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Centre for Doctoral Training in Energy Demand

Vision and leadership for a sustainable built environment

Sizing of district heating systems based on smart meter data

Quantifying the aggregated domestic energy demand and demand diversity in the UK

Zhikun Wang

LoLo/ERBE Annual Colloquium 2019

7 November 2019

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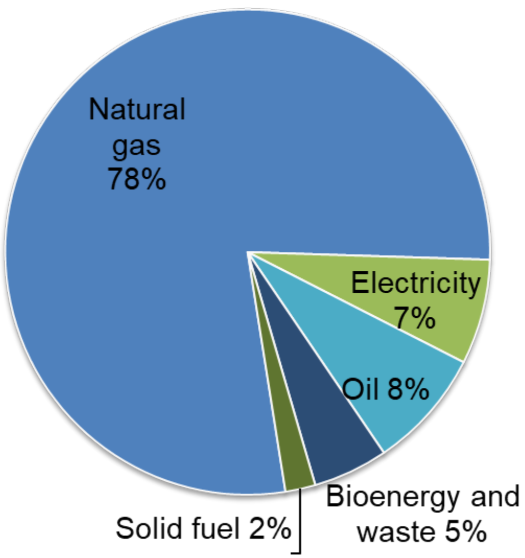
PhD student, UCL Energy Institute

UCL
Loughborough University
EPSRC Engineering and Physical Sciences Research Council

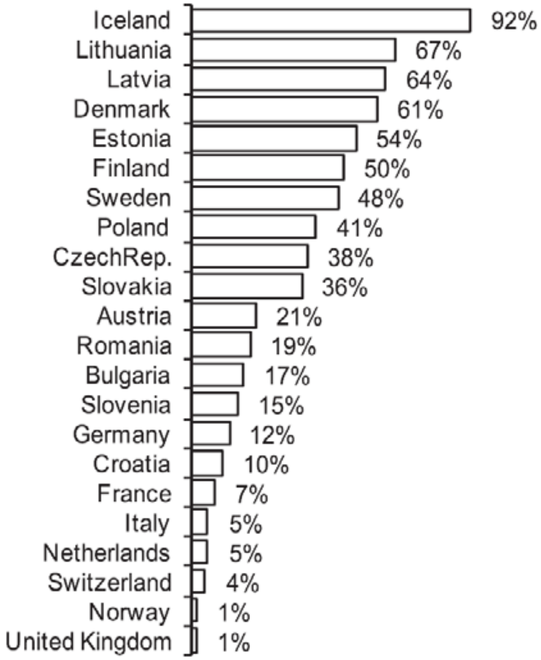
My PhD: Management of electric heating through heat pumps: A systematic exploration of comparative advantages of individual scale versus district level

- Domestic heat demand and district heating in the UK
- Appropriate sizing of district heating systems
- Analysis of energy demand and diversity from smart meter data
- Insights and applications

Domestic heat demand and district heating in the UK



Fuel consumption for domestic heating in the UK



District heating market shares

First generation district heating in Manchester, 1901.

- District heating is **not a new concept** in the UK
- It is considered as an **expensive** and **risky** technology/business
- Most of existing networks are considered as **small schemes** (less than 100 dwellings)

Appropriate sizing of district heating systems

Undersizing:

- Insufficient capacities
- Interruptions of service

Oversizing:

- Ensures supply security
- Prepares for severe weather
- Reduces efficiency
- Increases capital and running costs

Common practice tends to become **defensive** and domestic heating systems are typically **oversized**.

Empirical quantifications of energy consumption and peak demand to avoid under or oversizing thorough:

Empirical energy demand load profiles
&
Energy demand **diversity** analysis

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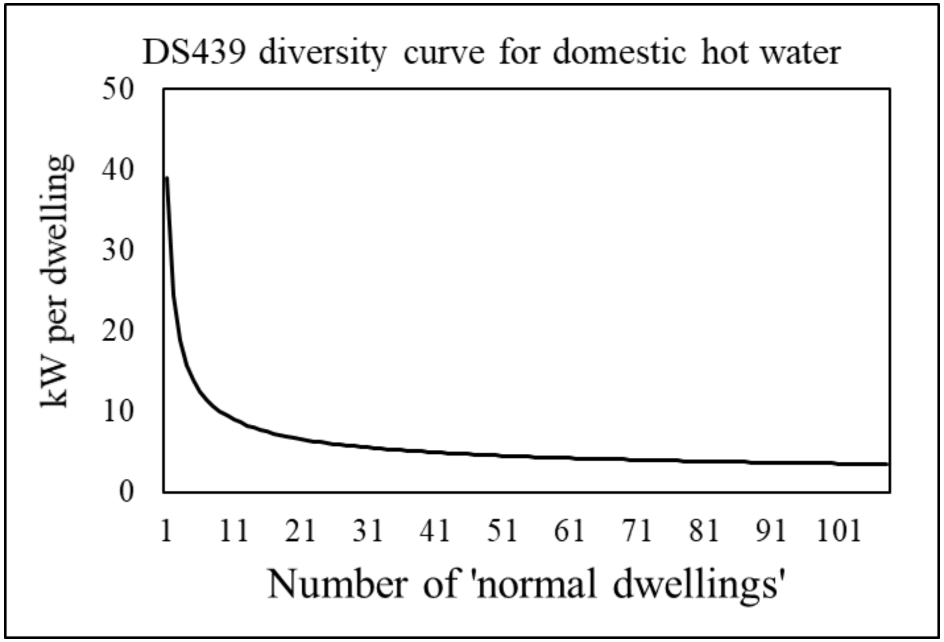
Energy demand and demand diversity from smart meter data analysis

What is energy **Demand Diversity** and **After Diversity Maximum Demand**?

Demand Diversity:

$$Diversity\ fator\ = \frac{\sum Individual\ maximum\ demand}{maximum\ demand\ of\ the\ aggregated\ system}$$

$$Coincident\ factor = \frac{1}{Diversity\ factor}$$



After Diversity Maximum Demand:

$$ADMD = \lim_{N\to\infty} \frac{1}{N} \sum_{i=1}^{N} MD_i$$

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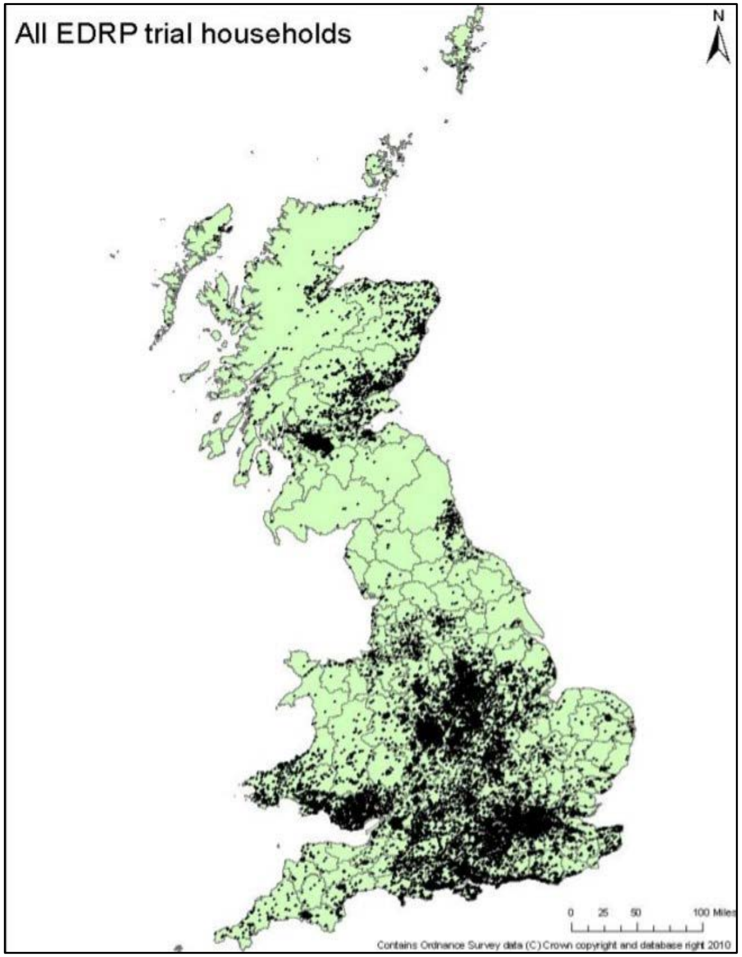
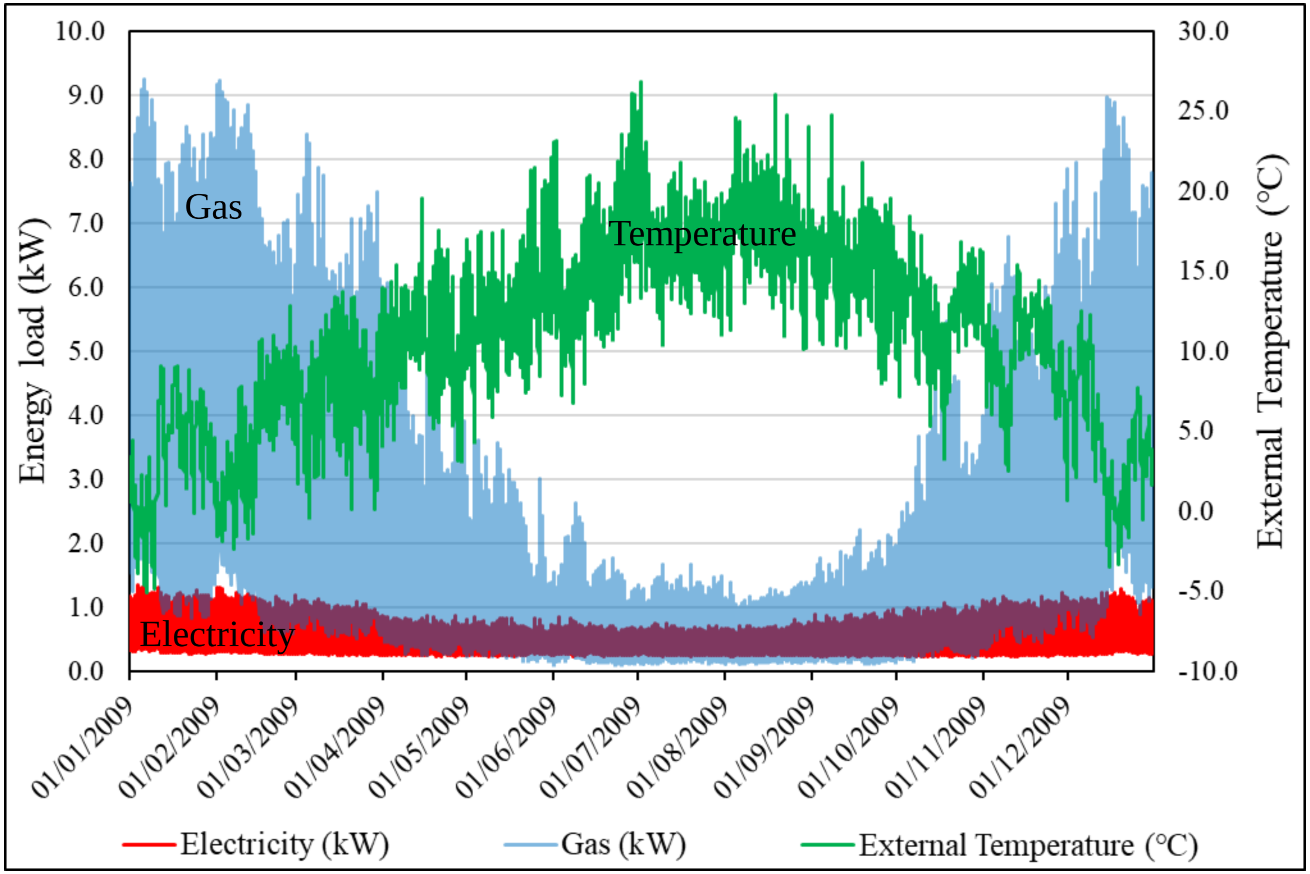
Energy demand and demand diversity from smart meter data analysis

