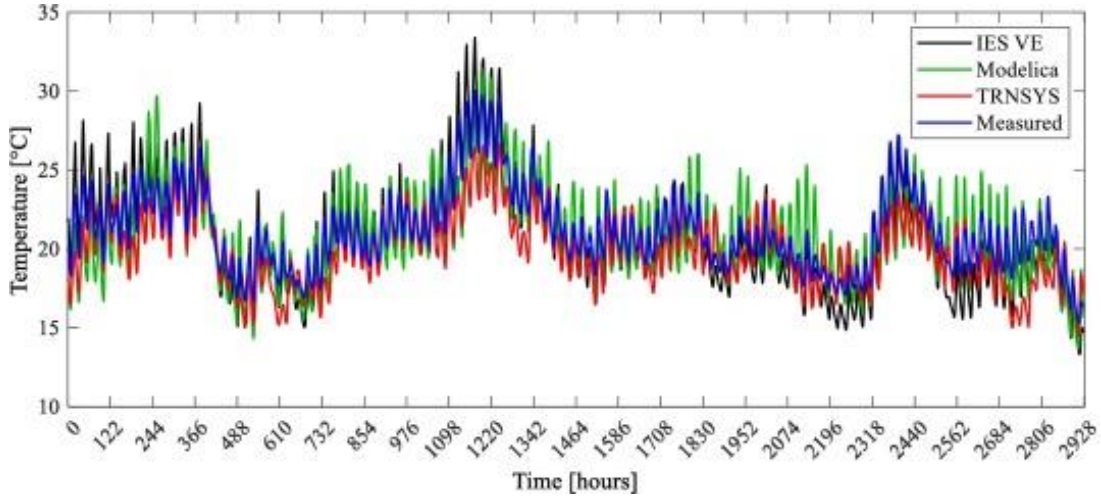
➢ IES VE model verification (house in Loughborough)

House modelled in IES VE

Roberts BM, *et al.*, *A dataset from synthetically occupied test houses for validating model predictions of overheating*. **CIBSE Tech. Symp**., Loughborough University; 2022



Averaged indoor temperature



RMSE between the experimental data and simulation results

Software engine	MAE (°C)	RMSE (°C)
TRNSYS	1.48	1.85
IES VE	1.15	1.40
Modelica	1.25	1.56

Saleem A, Ugalde-Loo CE, *Thermal performance analysis of a heat pump-based energy system to meet heating and cooling demand of residential buildings*. **Applied Energy,** 383, 125306, 2025

Cooling Demand for Individual Dwellings (2)

Creating cooling demand datasets

- Limit the number of simulations by removing extraneous variables.
- 11 dwelling types, 5 initial locations, 4 orientations.

Cardiff	00	90	180	270
Bungalow				
Flat.Bottom				
…				
…				
Terraced.End				

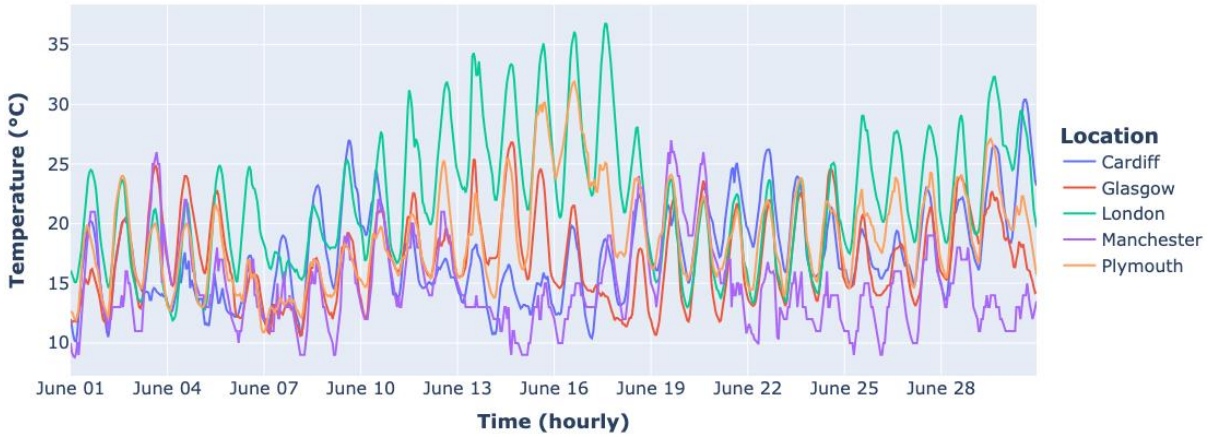
Year	Foundations (U-value W/m²K)	Walls (U-value W/m²K)	Windows/Doors (U-value W/m²K)	Roofs (U-value W/m²K)
Pre-1920	225 mm concrete slab (≈ 3.25)	Single layered brick/stone 315 mm (≈ 1.84)	N/A	N/A
1920	-	Uninsulated cavity walls (≈ 1.6)	N/A	N/A
1930	300 mm concrete slab (≈ 2.94)	-	N/A	N/A
1965	Thermal insulation on slab (1.2)	Uninsulated cavity walls (1.7)	N/A	Insulated Roofs (1.6)
1970	-	-	Single glazed window (4.8)	
1980	-	Insulated cavity walls (1)	-	Insulated Roofs (0.68)
1990	-	Insulated cavity walls (0.6)	-	Insulated Roofs (0.4)
2000	Thermal insulation on slab (0.51)	Insulated cavity walls (0.45)	Double glazed window (3.1)	Insulated Roofs (0.35)
2010	Thermal insulation on slab (0.22)	Insulated cavity walls (0.3)	Low emissivity double glazed window (2.0)	Insulated Roofs 0.22)
2016	Thermal insulation on slab (0.13)	Insulated cavity walls (0.18)	Double glazed low emissivity window with Argon gas filler (1.4)	Insulated Roofs (0.13)
Present (2021)	Thermal insulation on slab (0.13)	Insulated cavity walls (0.18)	Double glazed low emissivity window with Argon gas filler (1.2)	Insulated Roofs (0.11)

Time	1111	1112	1113	1114	1115	1116
0	…	…	…	…	…	…
1	…	…	…	…	…	…
2	…	…	…	…	…	…
3	…	…	…	…	…	…
…	…	…	…	…	…	…
8759	…	…	…	…	…	…
8760	…	…	…	…	…	…

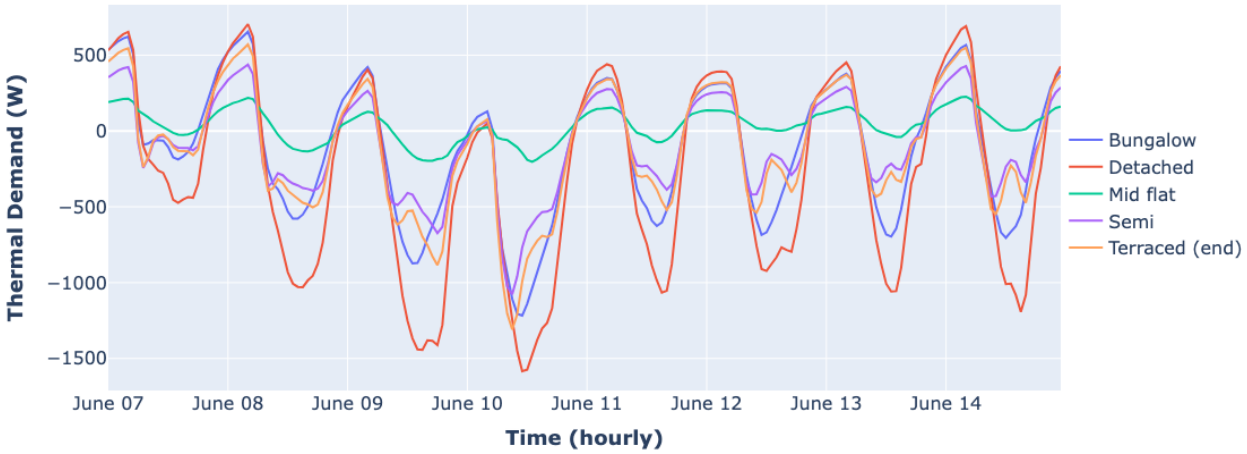
Cooling Demand for Individual Dwellings (3)

➢ Results (examples of cooling demand)

External dry bulb temperature

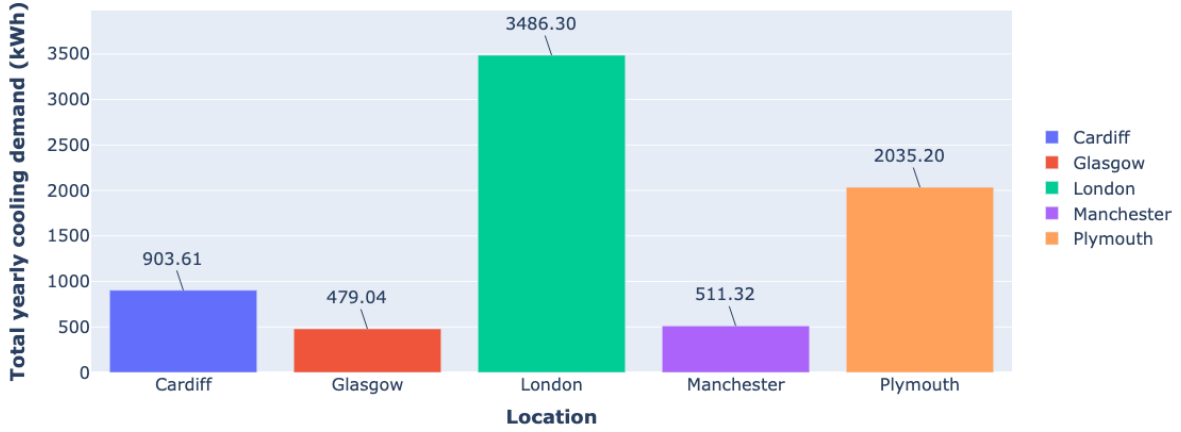


Hourly thermal demand, Cardiff, north-facing, code '1111'



Corcoran L, Saikia P, Ugalde-Loo CE, Abeysekera M, *An effective methodology to quantify cooling in the UK housing stock*. **Applied Energy,** 380, 125002, 2025

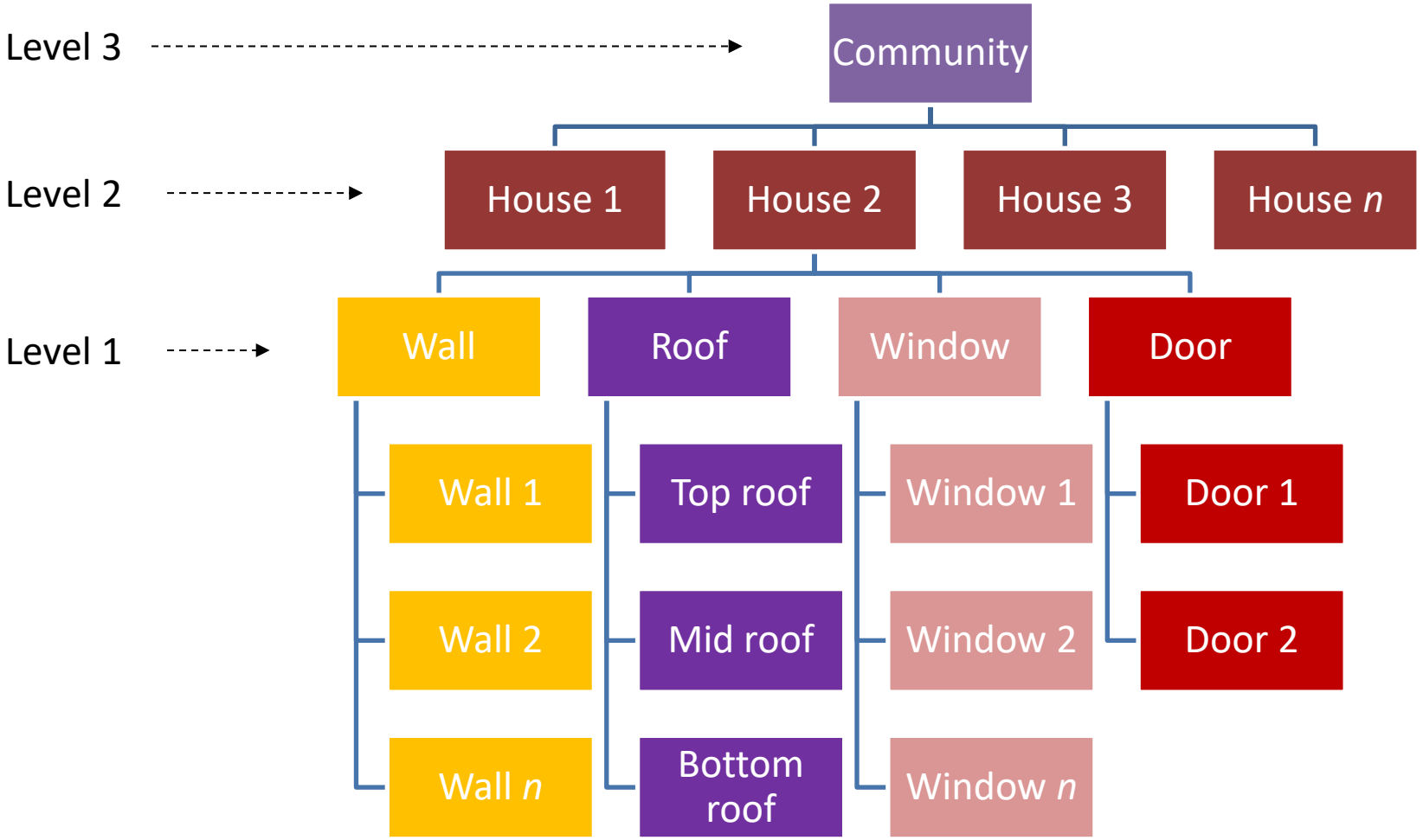
Detached house: Total yearly cooling demand, north-facing, code '7654'