- Energy consumption data collected from the EDRP field trials
  - The **largest** smart meter field trial in the UK
  - **Half-hourly** electricity and gas consumption data
  - Monitored between January 2008 to September 2010, including **two particularly cold winters**
- Data from the EDF Energy subset
  - 1879 dwellings
  - Including winter 2009/2010, the **coldest winter** since 1978



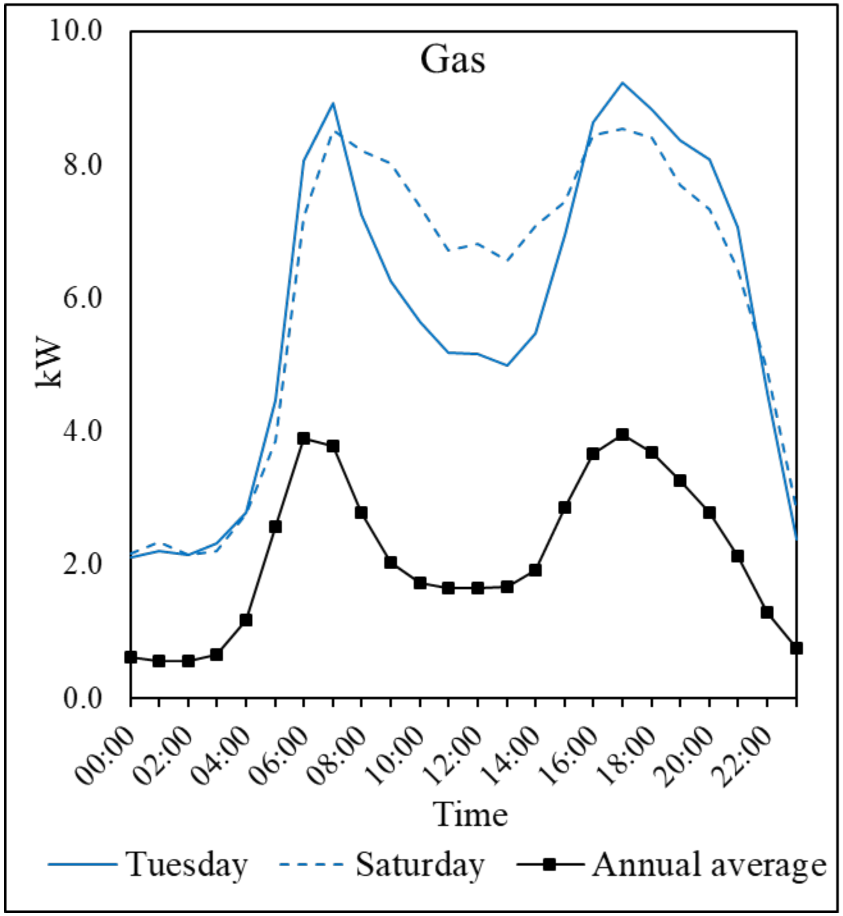
Source: Office of Gas and Electricity Markets (Ofegm)

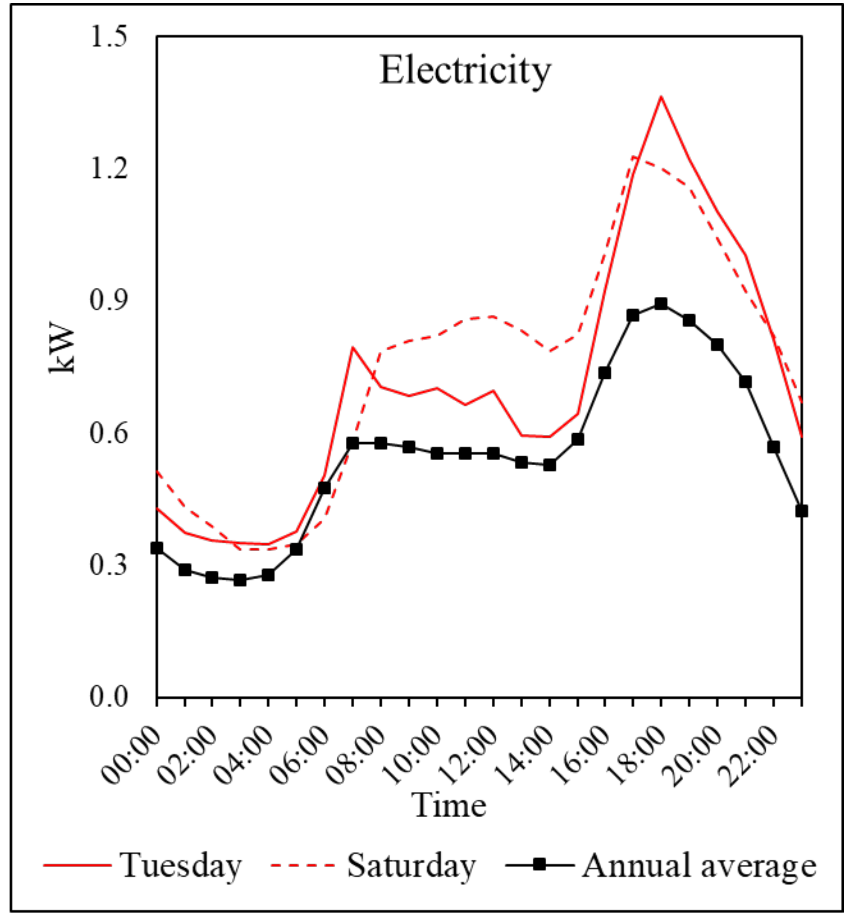
Hourly electricity and gas load profiles versus external temperature in 2009



- Annual gas consumption was **four times** higher than electricity consumption.
- Peak hourly gas demand was **seven times** higher than peak hourly electricity demand.

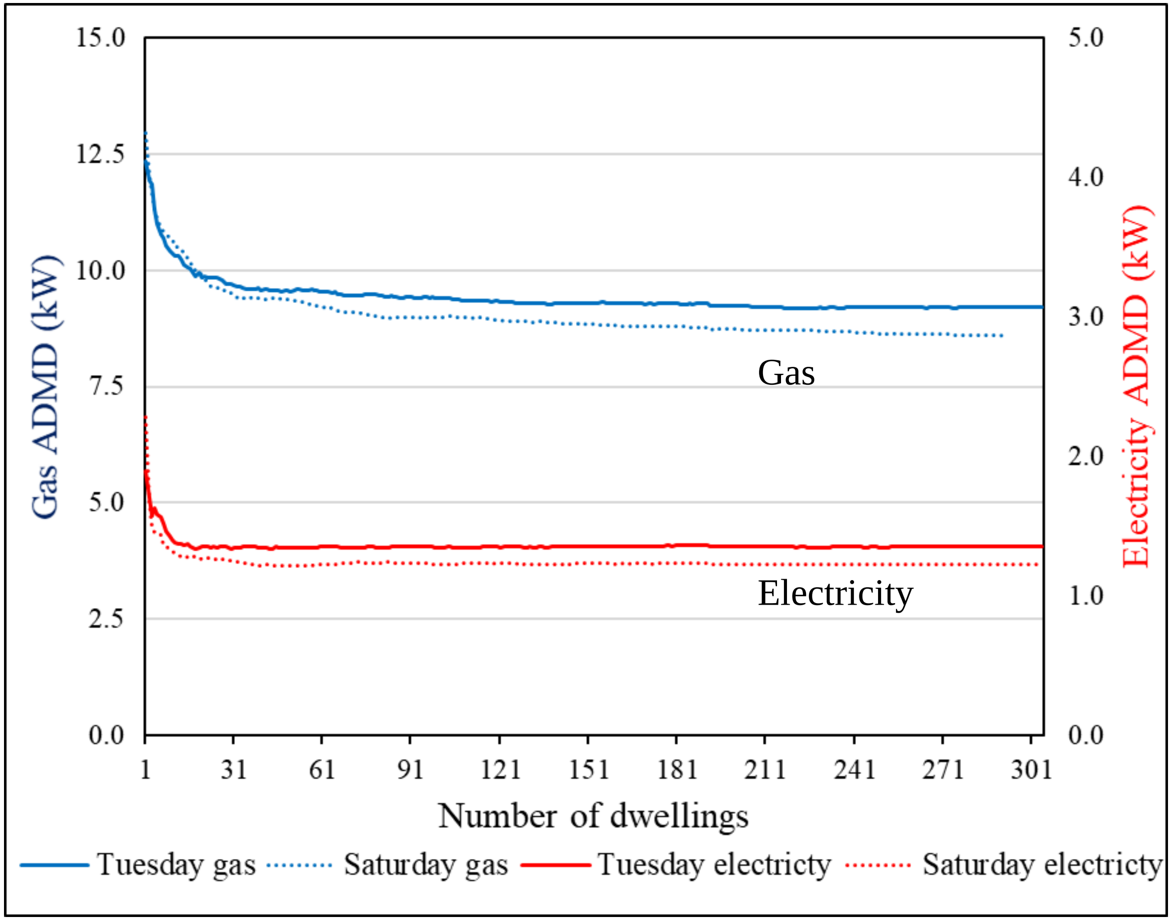
24-hour load profiles on the two coldest day of 2009.





Tuesday 6th January and Saturday 10th January 2009

After diversity maximum demand on the two coldest days of 2009



Tuesday 6th January and Saturday 10th January 2009

$$ADMD = \lim_{N \to \infty} \frac{1}{N} \sum_{i=1}^{N} MD_i$$

On the coldest day (Tuesday 6th Jan)

For one dwelling:
- Peak gas: 12.4 kW
- Peak electricity: 1.9 kW

For 100 dwellings:
- Peak gas: 9.4 kW per dwelling (**24% drop**)
- Peak electricity: 1.35 kW per dwelling (**29% drop**)

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Insights and applications from this study

Industry

- Energy suppliers, building services and infrastructure companies
- Determine the **size** of district energy generation, transmission, and distribution **capacities** to avoid unnecessary **costs**, improve system **efficiency** and ensure energy **security**
- Design energy market **management strategies**, **economic** grid **operations** and evaluate **investment**
- **Forecast demand**, plan short-term and long-term **generation** and **purchasing**, and design **load control** mechanism

Policy

- Assist national and area based **strategic planning** to meet future energy demand
- Regulate energy **contracts and tariffs**
- Legislate infrastructure requirements and industrial standards, e.g. Code of Practice

Academia

- A **quantitative understanding** of domestic energy demand and the effect of diversity
- An **empirical basis** to develop and validate **energy models**

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Thank you!

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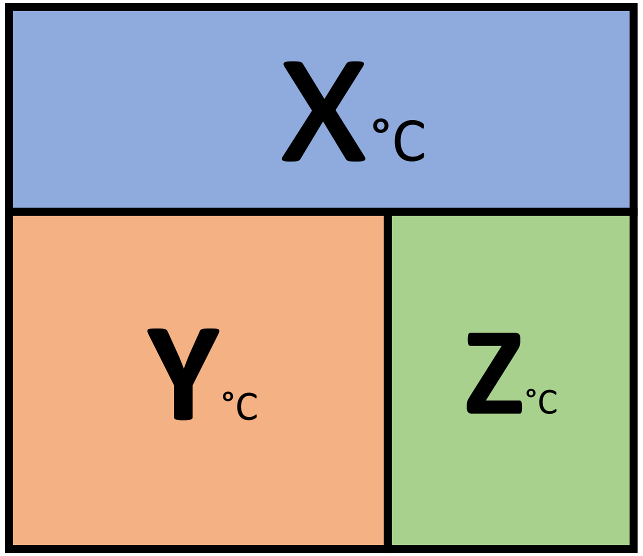

A **socio-technical** assessment of the **energy saving** potential of domestic **zonal space heating controls**

Dan Wright[1], Dr Victoria Haines[2] & Dr Davi
Allinson[1]

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WHAT ARE ZONAL SPACE HEATING CONTROLS?

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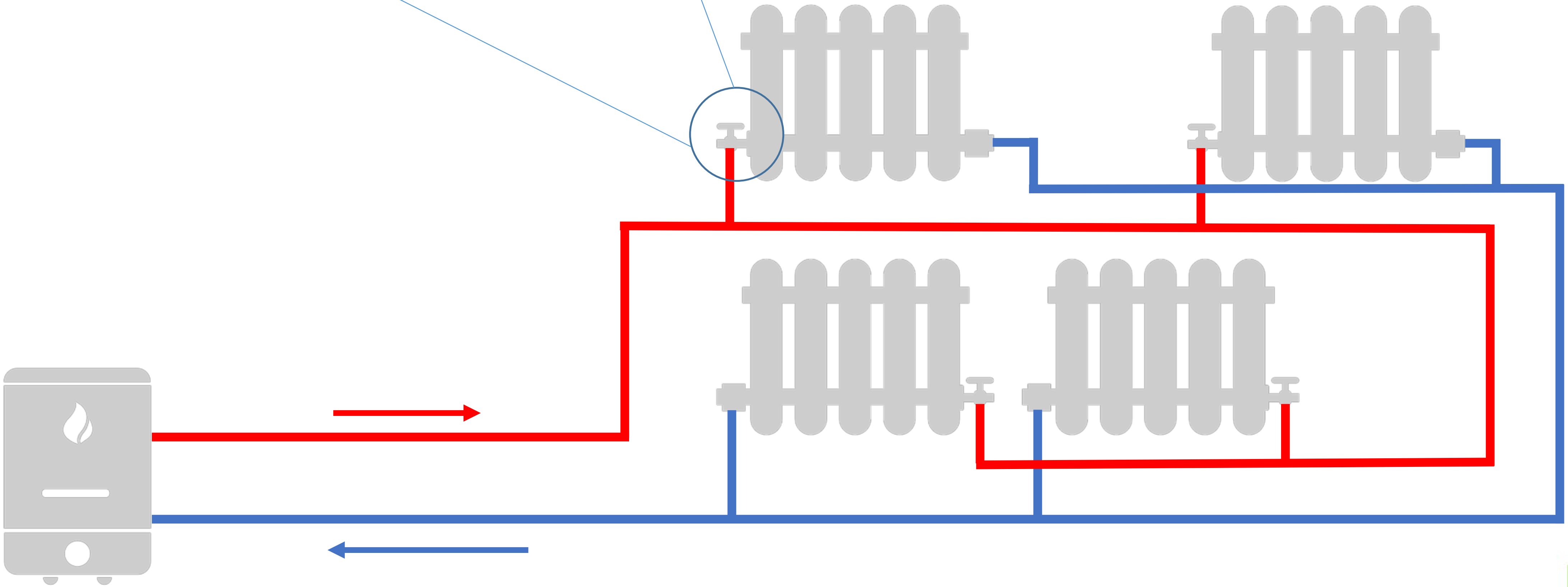
Thermostatic radiator valves (TRVs)



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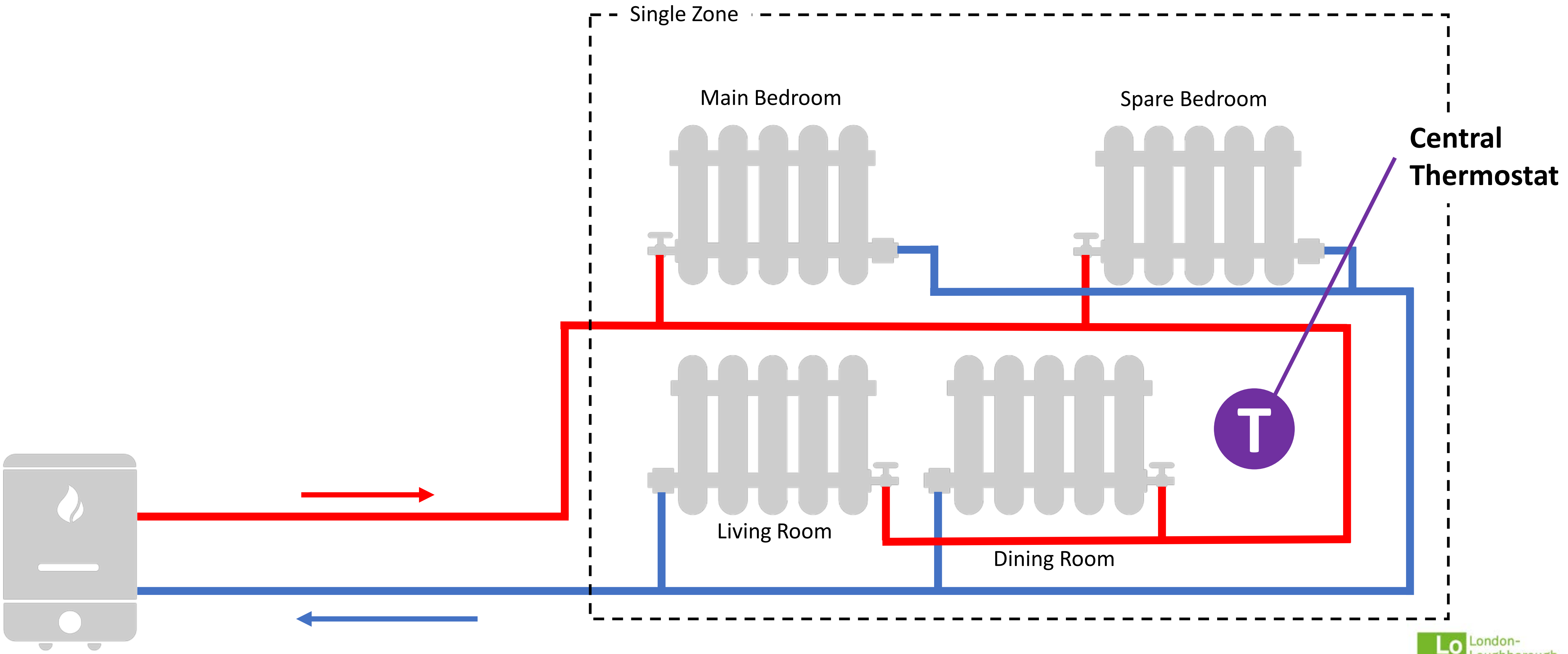

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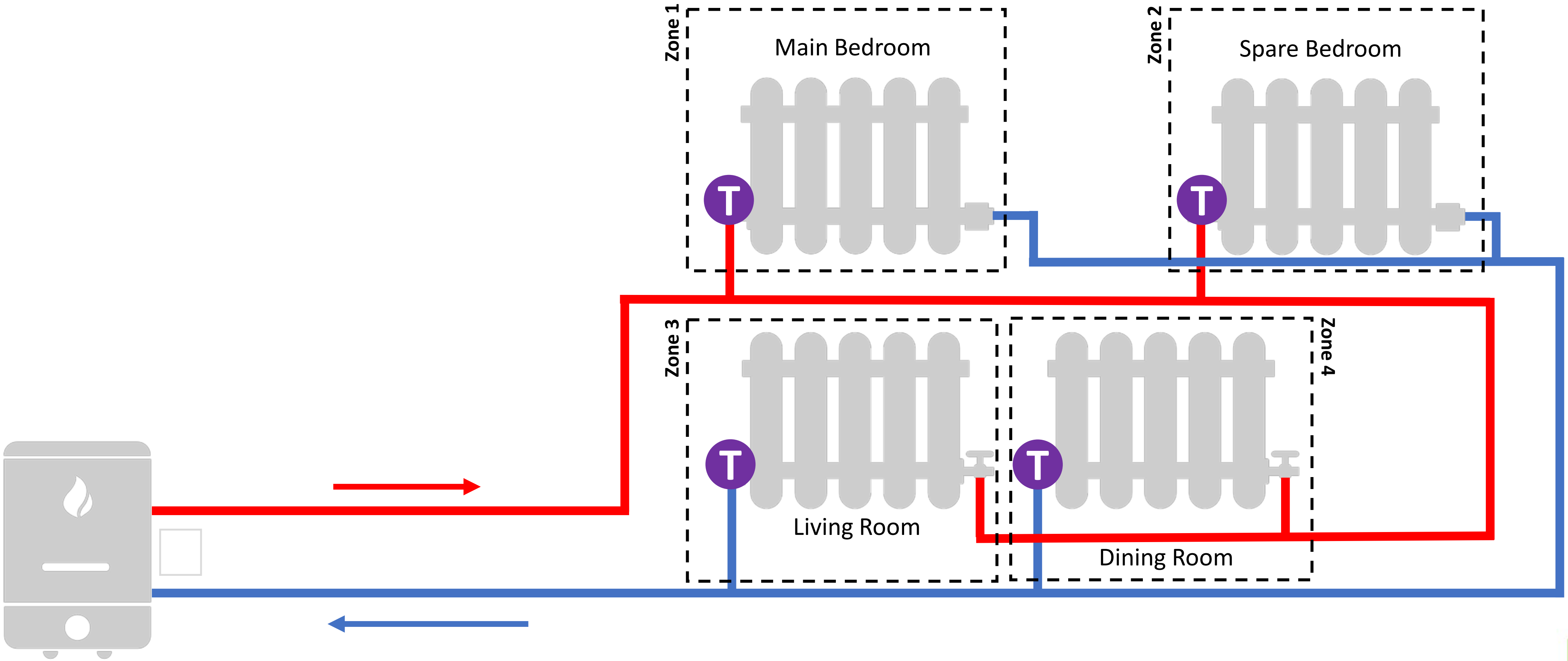

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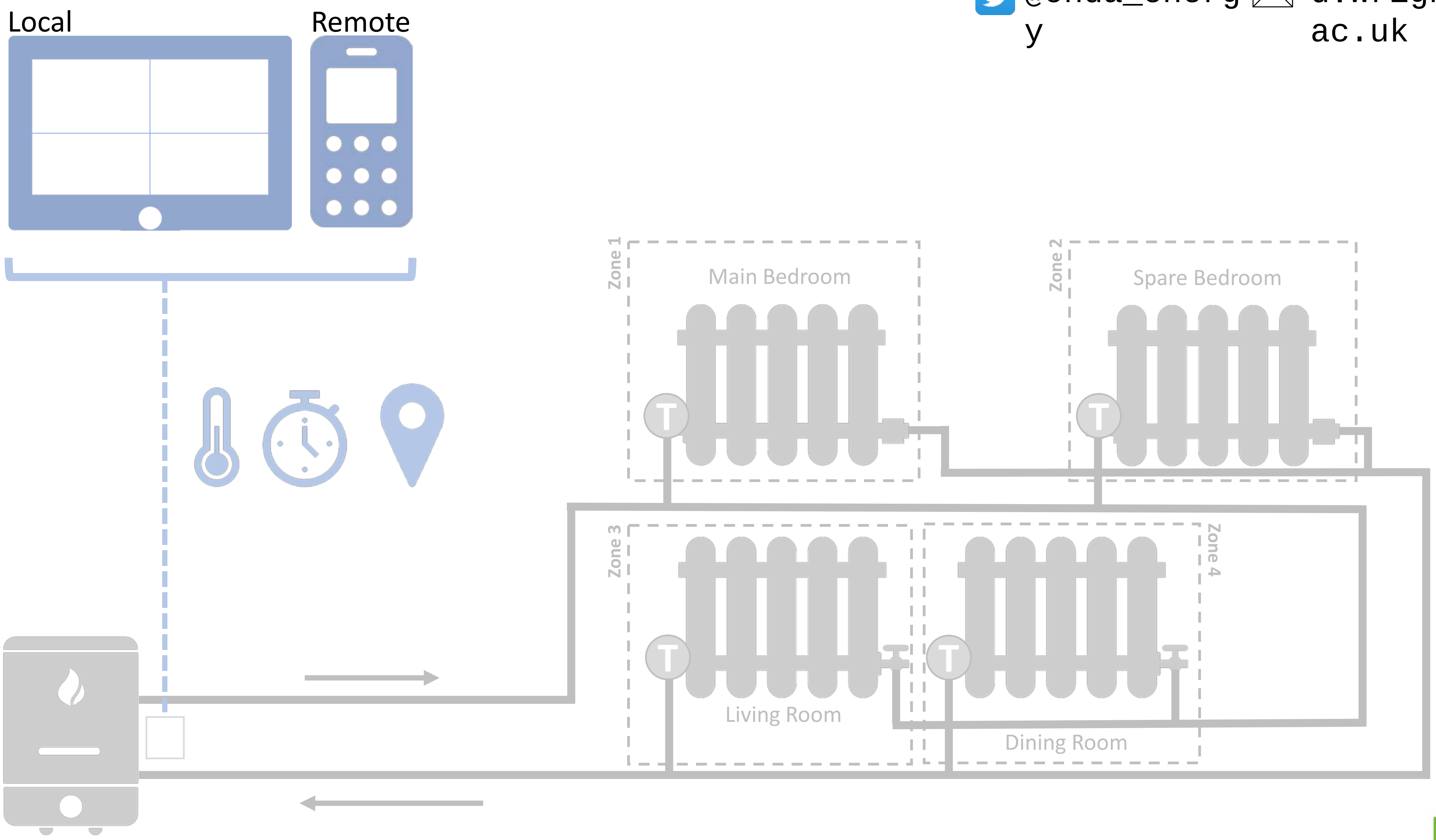

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WHO AND WHAT?