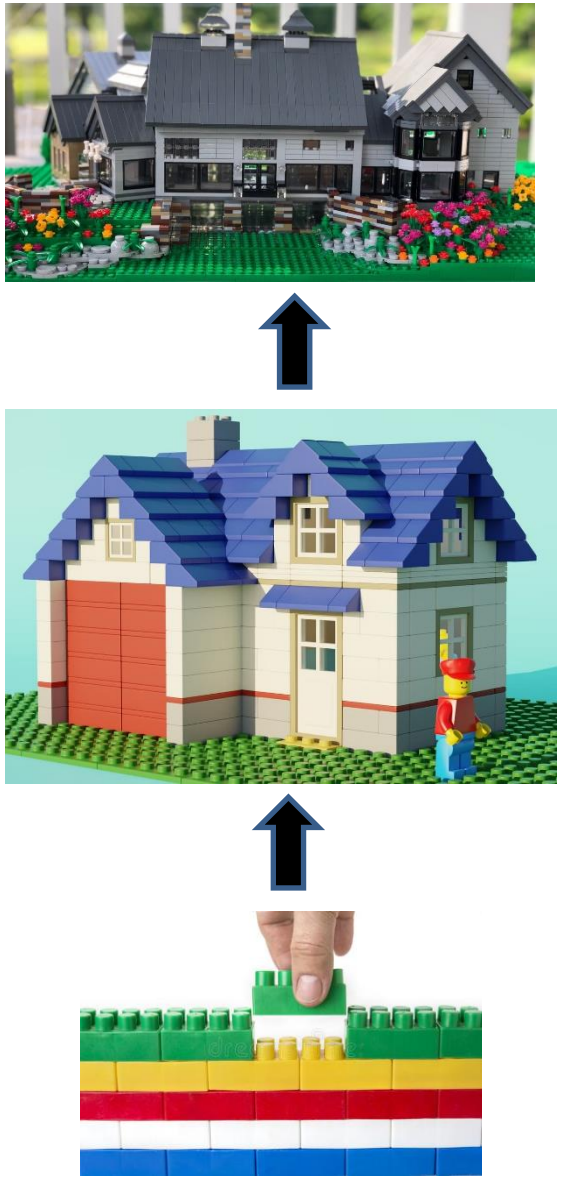


- Multiple studies can be conducted with the methodology developed (e.g. **passive cooling, heatwaves, cooling demand forecasting**).
  - **Journal papers** under preparation for **Applied Energy, Energy and Buildings,** and **Nature Energy.**

Community-Level Cooling Demand

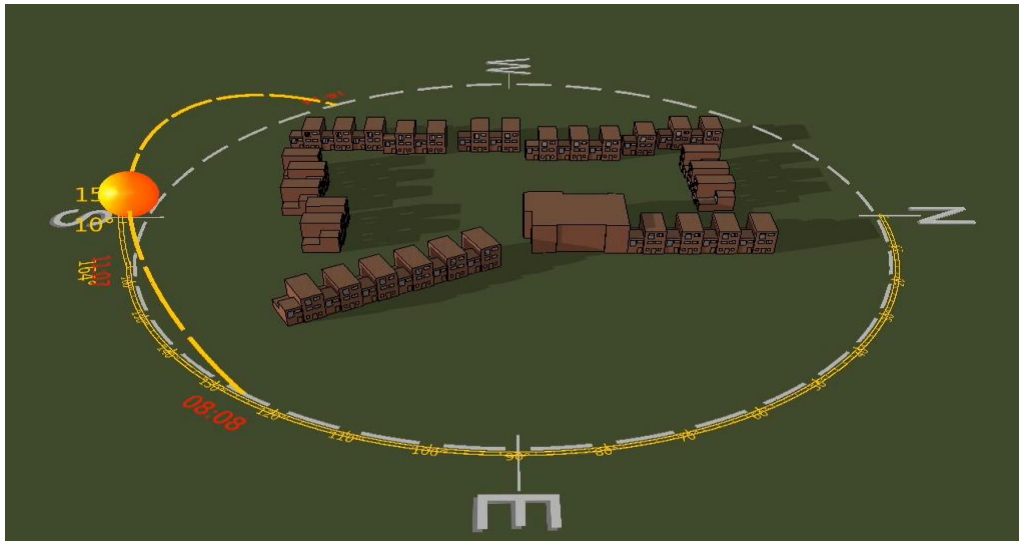
➢ Modelling levels in OpenModelica



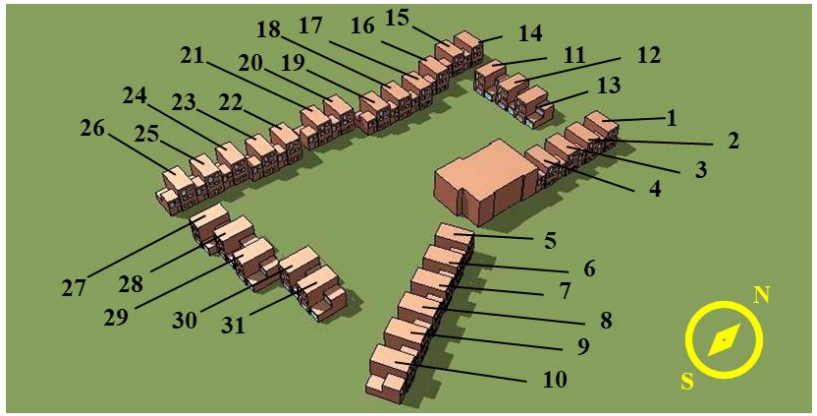


Community-Level Cooling Demand (2)

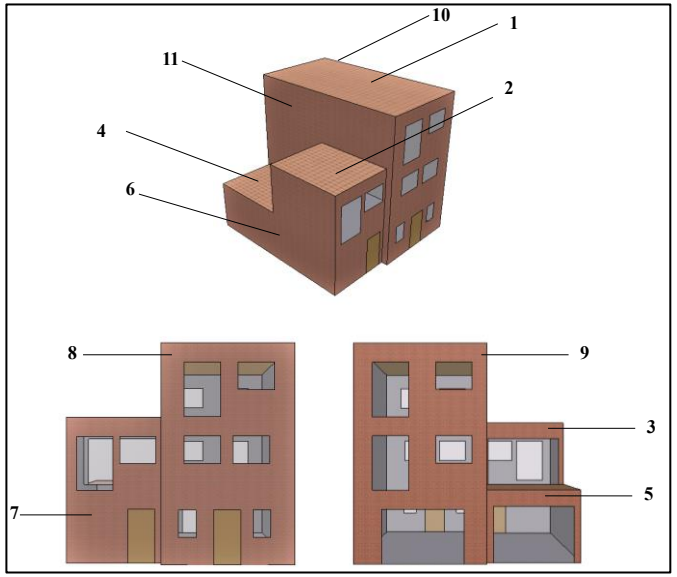
➢ Modelling cooling demand at community level



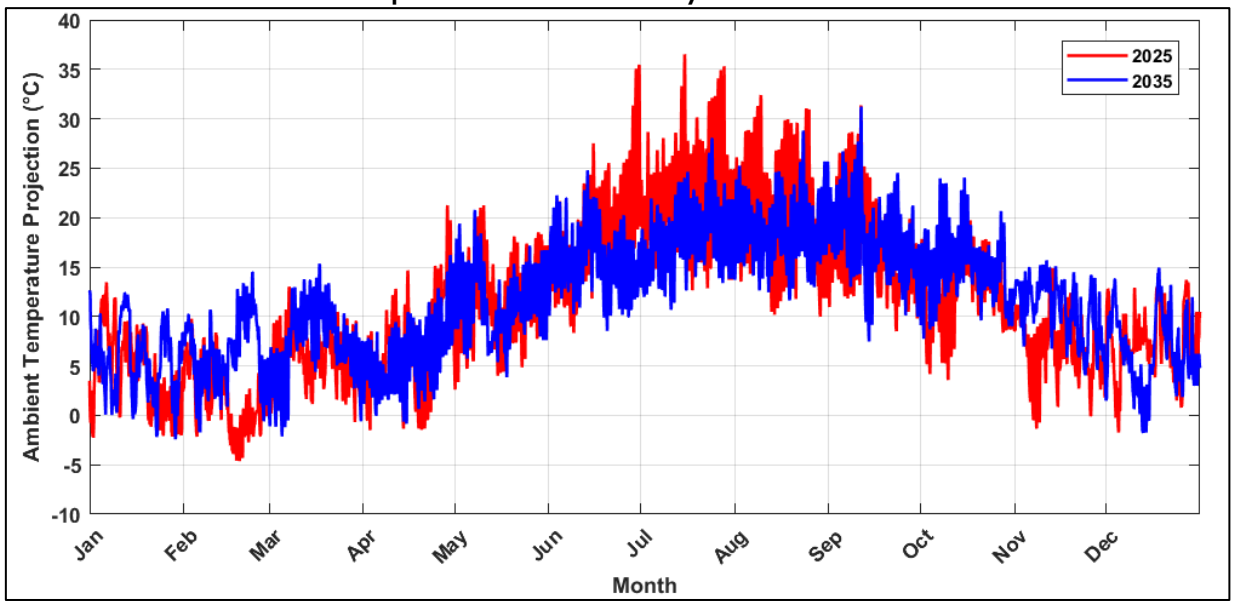
Housing estate modelled in IES VE



Individual house



Ambient temperature in the years 2025 and 2035

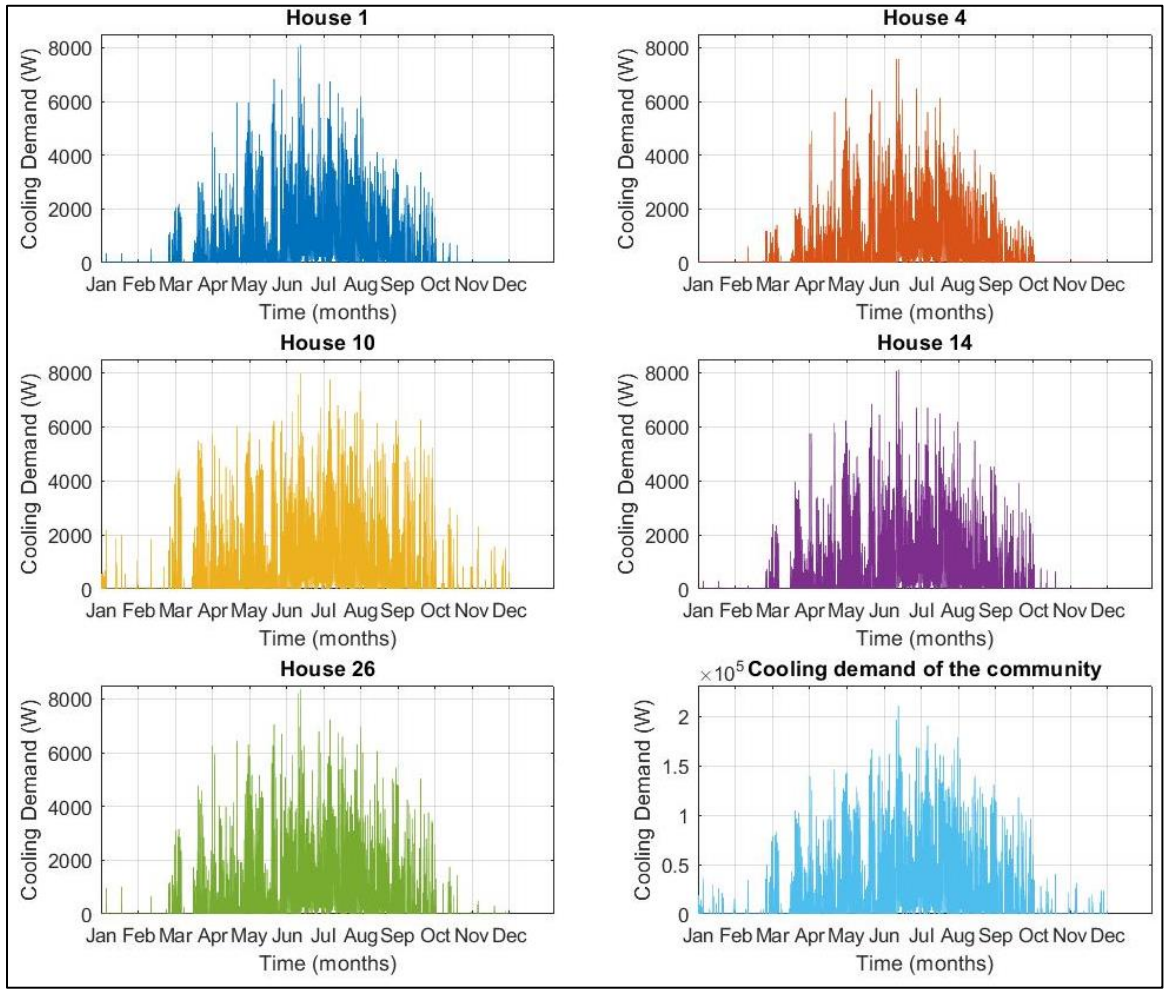


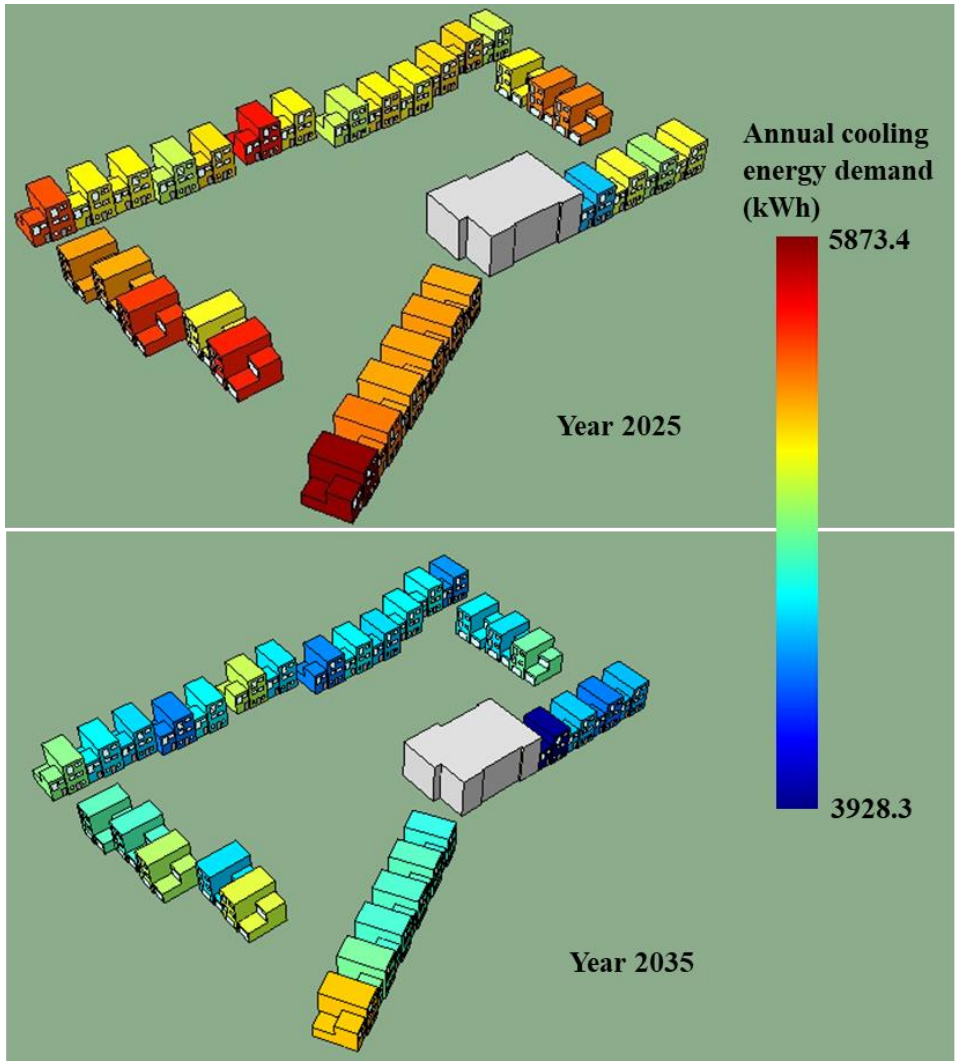
Community-Level Cooling Demand (3)

➢ Community cooling demand profiles

Saikia P, Corcoran L, Ugalde-Loo CE, Abeysekera M, *A cooling demand estimator for housing communities in a warming world*. **Applied Energy,** 377 (Part D), 124597, 2025

Year 2025





Cooling Technologies

➢ Modelling and design of cooling technologies

- Modelling, simulation, and verification of **thermal stores** for **heating** and **cooling**.
- Investigate the use of **reversible heat pumps** to provide **cooling services**.