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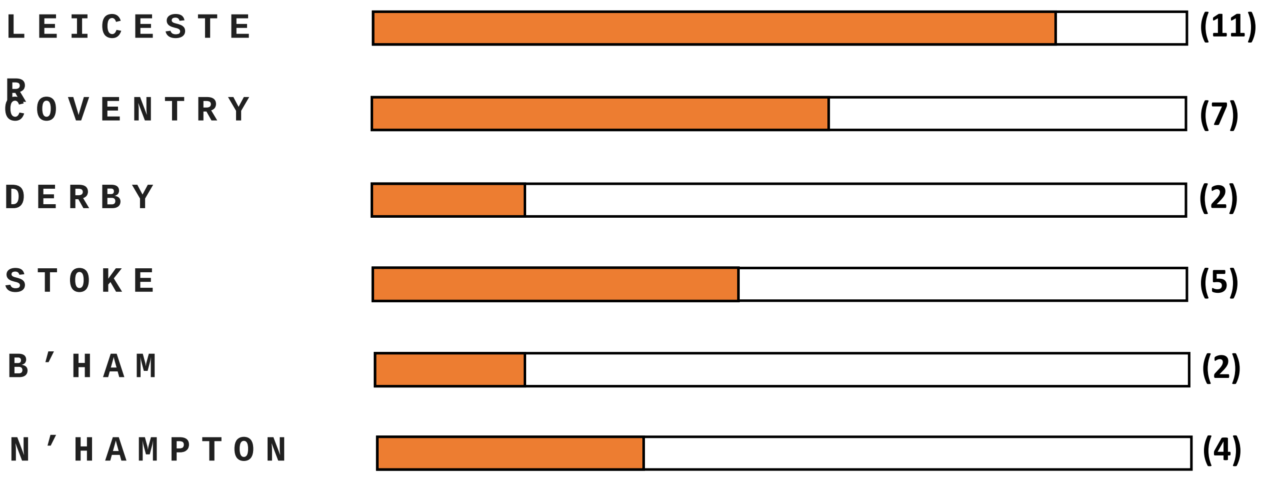
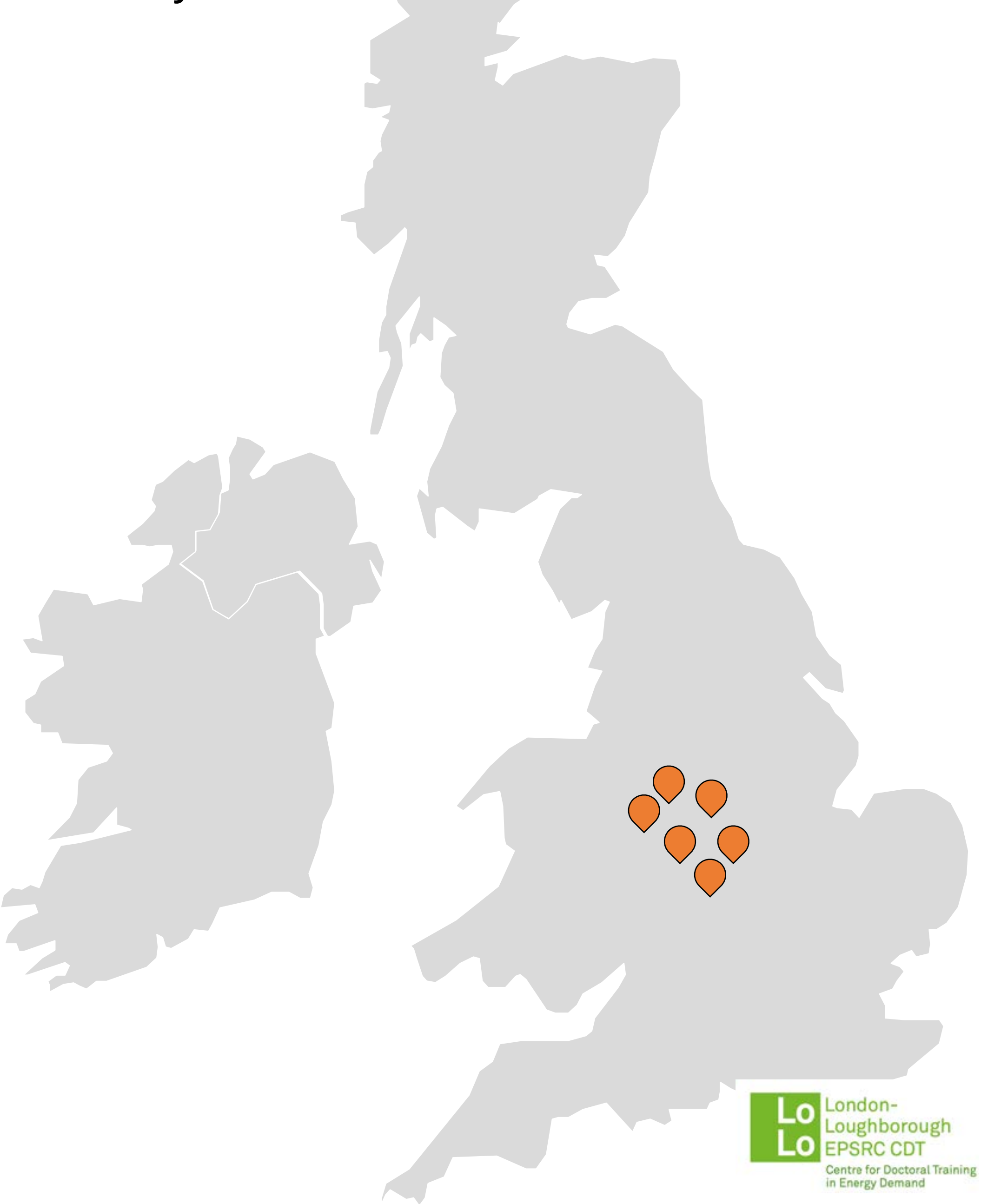
COHORT MAP

■ **31 HOMES WITH ZONAL CONTROLS: All pre-1981, semi-detached, occupier-owned dwellings.**





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Physical data

Questionnaires & Surveys

Interviews

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DO ZONAL CONTROLS SAVE ENERGY?

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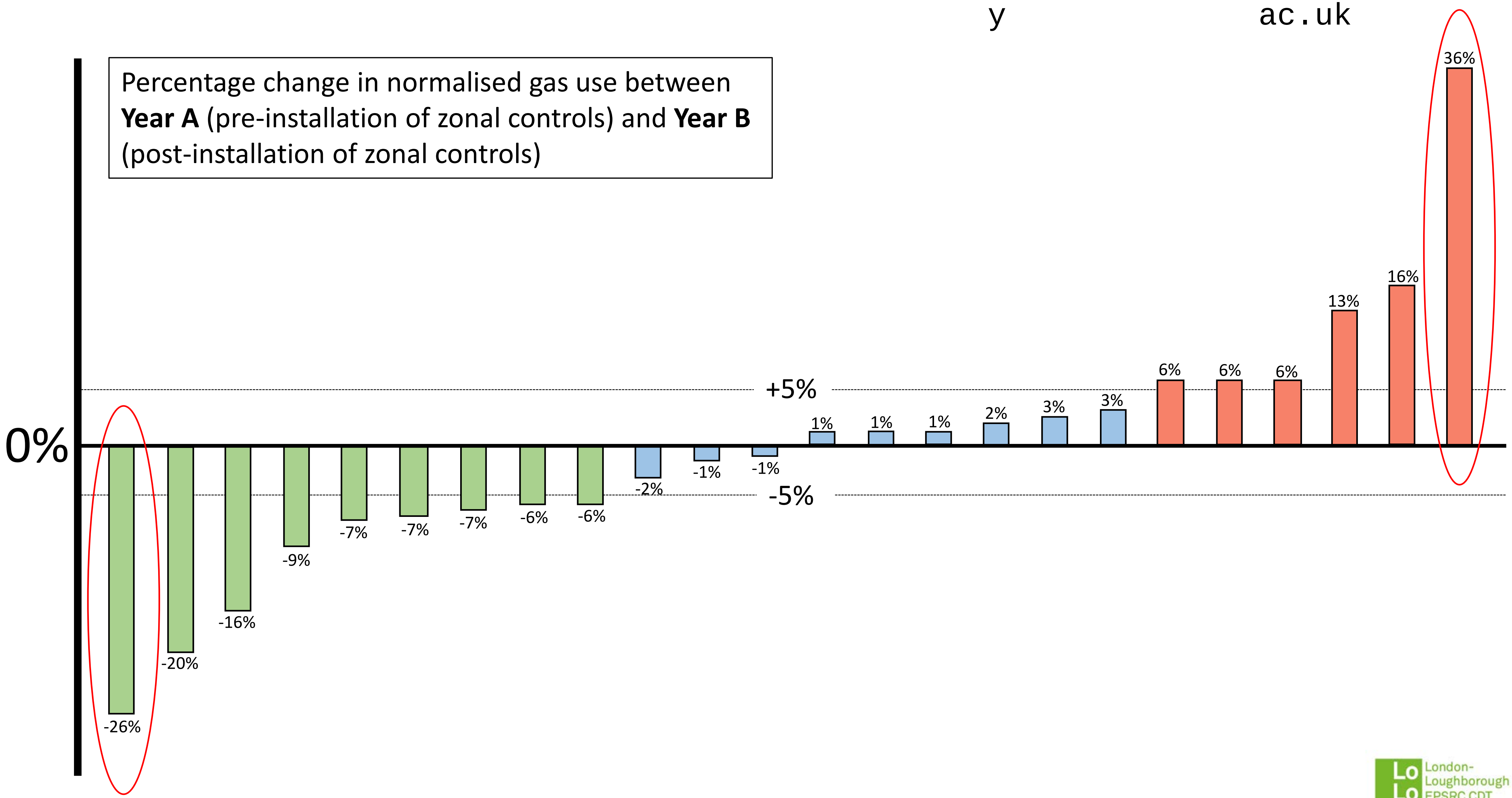

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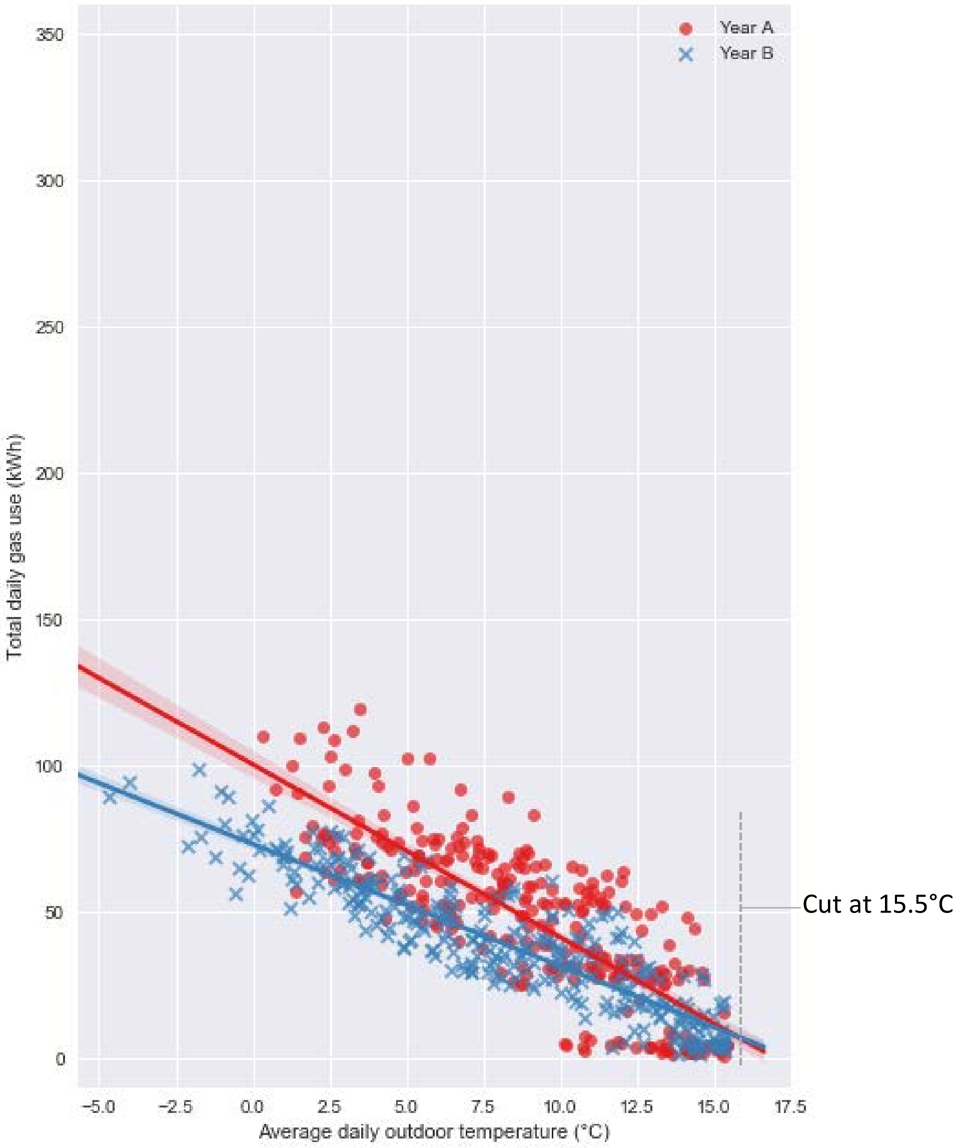
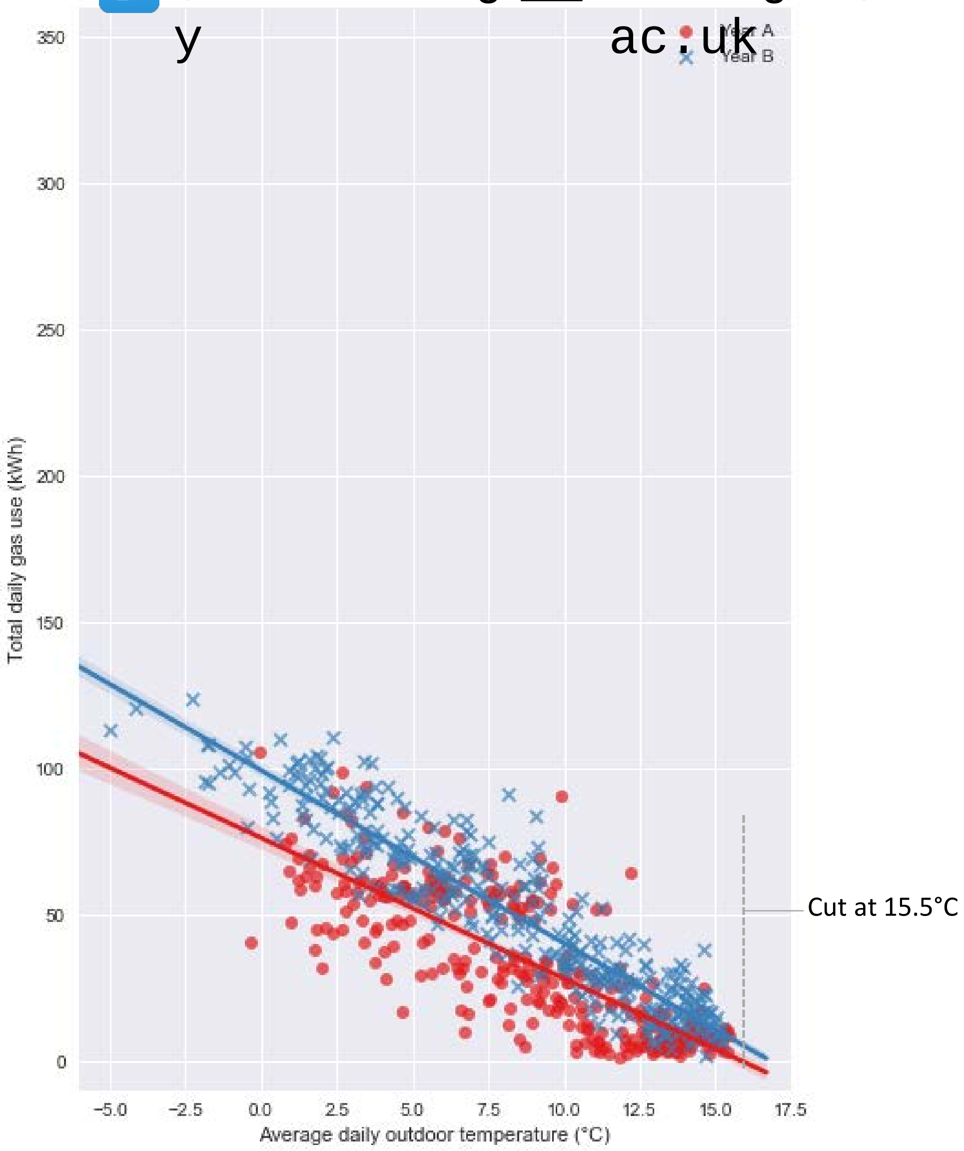


This household used 26% less gas compared to a pre-installation baseline year (Year A)



This household used 36% more gas compared to a pre-installation baseline year (Year A)

HOW DO INDOOR AIR TEMPERATURES CHANGE?

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This household used 26% less gas compared to a pre-installation baseline year (Year A)

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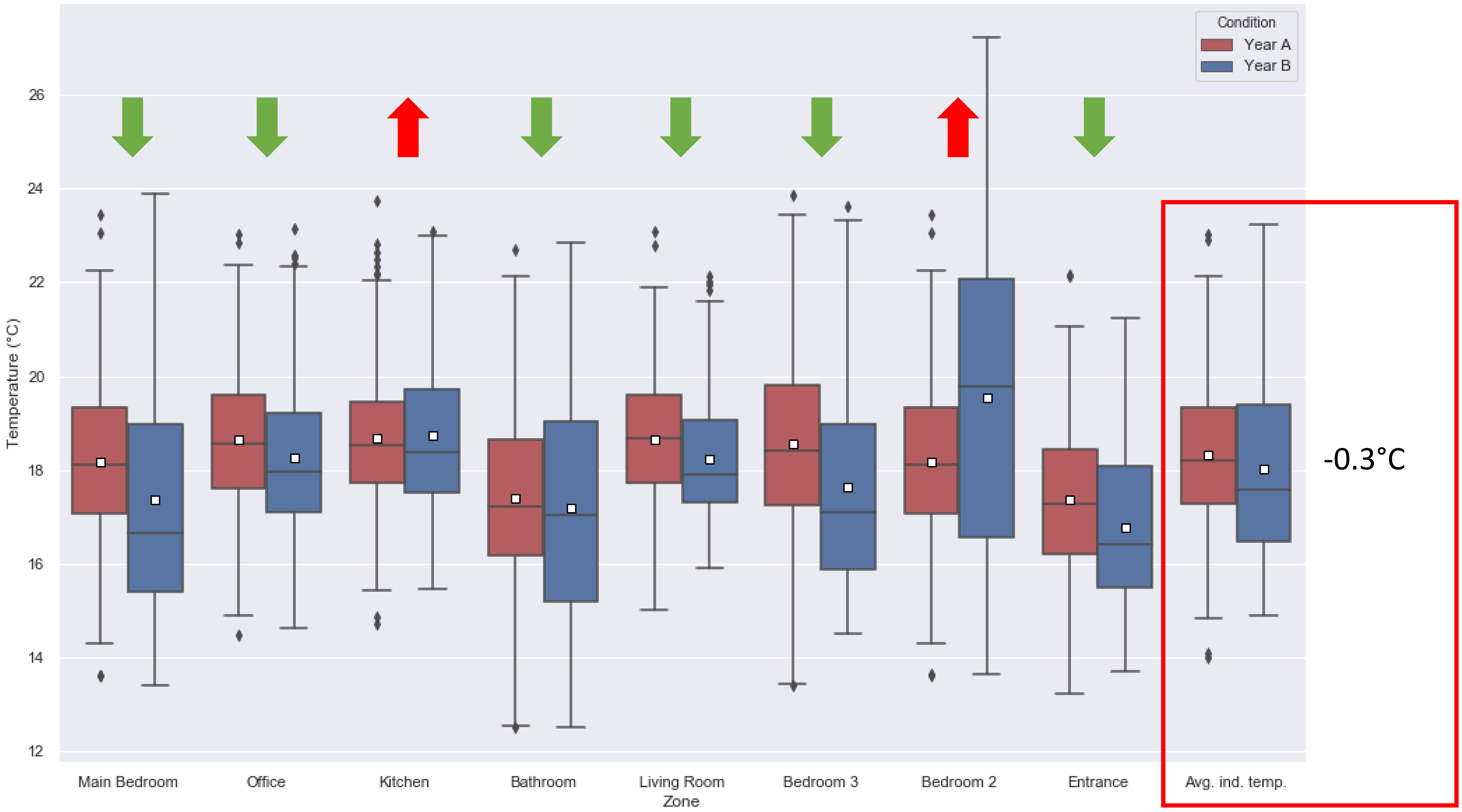

This household used 36% more gas compared to a pre-installation baseline year (Year A)