Thermal stores:

- 1-D models of **sensible and latent heat** units.
- Simulations performed in **MATLAB** and **Apros**.
- Verification against experimental data.
- Calculation of **state-of-charge** (sensible and latent heat units) for **heating** and **cooling**.

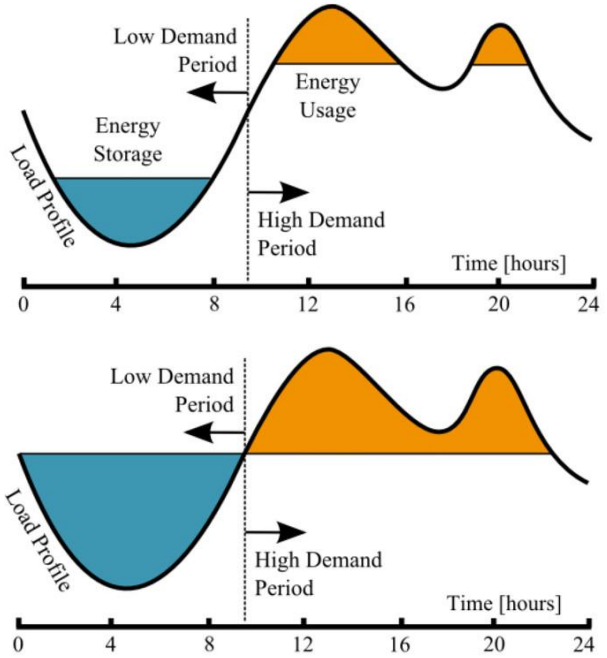
Heat pumps:

- Literature review on **heat pumps** and integration with **thermal stores**.
- Simulation of **thermal** loads in **TRNSYS**.
- Detailed **case study** for a house in Cardiff.

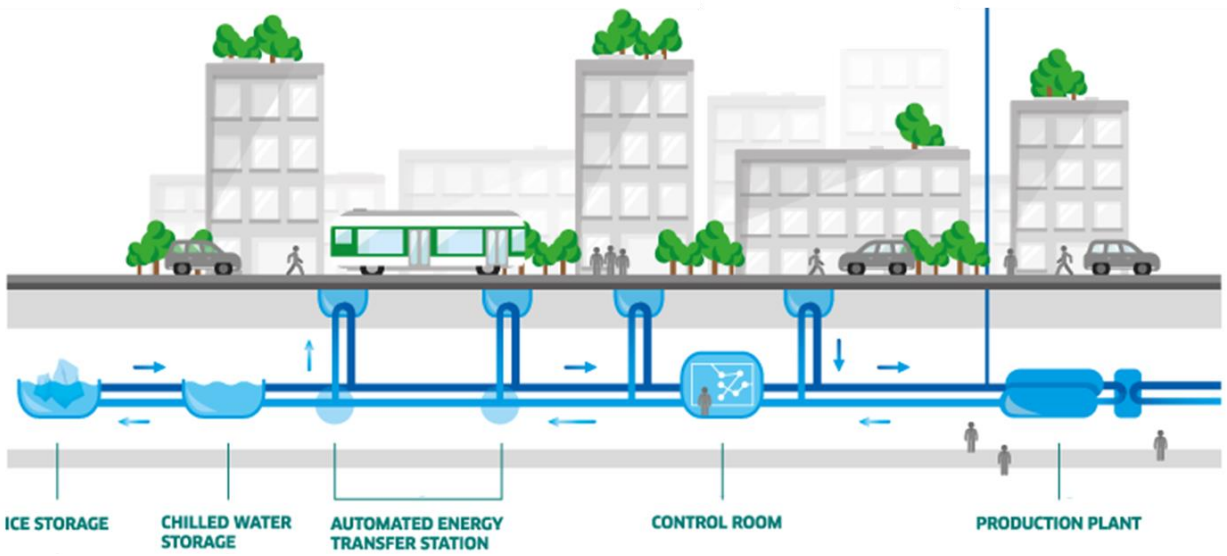
Cold Stores

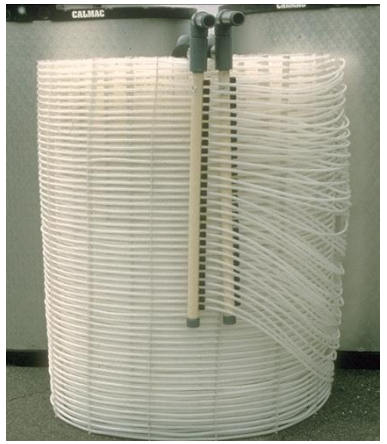
Thermal batteries

- Thermal stores serve as **batteries** for **heating** and **cooling** systems.
- **Thermal batteries** can provide **flexibility** services.
- **Latent heat batteries** may be preferred to sensible heat batteries. These are based on **phase change materials (PCM)**.
- Calculating their **state-of-charge** (SoC) is **non-trivial.**

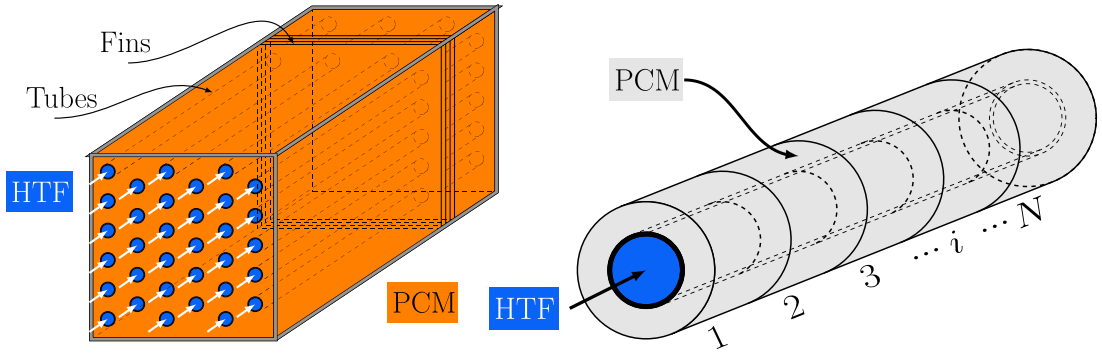


https://www.engie.com/

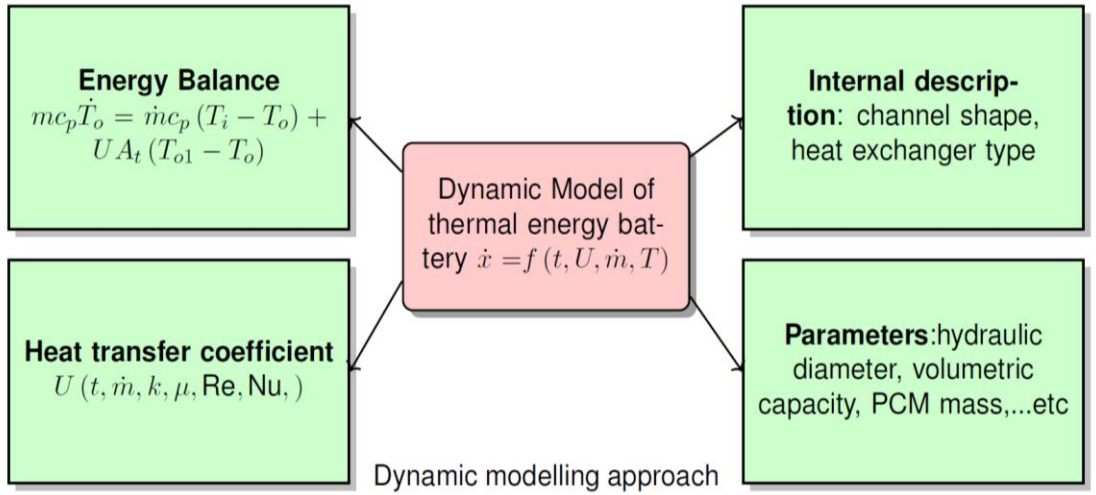




Modelling of Thermal Stores

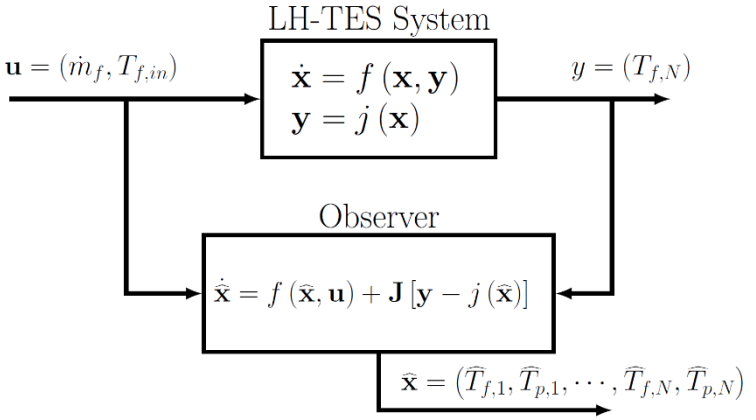


1. Modelling



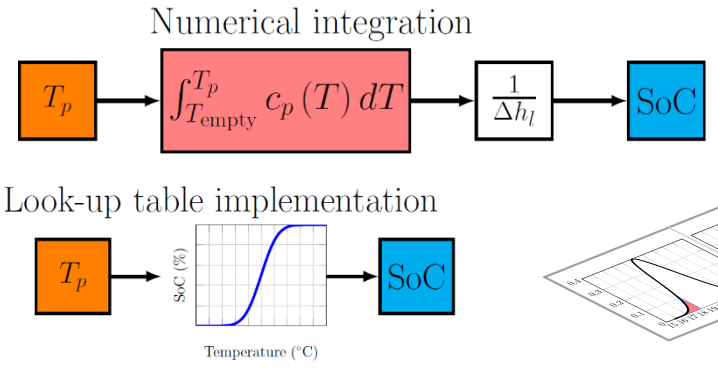
2. Temperature Estimation

1. **1-D model** of thermal store
2. **Observer** design for internal temperatures (<u>without sensors</u>)

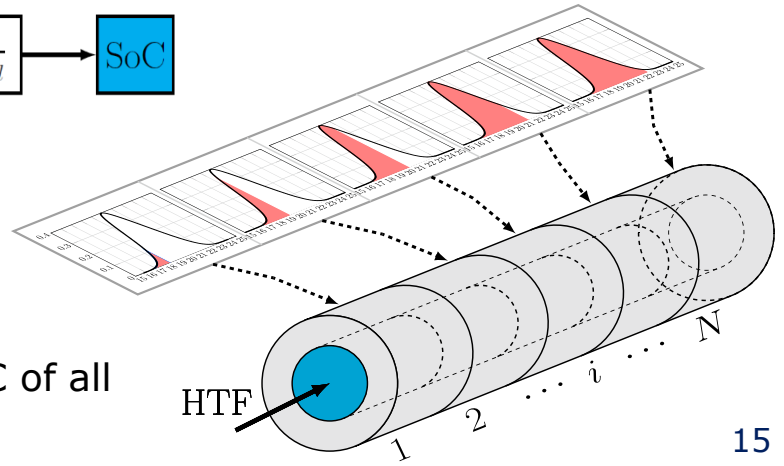


3. SoC calculation

- Definition of a **specific heat vs temperature** curve.
- Integration of curve provides the **latent heat**.



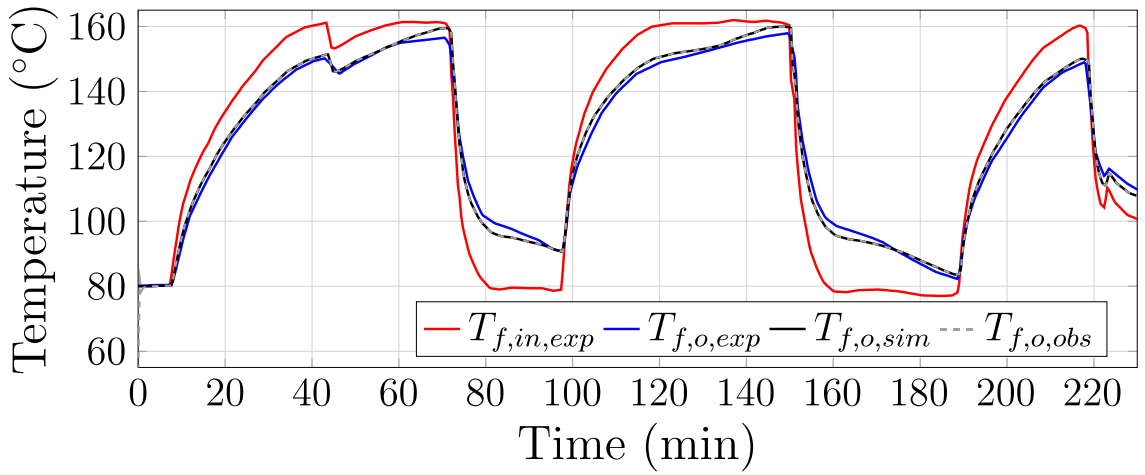
- **Total SoC:** average SoC of all nodes.



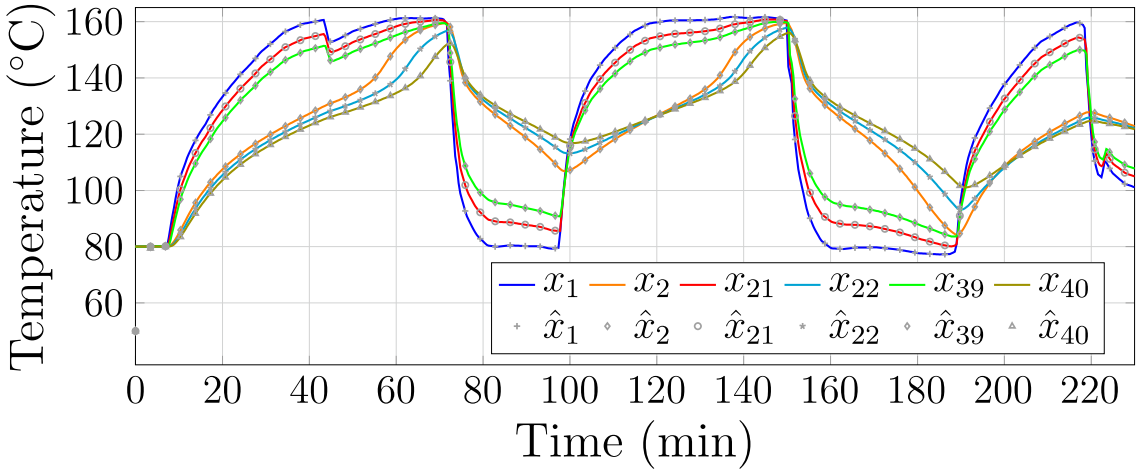
Modelling of Thermal Stores (2)

➢ Verification of SoC estimation with experimental data

Model and observer: HTF output temperature

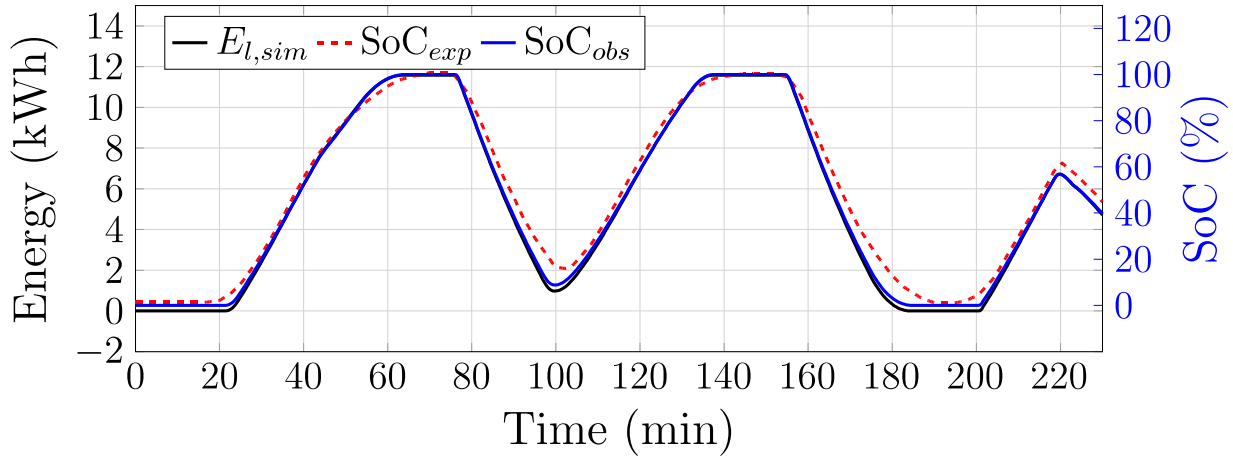


Estimation of the internal temperatures



- A sequence of charging/discharging (at 1.09 kg/s) was conducted for a shell and tube battery.

State-of-charge calculation



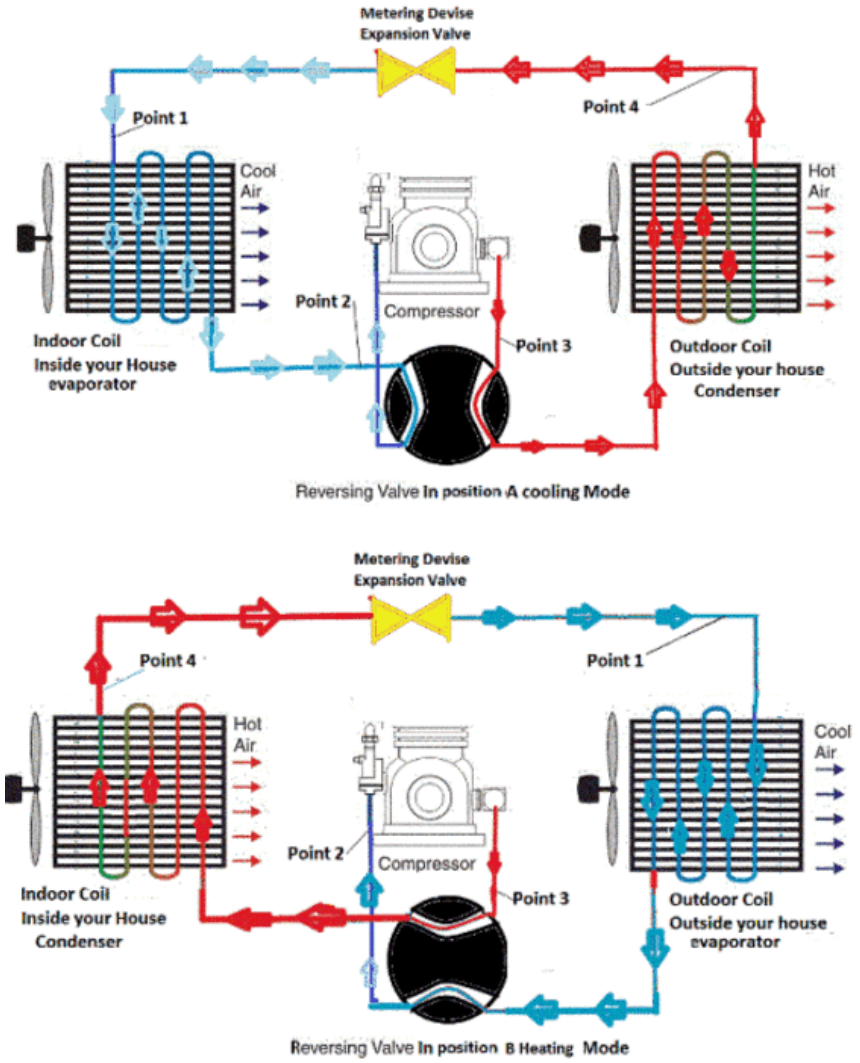
- ✓ There is **no need** to install internal **temperature sensors**.
- ✓ Only **3 measurements** are required.
- ✓ The estimation is based on **simplified models**.
- ✓ **Reduced computational burden** with look-up table.

Bastida, De la Cruz and Ugalde-Loo, *Effective Estimation of the State-of-Charge of Latent Heat Thermal Energy Storage for Heating and Cooling Systems using Non-Linear State Observers*, **Applied Energy**, 331, 2023.

Heat Pump Technologies

Heat pumps

- **Reversible heat pumps** can be used for both **cooling** and **heating**.
- **Water-to-water heat pumps** and **ground-source heat pumps** lead to an **improvement** in energy performance and a reduction in operating costs, compared to traditional air-source heat pumps.
- When integrated with **thermal stores**, the **coefficient of performance (COP)** of heat pumps can be improved.



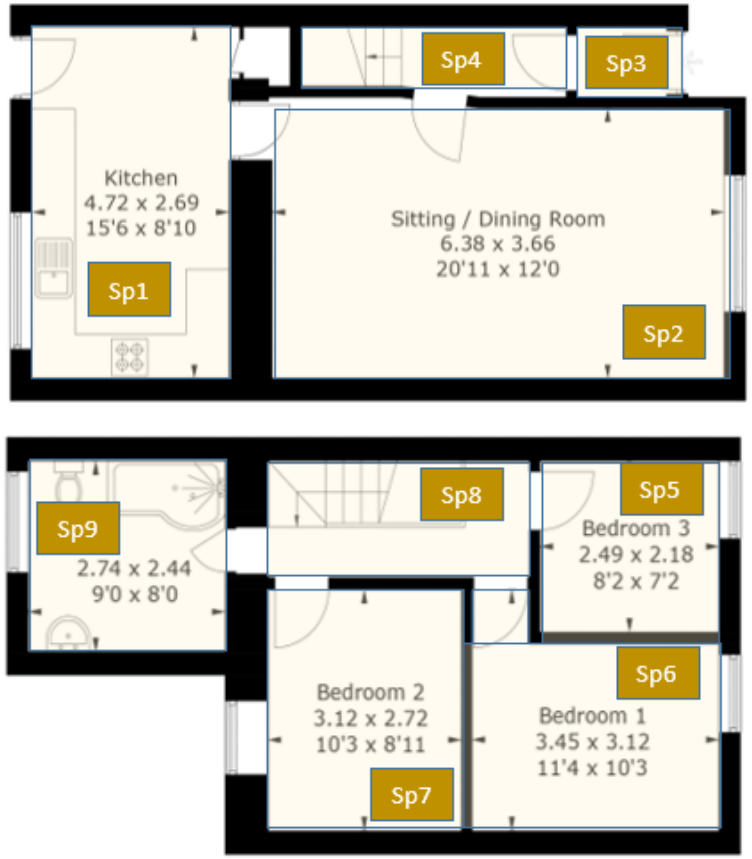
Heat pump model in cooling and heating modes

Saleem A, Ambreen T, Ugalde-Loo CE, *Energy storage-integrated ground-source heat pumps for heating and cooling applications: A systematic review*. **Journal of Energy Storage,** 102 (Part B), 114097, 2024

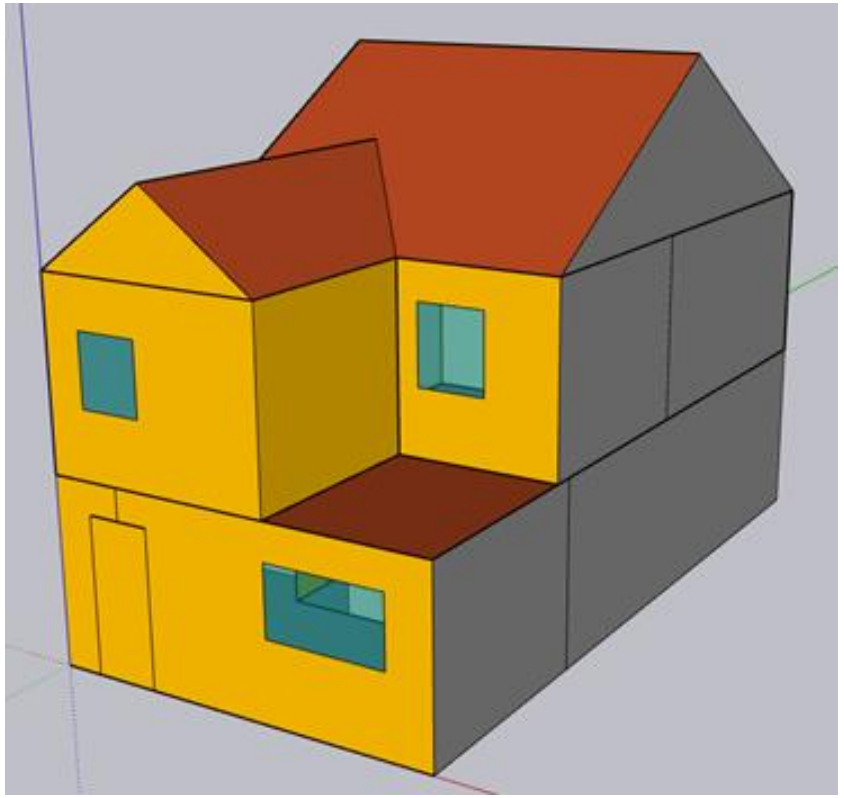
Heat Pump Technologies (2)

➢ Simulation of thermal loads in residential dwelling

Building floor plan (in **Cardiff**)