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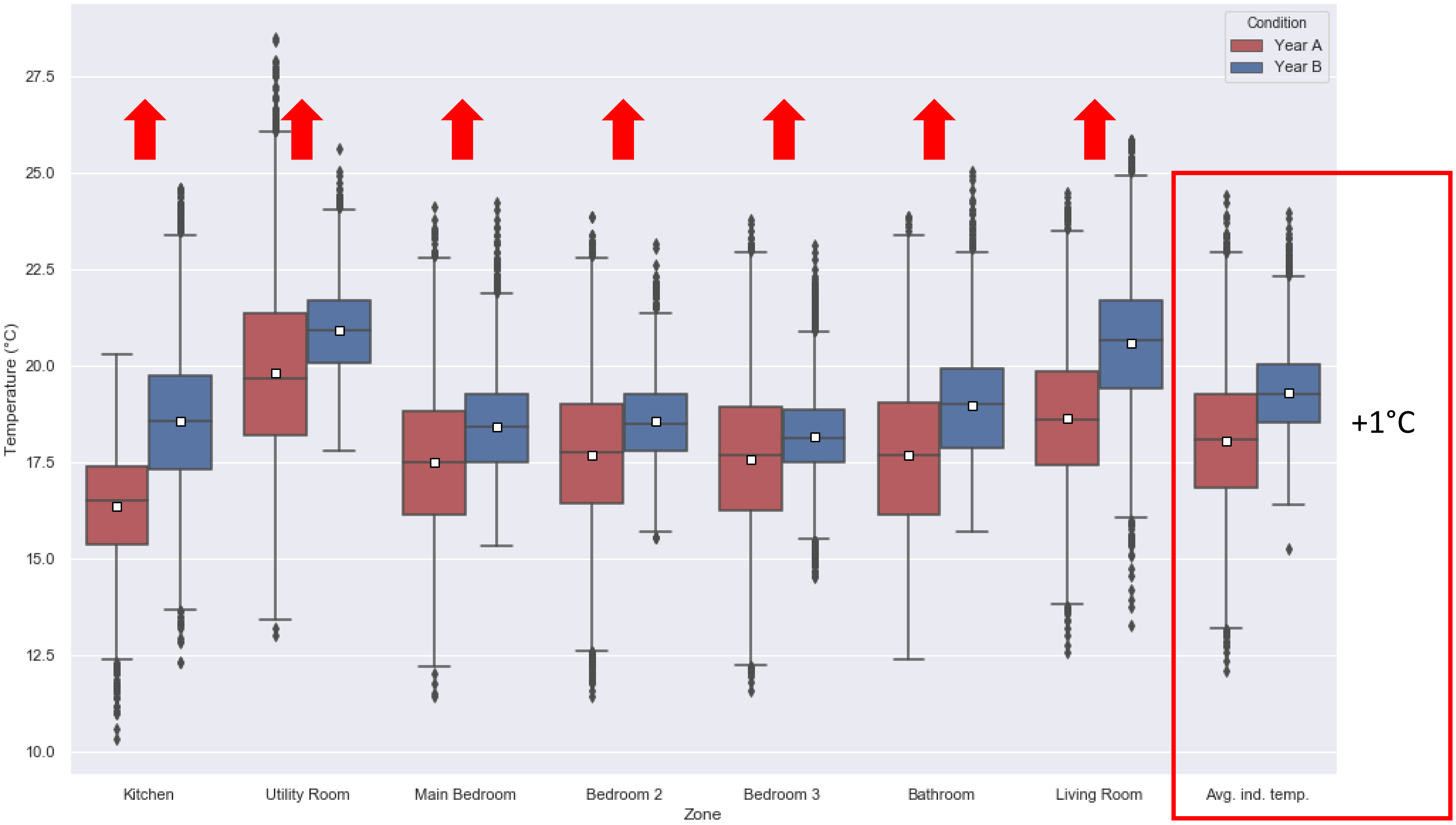

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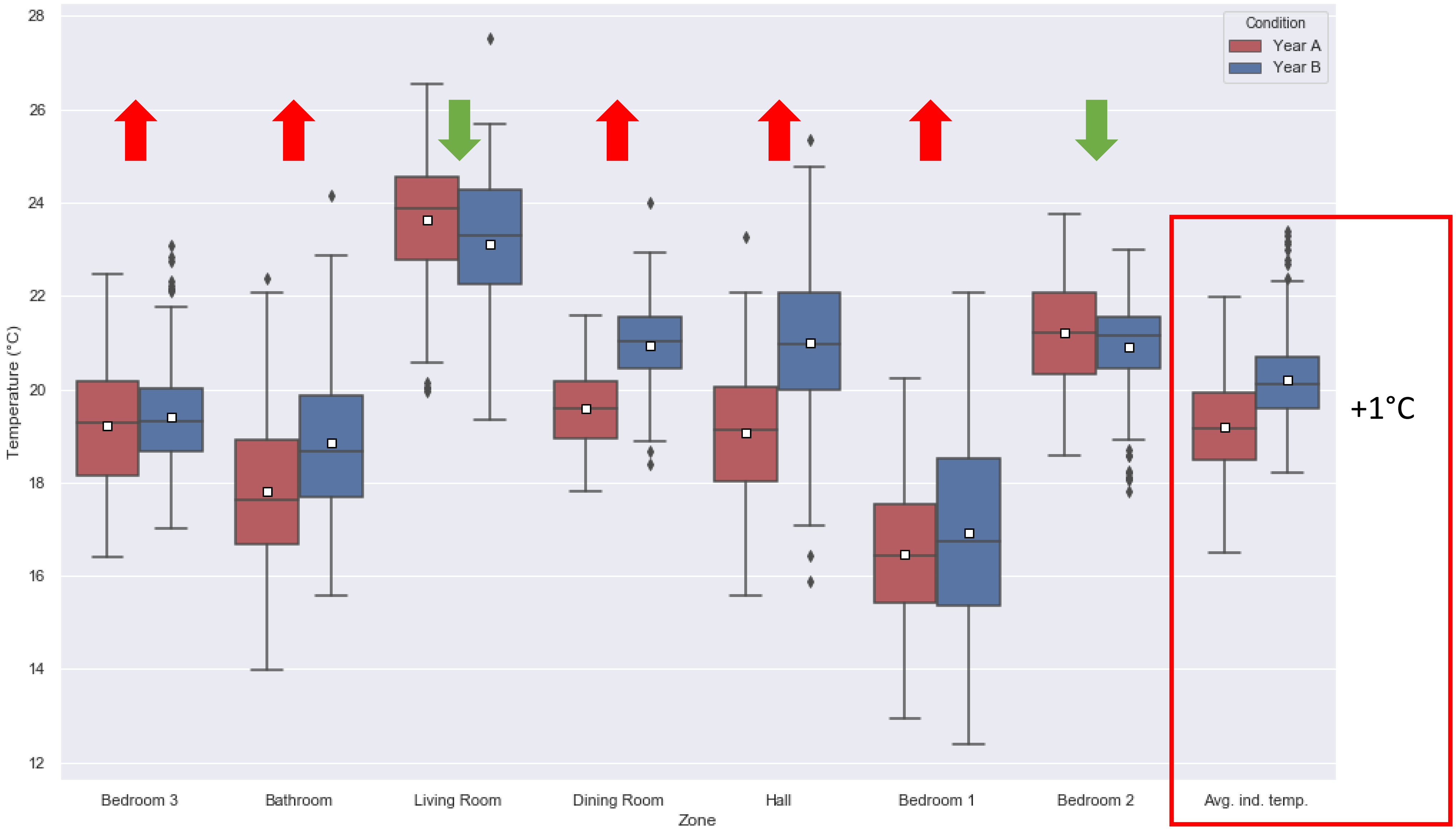

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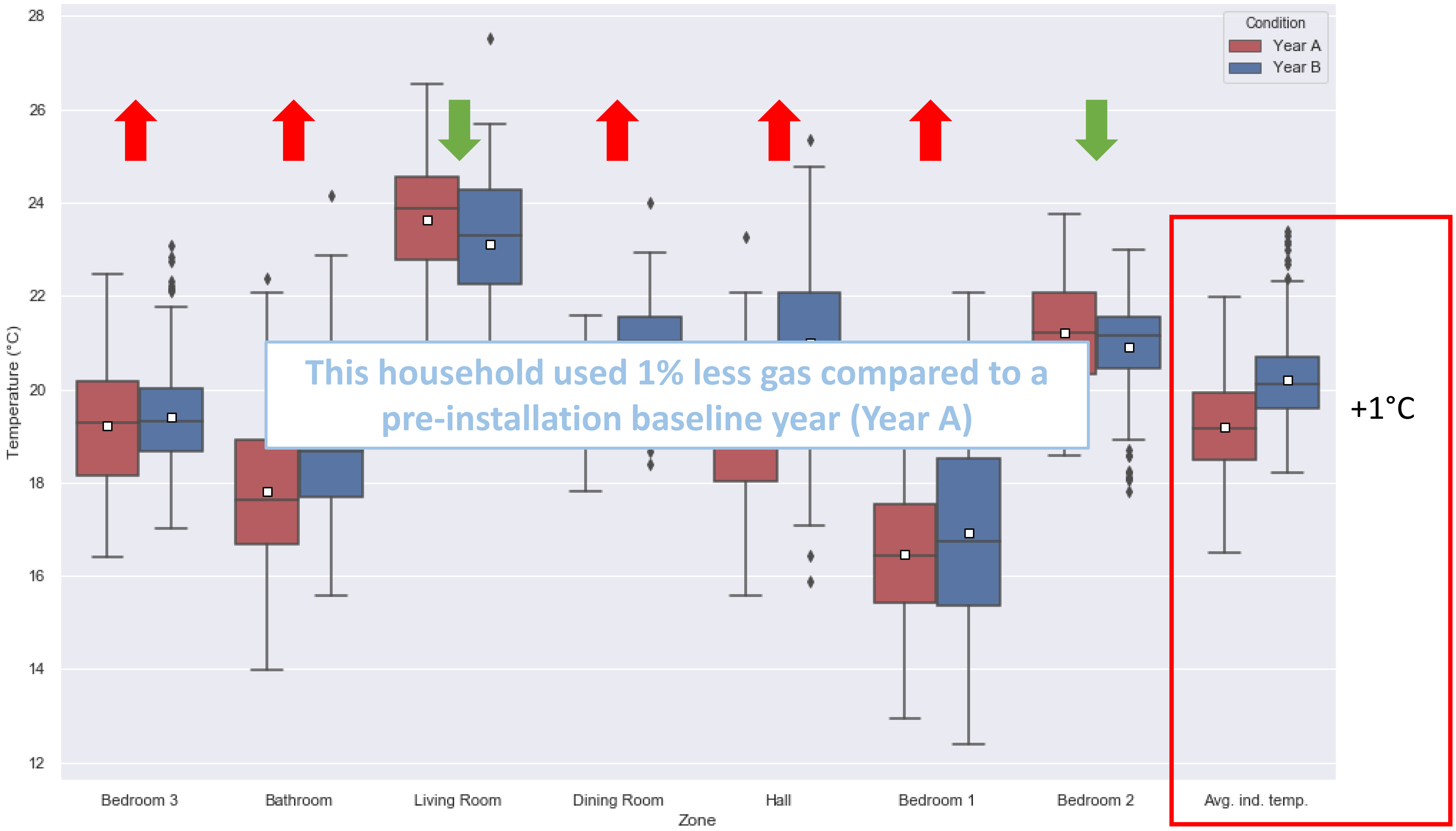

This household used 1% less gas compared to a pre-installation baseline year (Year A)

STRATEGIES FOR SAVING ENERGY WITH ZONAL CONTROLS

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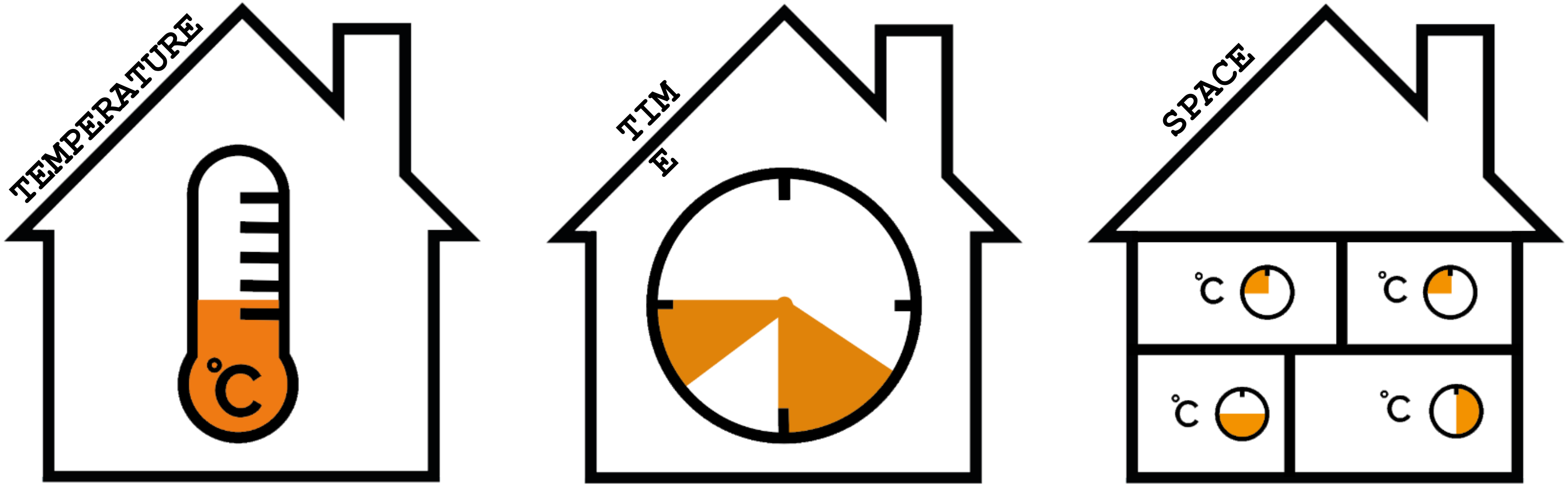