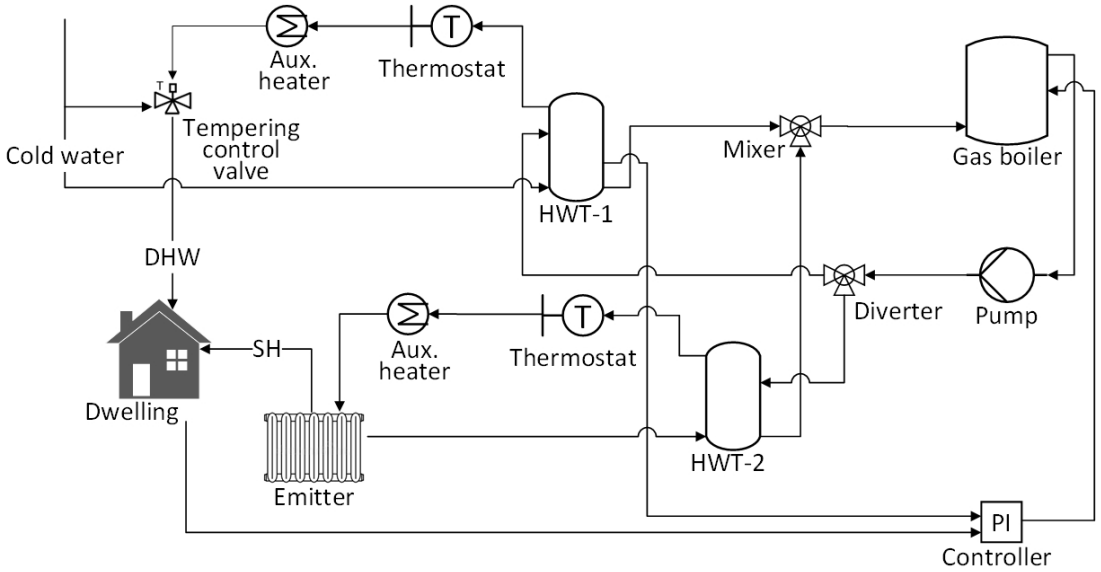
Model developed in **SketchUp**



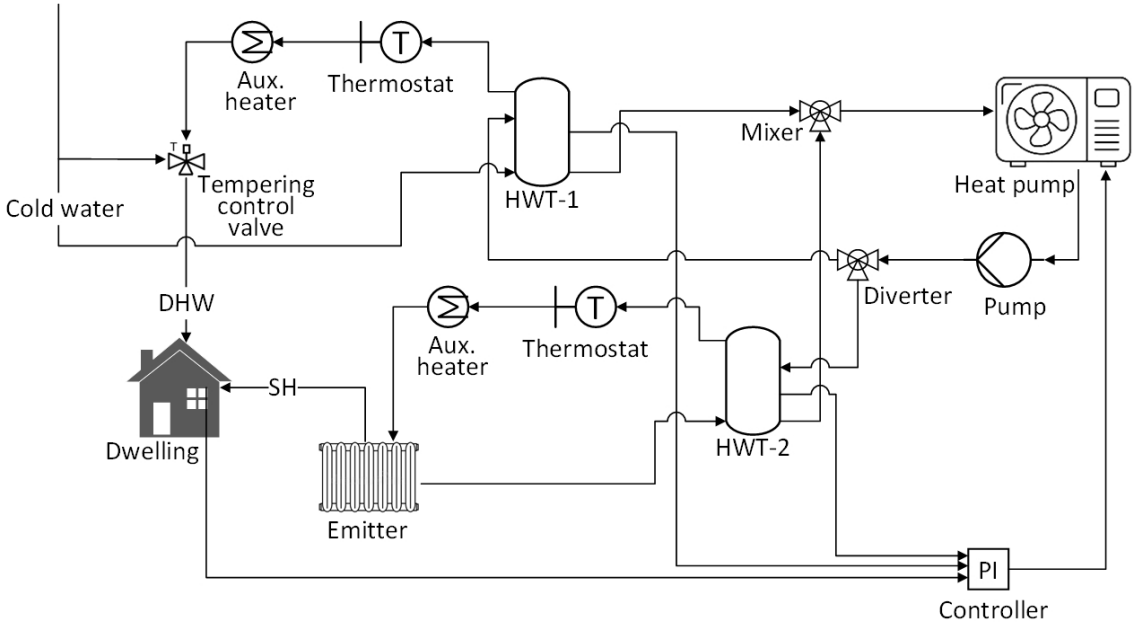
Heat Pump Technologies (3)

Case study examples

- **Heating demand** met by **gas boiler**.



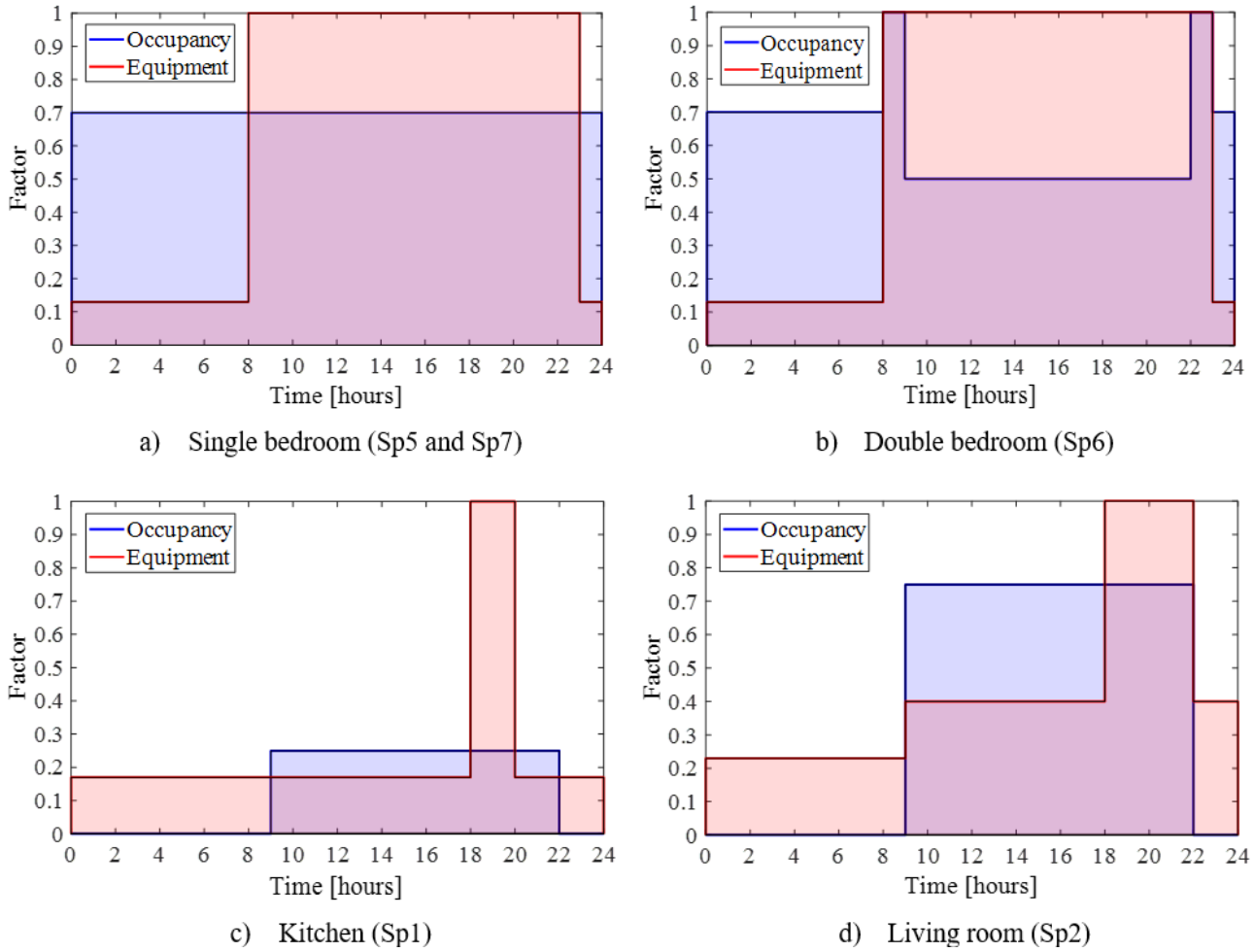
- **Heating demand** **and** **cooling demand** met by **heat pump**.



Heat Pump Technologies (4)

➢ Case study examples

Occupancy patterns



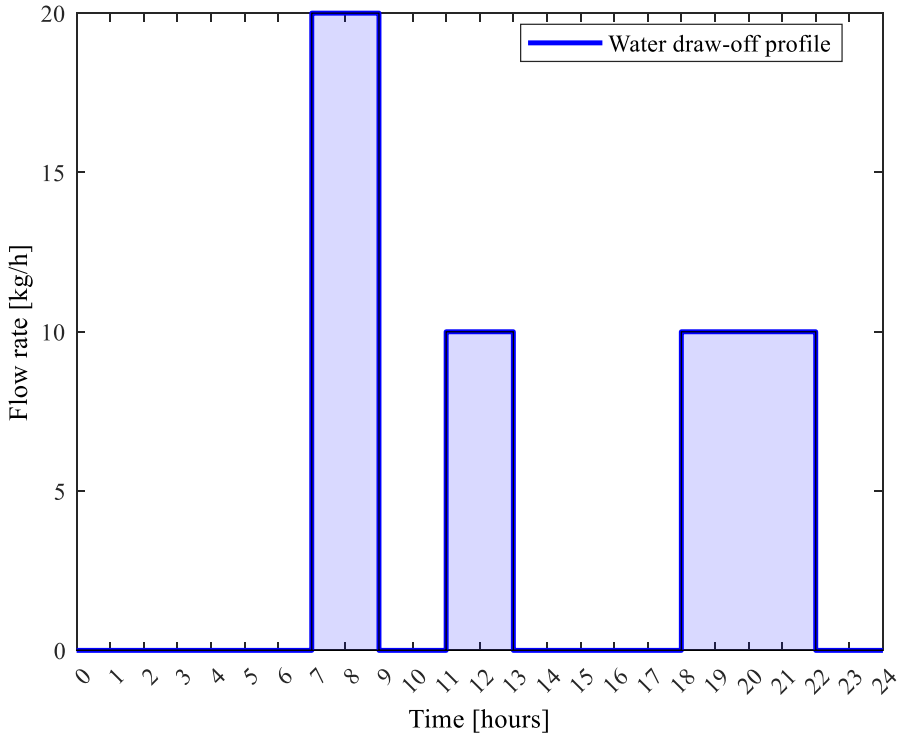
a) Single bedroom (Sp5 and Sp7)

b) Double bedroom (Sp6)

c) Kitchen (Sp1)

d) Living room (Sp2)

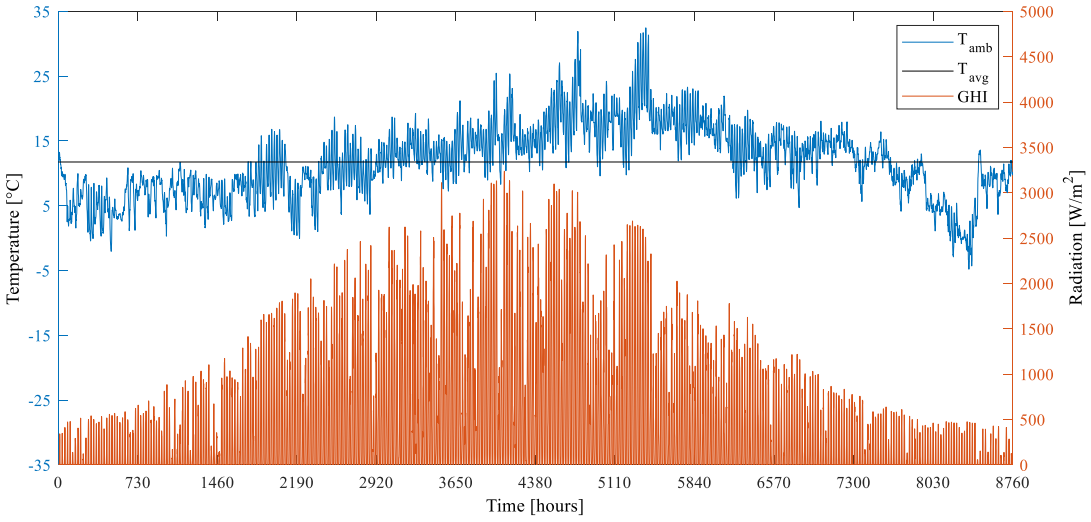
Water draw-off profile



Heat Pump Technologies (5)

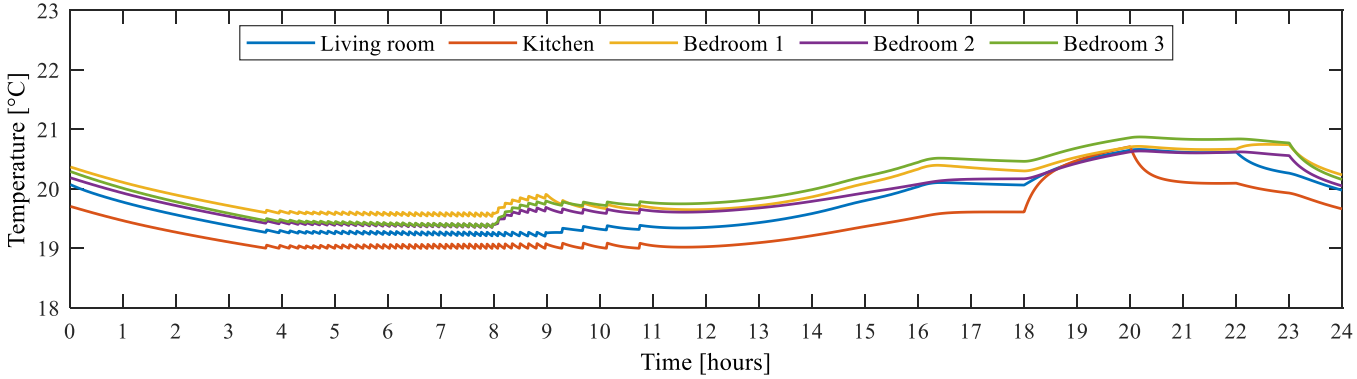
➢ Case study examples. Gas boiler-based system

Historical weather data for Cardiff (Year 2022)

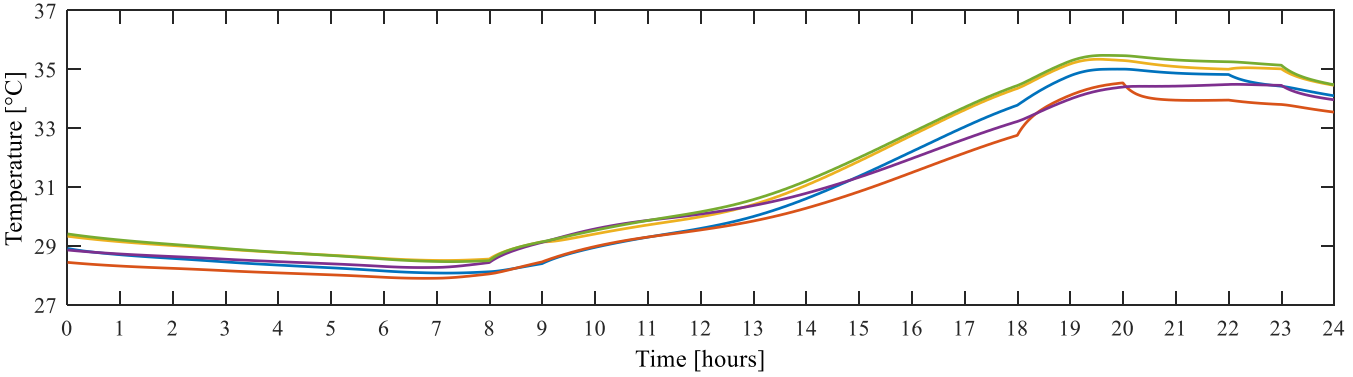


- Presence of **heatwave** during **August 2022**: **outdoor temperatures** over 32°C.
- **Heating** is activated if **indoor temperature** (kitchen) drops below 19°C.

Temperature control by gas boiler (**heating**): **15th January**



No cooling provision: **13th August**



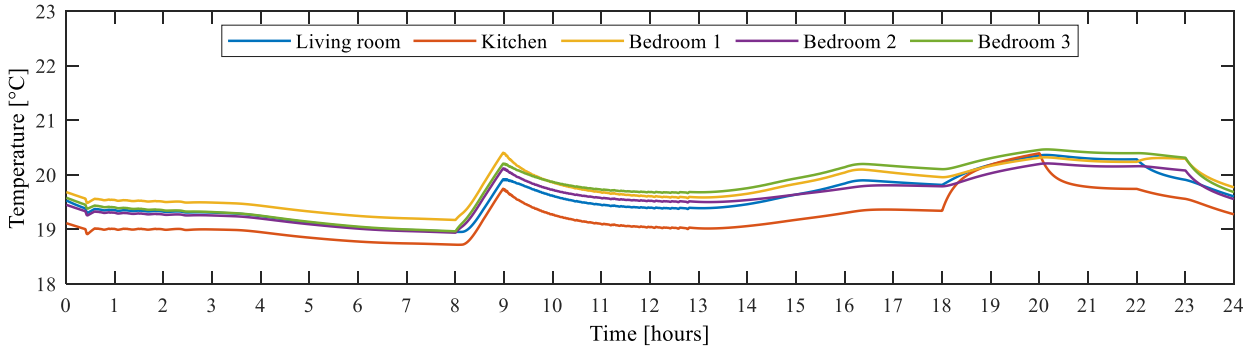
- **Clear difference** in **indoor temperatures** without **active cooling**!

Saleem A, Ugalde-Loo CE, *Thermal performance analysis of a heat pump-based energy system to meet heating and cooling demand of residential buildings*. **Applied Energy,** 383, 125306, 2025

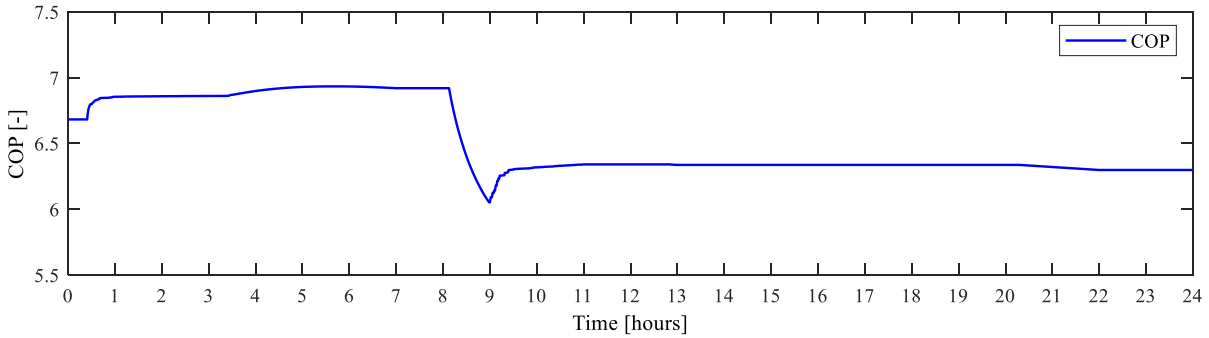
Heat Pump Technologies (6)

Case study examples. Heat pump-based system

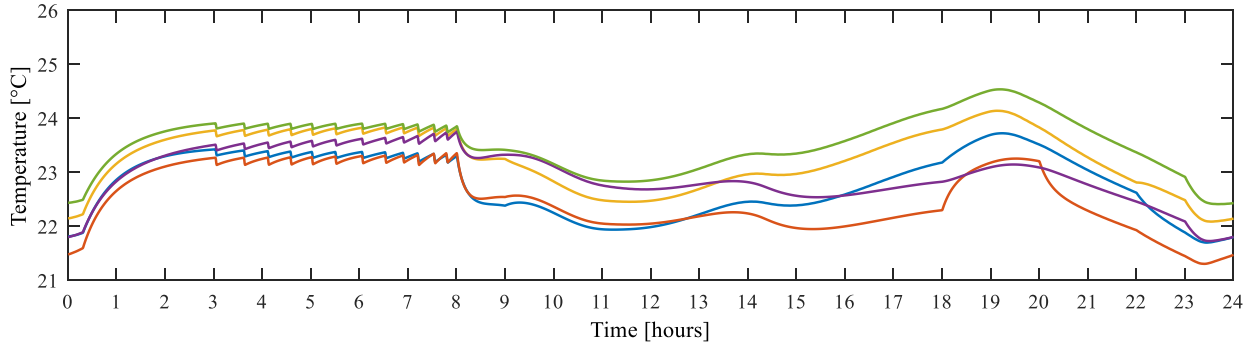
Temperature control by heat pump (**heating**): **15th January**



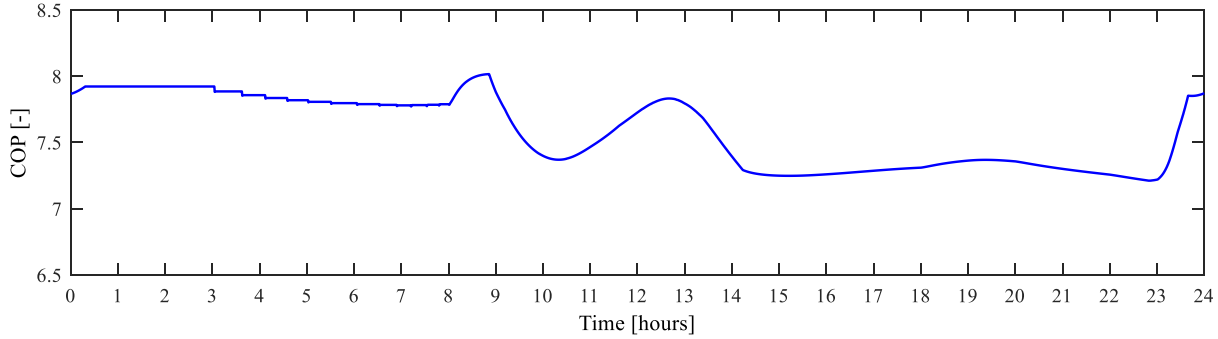
Coefficient of performance of heat pump: **15th January**



Temperature control by heat pump (**cooling**): **13th August**



Coefficient of performance of heat pump: **13th August**



- **Heating** is activated if **indoor temperature** drops **below** 19 °C.
- **Cooling** is activated if **indoor temperature exceeds** 23 °C.

Saleem A, Ugalde-Loo CE, *Thermal performance analysis of a heat pump-based energy system to meet heating and cooling demand of residential buildings*. **Applied Energy,** 383, 125306, 2025

PBIAA The SWITCH to Net Zero Buildings

- **UKRI (EPSRC) funded project**, with Swansea University (lead), ***Cardiff University*** and University of South Wales as academic partners — and civic and industrial partners.
- **Objectives:**

  1. Conduct research to deliver practical and innovative industry solutions and address challenges in **Swansea Bay City Region (SBCR)**.
  2. Accelerate the translation of **research outputs into impact** to drive economic growth and benefit people in **Wales**.

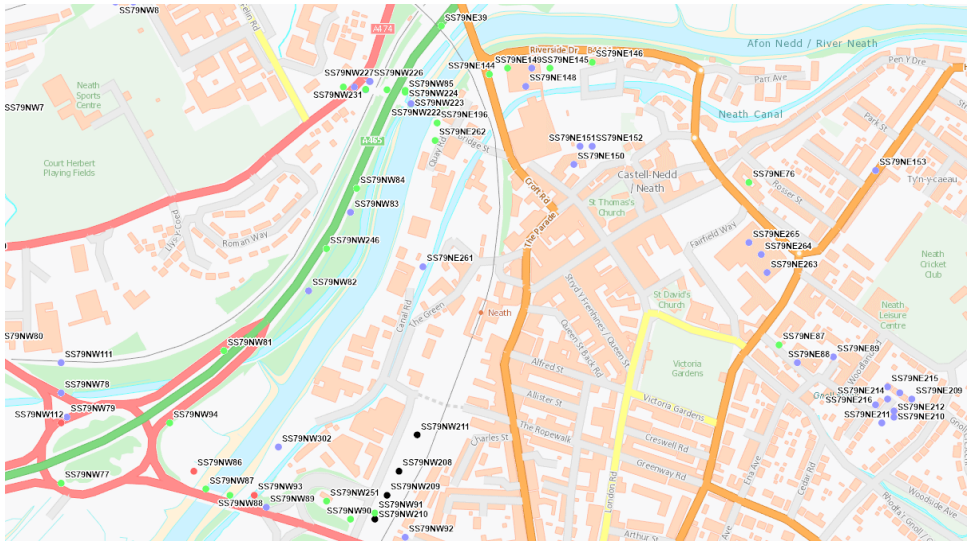
- **Impact Primer Project:** ***Design of a Solar Photovoltaic Coupled Ground-Source Heat Pump for a Small Residential Community***
  - Design of an integrated system combining **photovoltaic-thermal** (PVT) panels with a **ground source-heat pump** (GSHP) to provide **heating**, **cooling** and **hot water**.
  - Small residential community in **Neath-Port Talbot** (NPT).
  - ***Feasibility work***: ground site selection, borehole field design, energy system modelling, and performance evaluation.

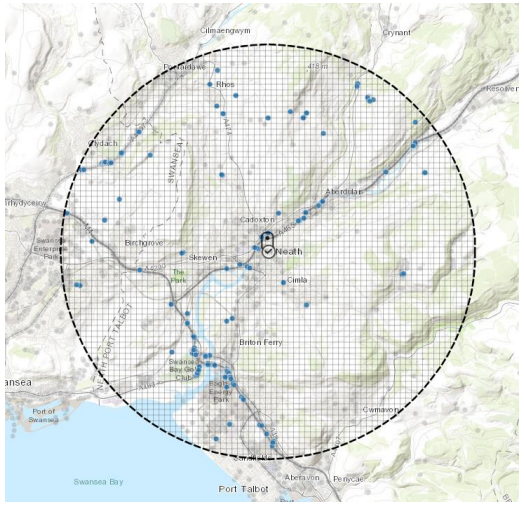
Impact Primer Project

- **Identification of site – British geological survey**
  (https://www.bgs.ac.uk/datasets/boreholes-index/)

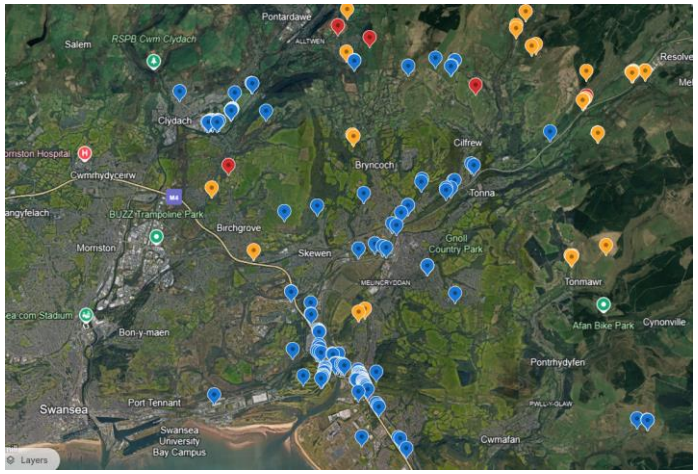
- **Around 200 sites with 30 m+ depth within 10 km radius**

- **Selection criteria:**
  - No moving ground water
  - No historical coal mining
  - No environmental concerns (MAGIC maps)





Borehole sites



Holst Soil Engineering Limited

Borehole No. E3

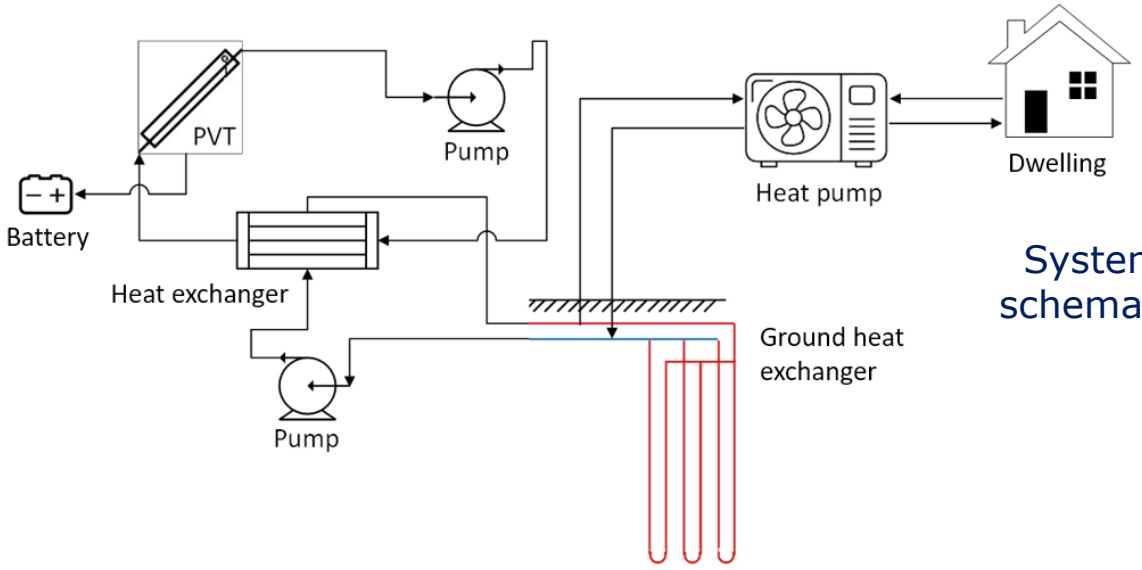
Contract No. F3593
Location Evans Rd, Neath
Client Neath B.C.
Method of Boring Percussion
Diameter of Borehole 200 mm

BOREHOLE LOG SS 79 NW 188
SS 7476 9631
Sheet 1 of 1
Chainage
Ground Level m.A.O.D.
Date 25/3/77.

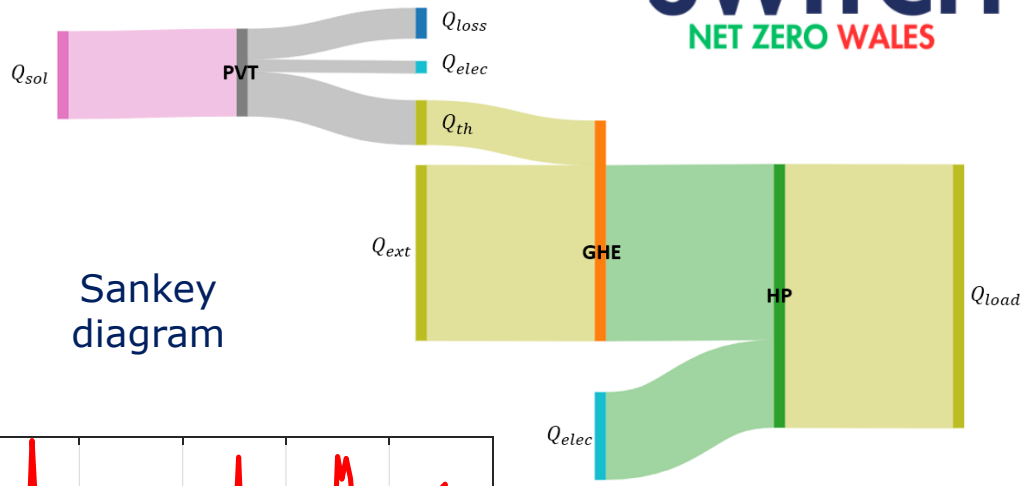
Description of Strata	Legend	Depth Below G.L.(m)	O.D. Level (m)	Casing Depth at Sampling	Sampling and Coring	"N"/ R.Q.D.%	Daily Progress
MADEGROUND - bricks hardcore		1.70			1.00 C 1.70 1.90	11	
Firm yellow and brown mottled sandy CLAY		2.40			2 50 2.80		
Very stiff brown mottled sandy stony CLAY							

Soil composition

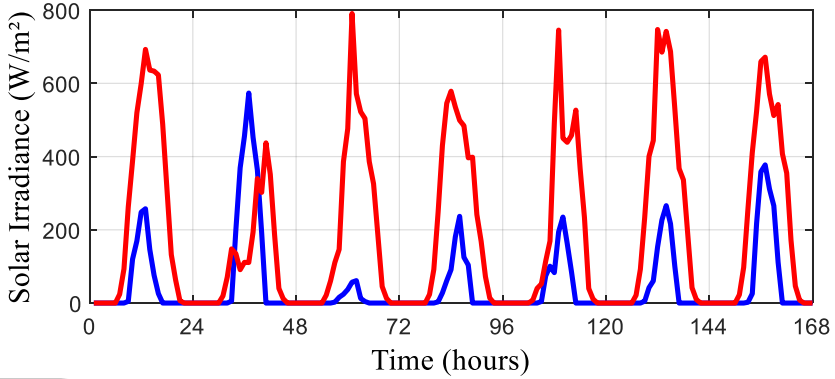
Impact Primer Project (2)



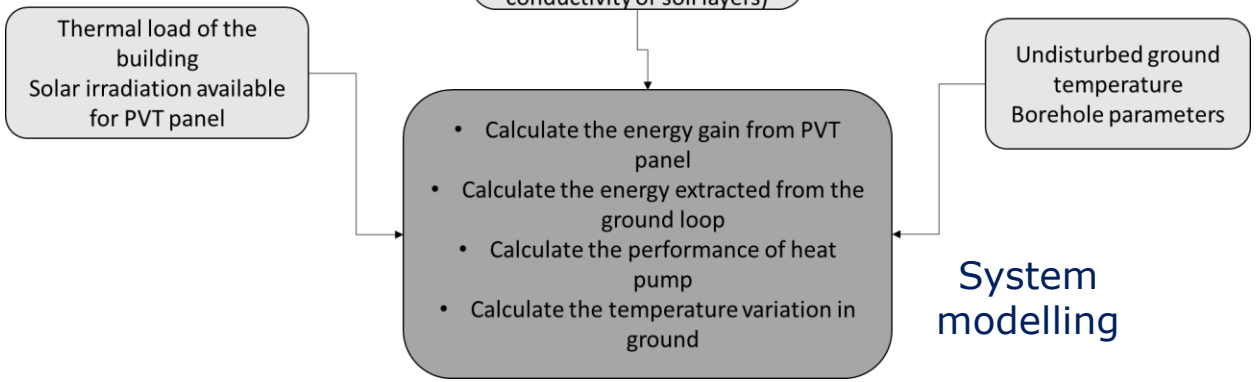
System schematic



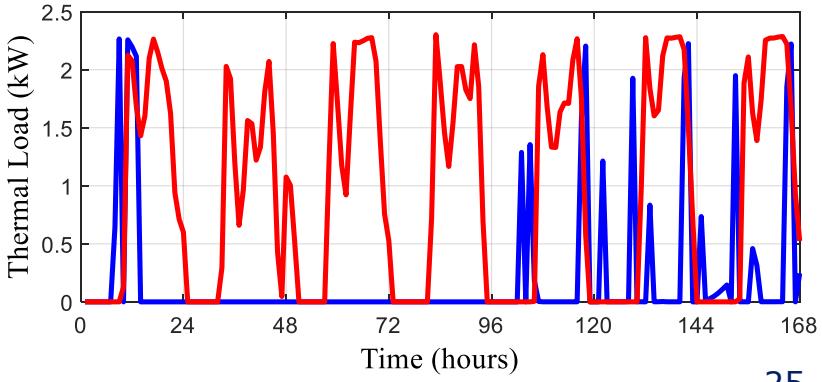
Sankey diagram



Solar irradiance



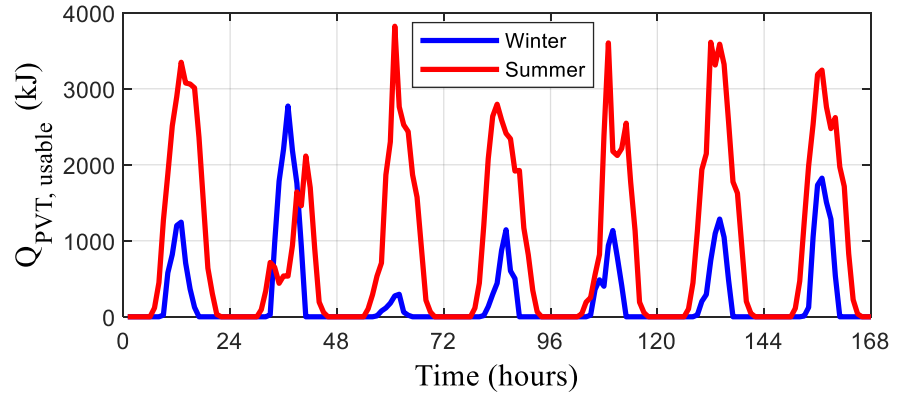
System modelling

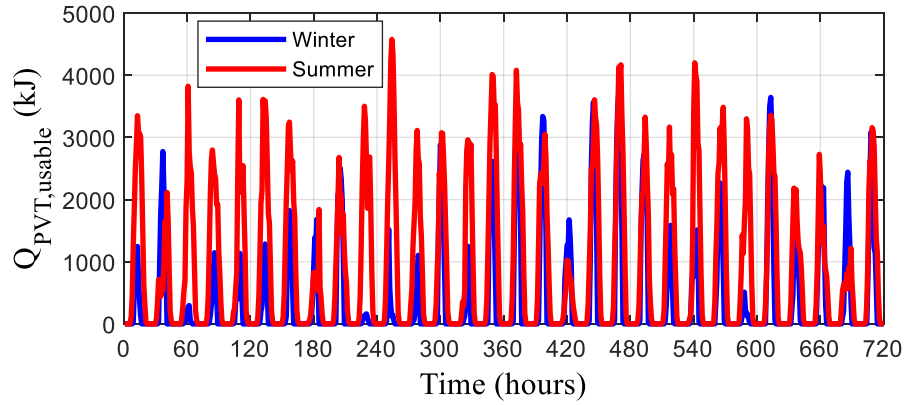


Thermal load of a residential house

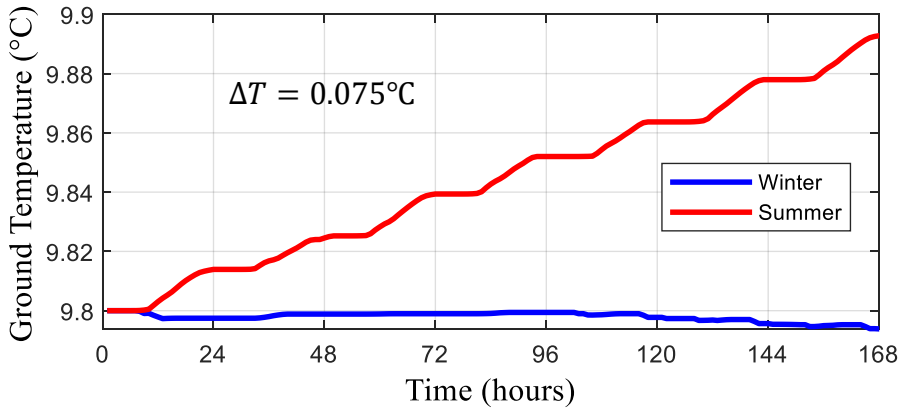
Impact Primer Project (3)

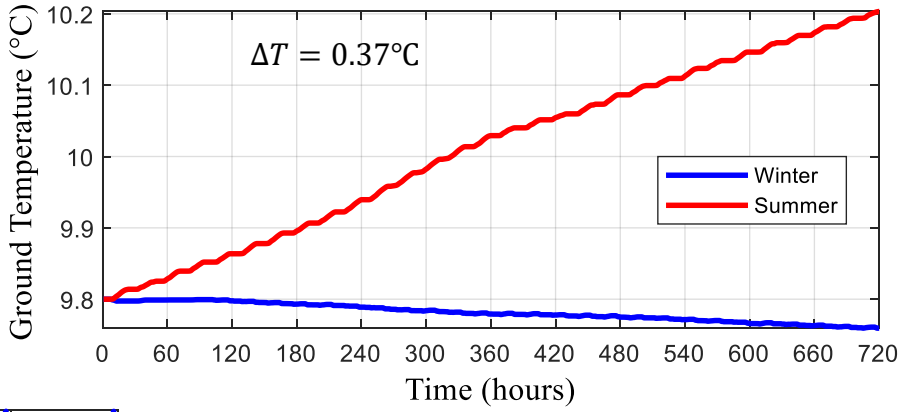
Thermal energy from PVT units



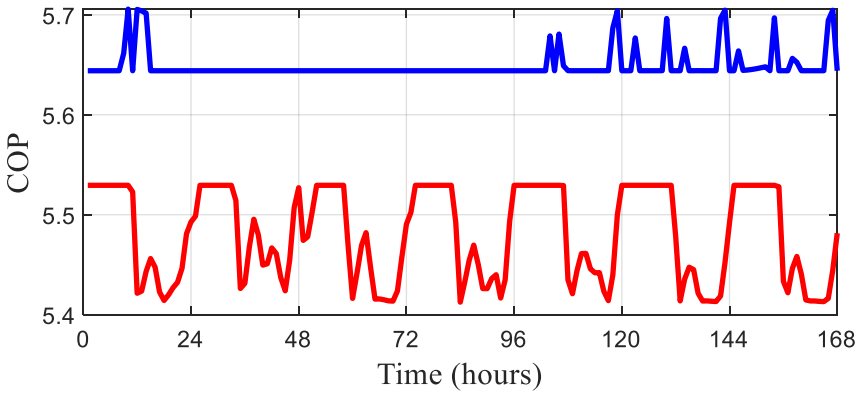


Temperature variation in the ground





Coefficient of performance



UKIERI/SPARC Project

Advancing Sustainable Building Practices: A Comprehensive Investigation into Estimation Techniques for Thermal Load of Buildings

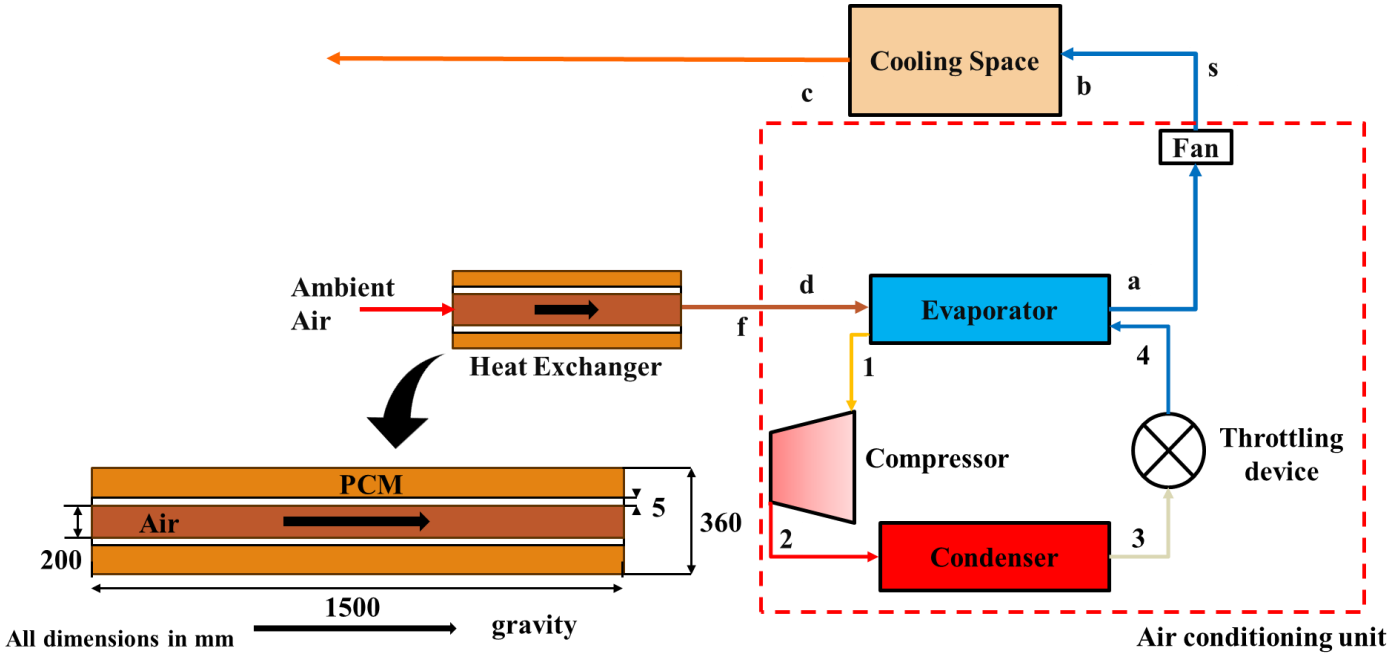
- **Objective:**
  - Promote ***academic and research collaboration*** between **IIT Delhi** and **Cardiff University** on **estimation of thermal load of buildings**.

- **Key activities and outputs:**
  - Research **workshops** and **seminars** at both institutions.
  - **Taught courses** on thermal load estimation for sustainable buildings at both institutions.
  - Student and academic staff **exchanges**.
  - Joint **publications**.
  - Specific research project on the **design** of **efficient heating, ventilation and air-conditioning (HVAC) systems** and **implementation** of **smart building solutions**.

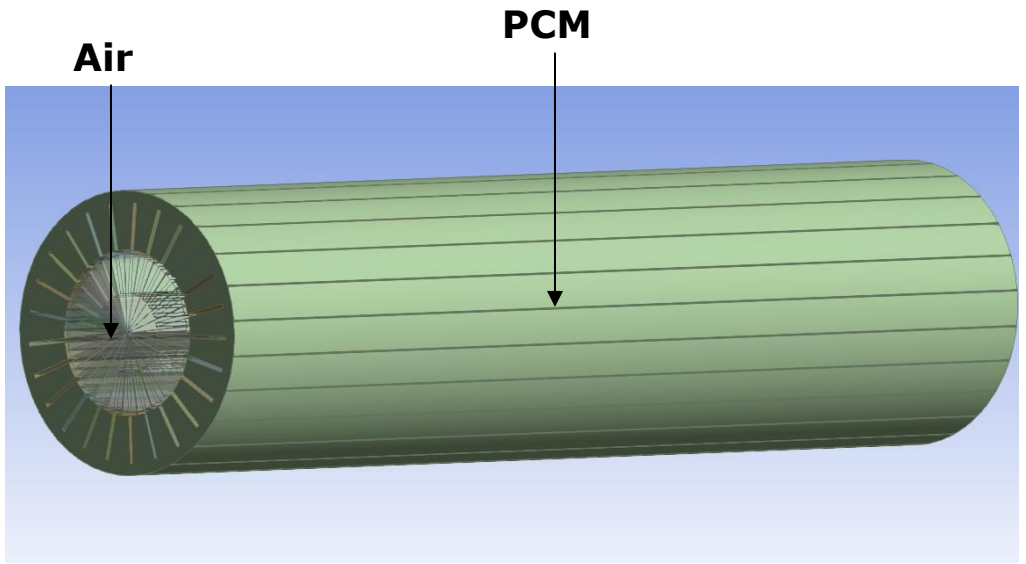
PCM-based Ventilation Load Reduction for HVAC Systems

Objectives:

- To reduce inlet air temperature of **HVAC system** using **latent heat store**.
- To compare **energy savings** of proposed approach with conventional HVAC system



Proposed configuration to reduce the fresh air load of an HVAC system



Heat exchanger with fins

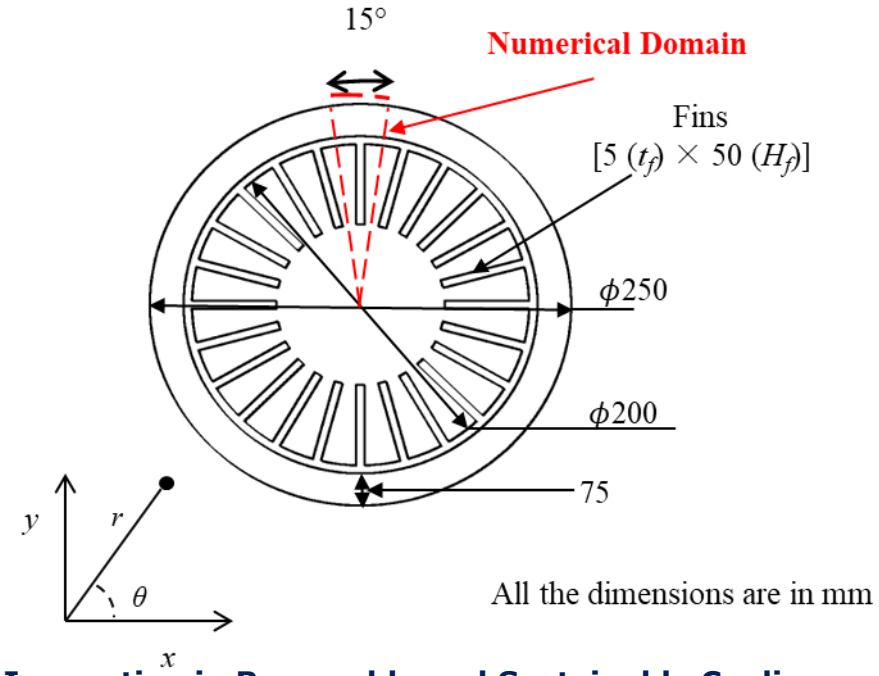
PCM-based Ventilation Load Reduction for HVAC Systems (2)

UKIERI UK-India Education and Research Initiative

Numerical modelling

- **Enthalpy-porosity** formulation to analyse **melting process**
- **PCM: Octadecane (melting point: 28°C)**
- **Inlet air:** Average air temperature (**May**, New Delhi)

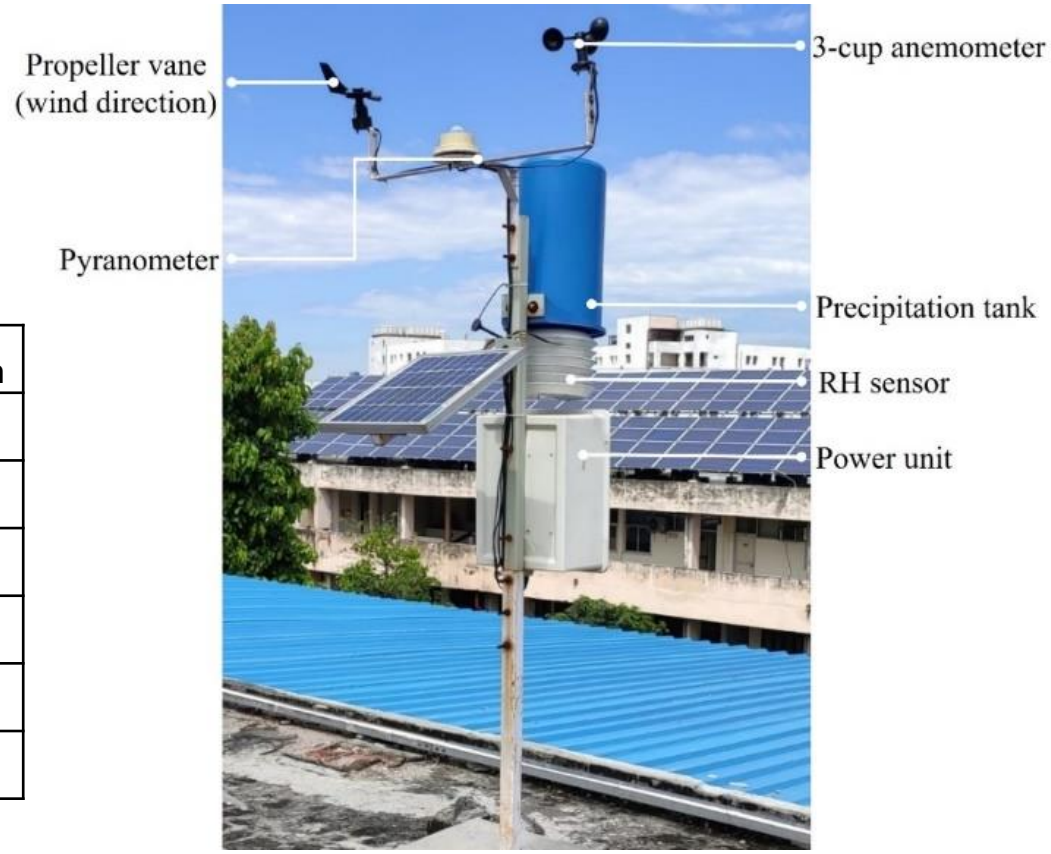
Cross-section and numerical domain of heat exchanger



Number/dimensions of fins

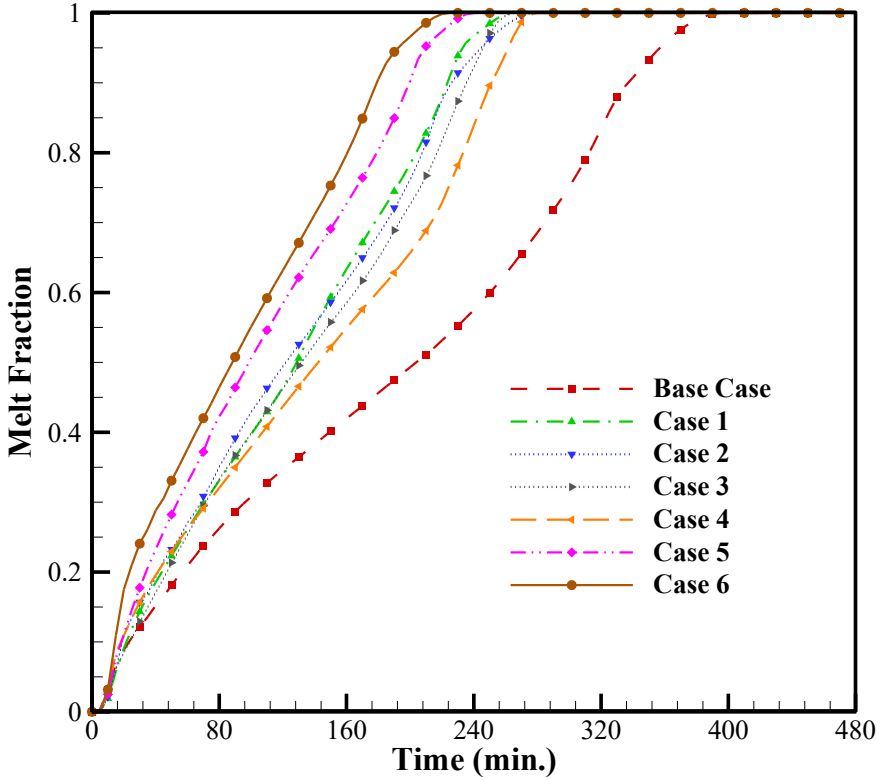
Case	Fins	Height	Width
1	1	30	10
2	2	30	5
3	2	50	3
4	2	15	10
5	3	25	4
6	3	50	2

Weather station to determine air inlet temperature

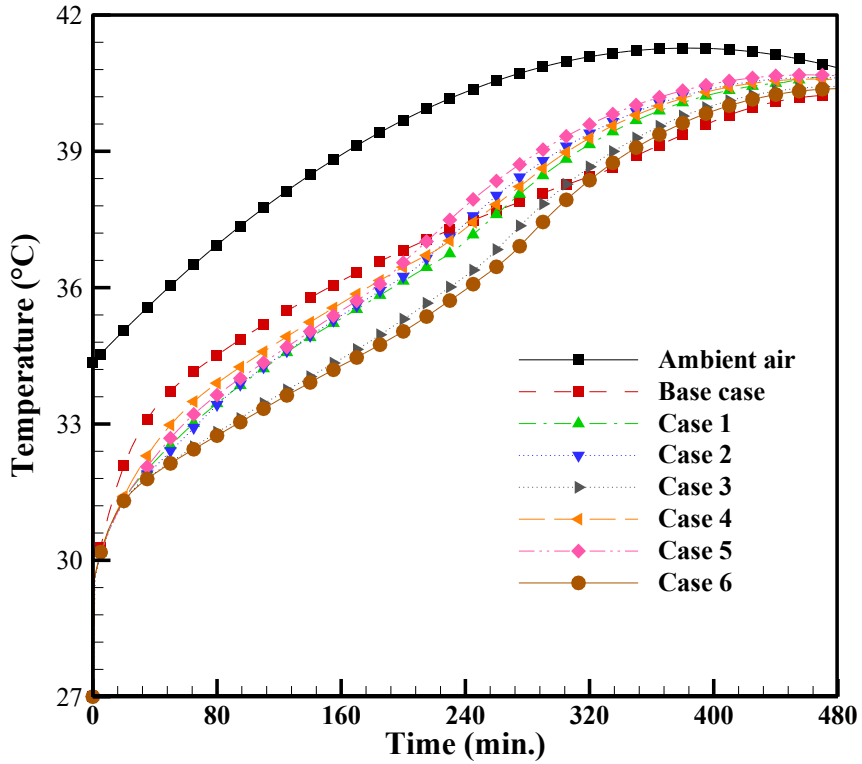


PCM-based Ventilation Load Reduction for HVAC Systems (3)

Melt fraction of PCM



Outlet air temperature



Case	Base	1	2	3	4	5	6
Average drop in air temperature (°C)	3.57	3.70	3.72	3.72	3.61	3.36	4.42
Melting Time (min)	395	265	240	265	280	225	280

Concluding Remarks

- **Decarbonising the energy sector** is **critical** towards achieving net-zero targets.
- **Decarbonising heat** is (very) challenging!
- **Decarbonising cooling** has been overlooked.
- There is limited data on **cooling demand**.
- Impact of **increased cooling demand** may be **considerable**.
- The **research conducted** may help inform **policy-making**, **home developers**, **network operators**, **homeowners** and other **researchers**.
- A **holistic approach in energy networks** can help **balancing supply and demand** efficiently and economically.
- It is critical to continue investigating how **cooling** may develop and understand how **cooling and energy storage technologies** can support integrated, socially acceptable, cost-effective and sustainable energy change.

Diolch!

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