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"At 7:30 the bathroom warms up, at 7:40 the hallway warms up…"

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"The temperature is just right… everywhere in the house…"

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IMPROVING UNDERSTANDING

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“We haven’t changed the setting since installation…”

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"Then, I noticed that my daughter had set her room to 30°C…"

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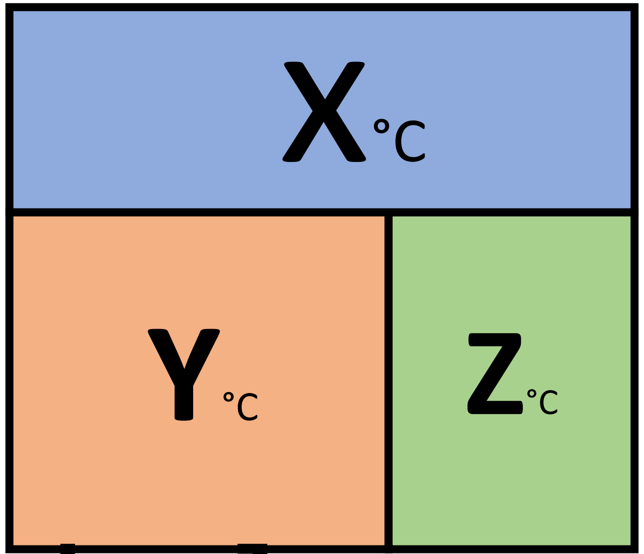
WHAT'S NEXT?

- Analysing the zonal control interaction data
- Conducting interviews with *non-savers*
- Analysing the third year of post-installation gas use

TAKE-AWAYS

- Zonal controls can sometimes save a lot of energy
- Zonal controls can sometimes increase energy use
- Critical insights for policy, industry and further research



A socio-technical assessment of the energy saving potential of domestic zonal space heating controls

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Loughborough University

Simble

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THERMAL VARIETY AND HEALTH: EVIDENCE FROM THE UK BIOBANK

Using a wrist-worn temperature sensor to understand participant's thermal environment.

Harry Kennard. (Supervisors: Gesche Huebner & David Shipworth)

LoLo/ERBE Annual Colloquium 2019

7 November 2019

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Research overview

- Research question: how does the measured temperature people experience (as opposed to static measures) relate to demographic, building and health factors?
- Data source: the UK Biobank – a large longitudinal UK health study.
- 103k participants wore an activity and temperature monitor on their wrist for a week each.

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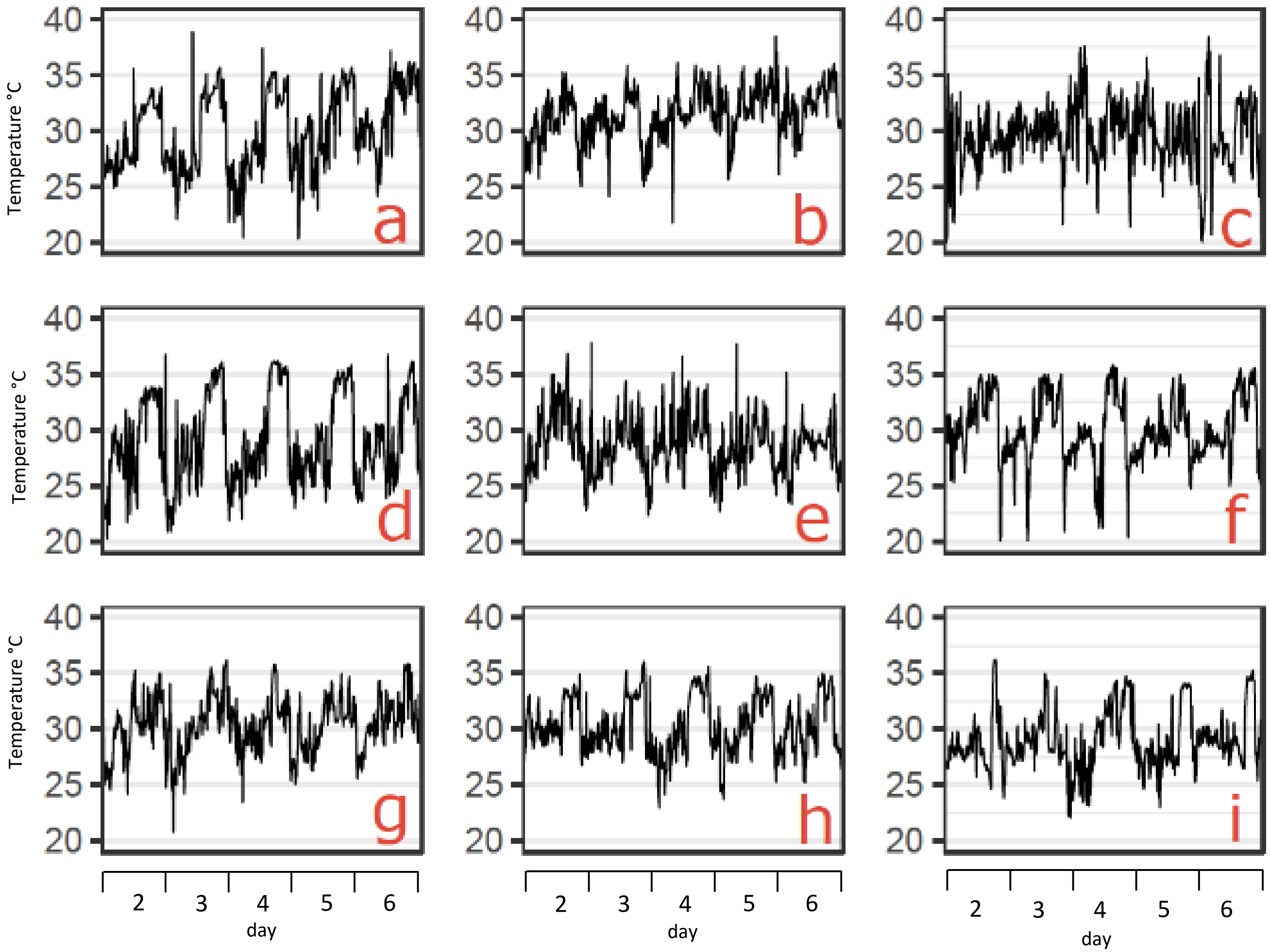
Time-series examples



Thermal variety (t_{sd}) is the standard deviation of the experienced temperature.

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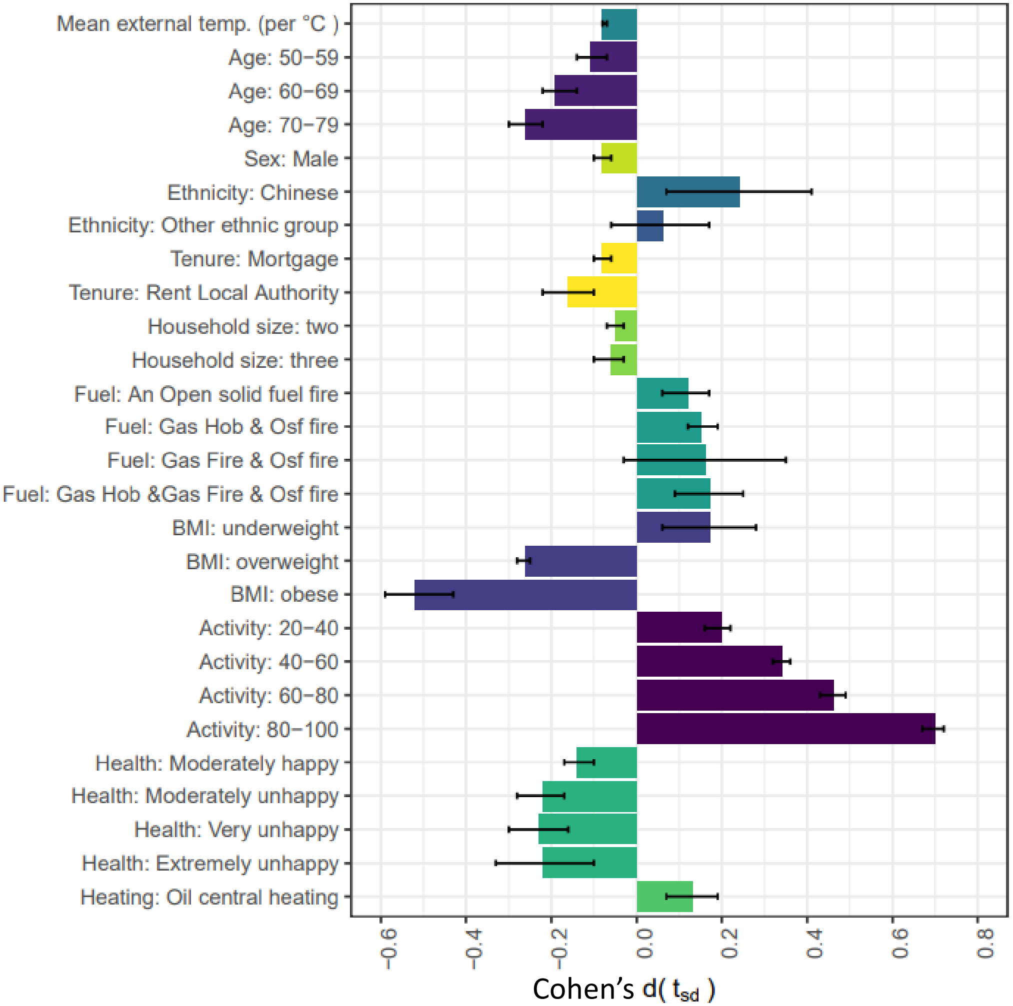
Multiple regression model using t_{sd}

t_{sd} decreases with:

- age
- BMI
- Being male

t_{sd} increases with:

- Activity level
- Health satisfaction
- Homes with open fires



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Multiple regression model using risk of illness associated with winter death, sample (n=77,762)

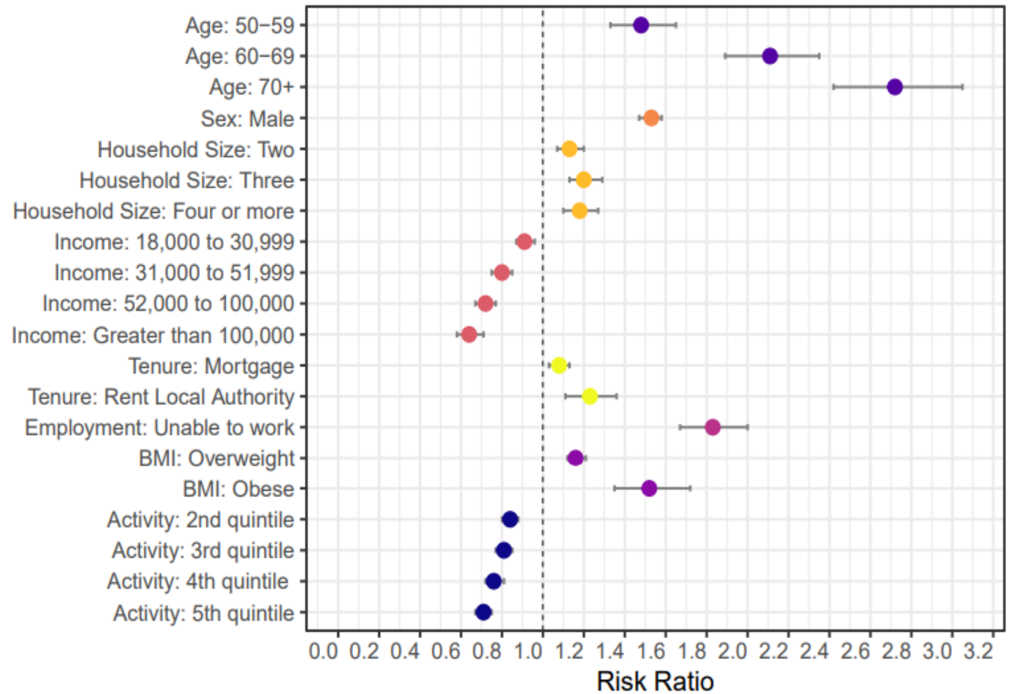
Risk increases with:

- age
- BMI
- Being male

Risk decreases with:

- activity
- Household income
- Increased thermal variety

RR = **0.95 per °C**



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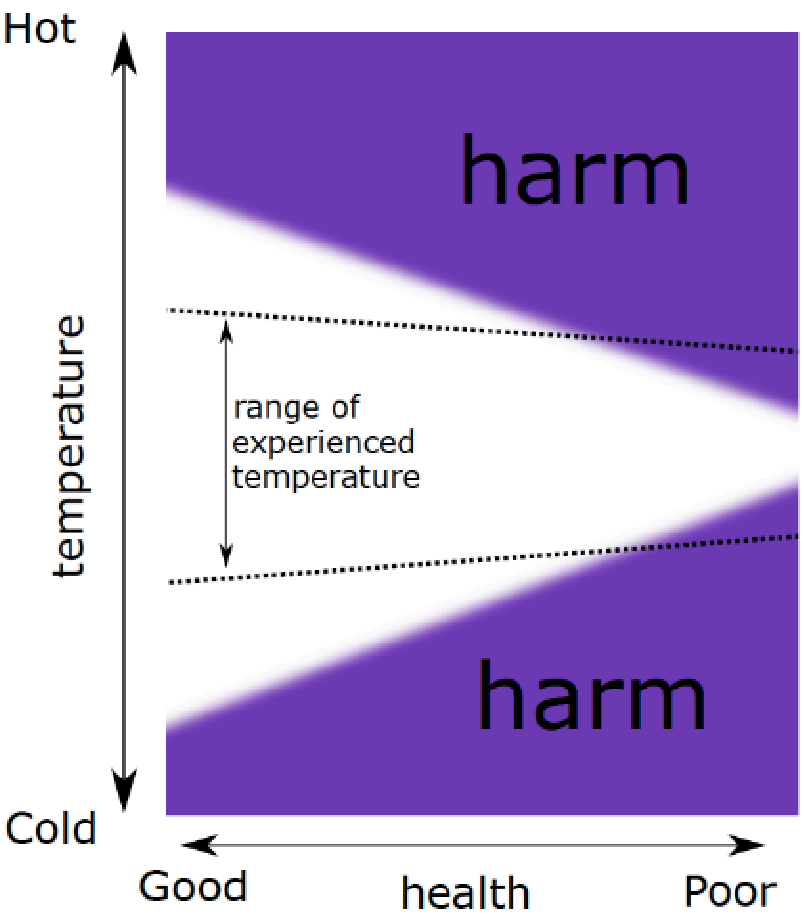
Implications

- Interpretation of the results is challenging.
- Could point to a narrowing of ambient temperature experienced as health becomes poor, but no causal claims possible (yet!).



What could this mean for energy use?

- Static temperatures may not be desirable from a health perspective.

- There's a tension between comfort provision and thermal health. Mildly stressing thermoregulatory system in proportion to health might be best approach.

- This could signal a move away from isothermal heating conditions and a reduction in energy demand.

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QUANTIFYING IN-USE THERMAL PERFORMANCE OF UK HOMES

Matthew Li (2nd year PhD, LU)

Supervisors: Dr David Allinson (LU), Prof Kevin Lomas (LU)

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UK greenhouse gas emissions by end-use

Business, 30%

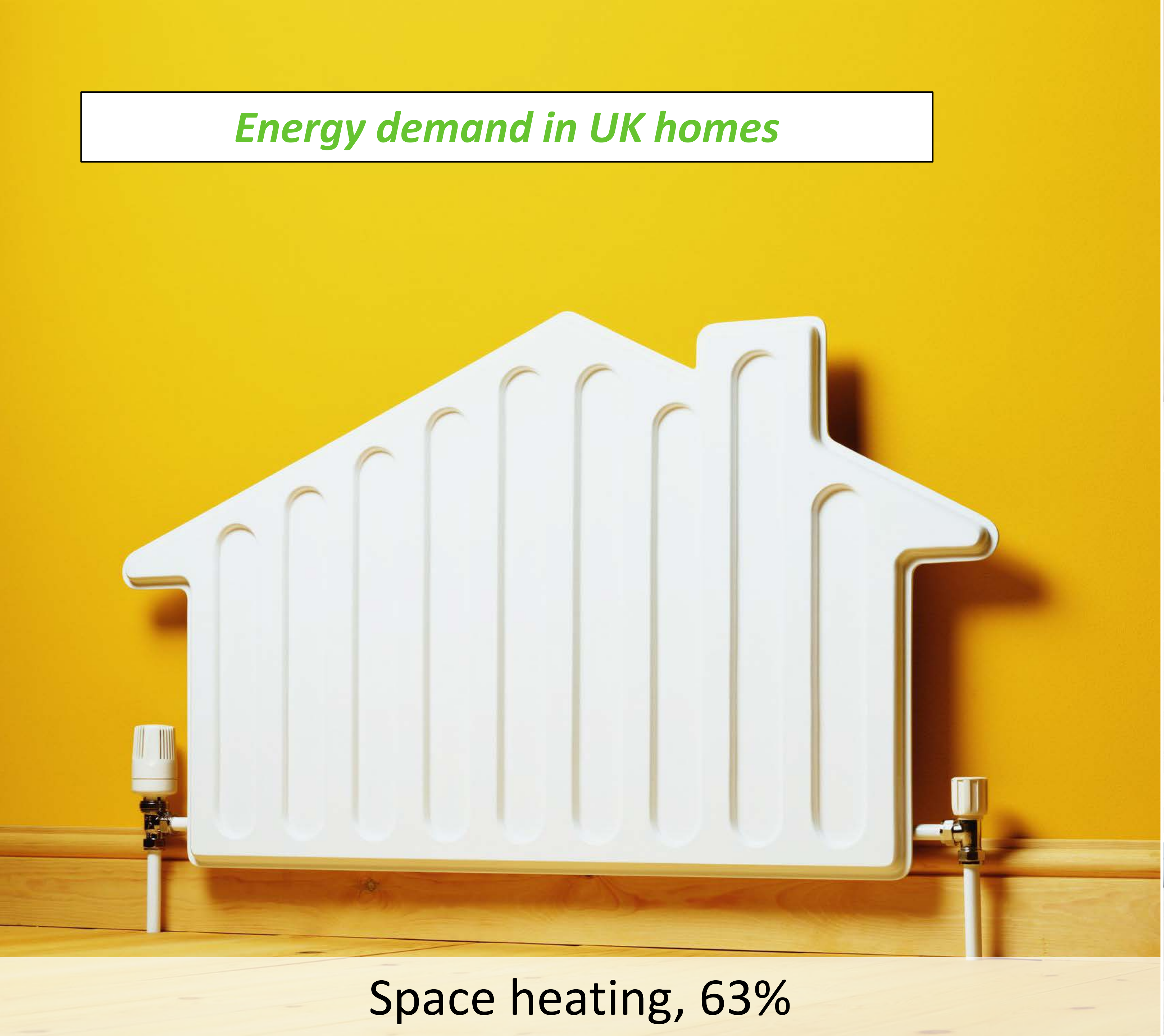
Homes, 23%

Agriculture, 10%

Other, 10%

Transport, 27%

Energy demand in UK homes

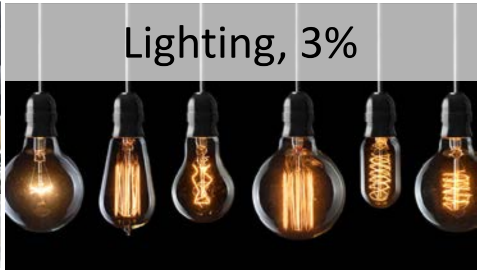


Space heating, 63%

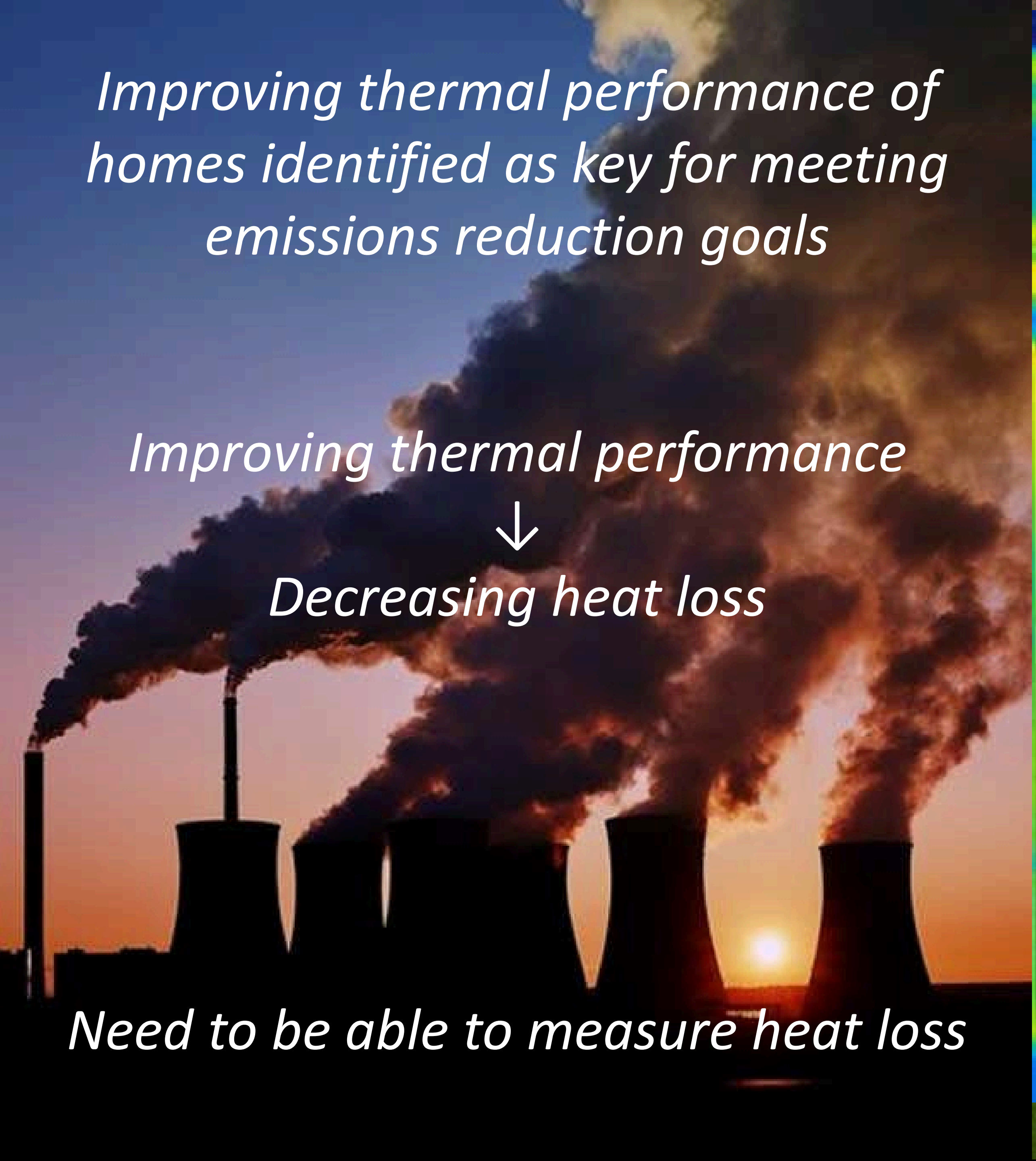
Water heating, 17%

Appliances, 13%

Cooking, 3%



Lighting, 3%



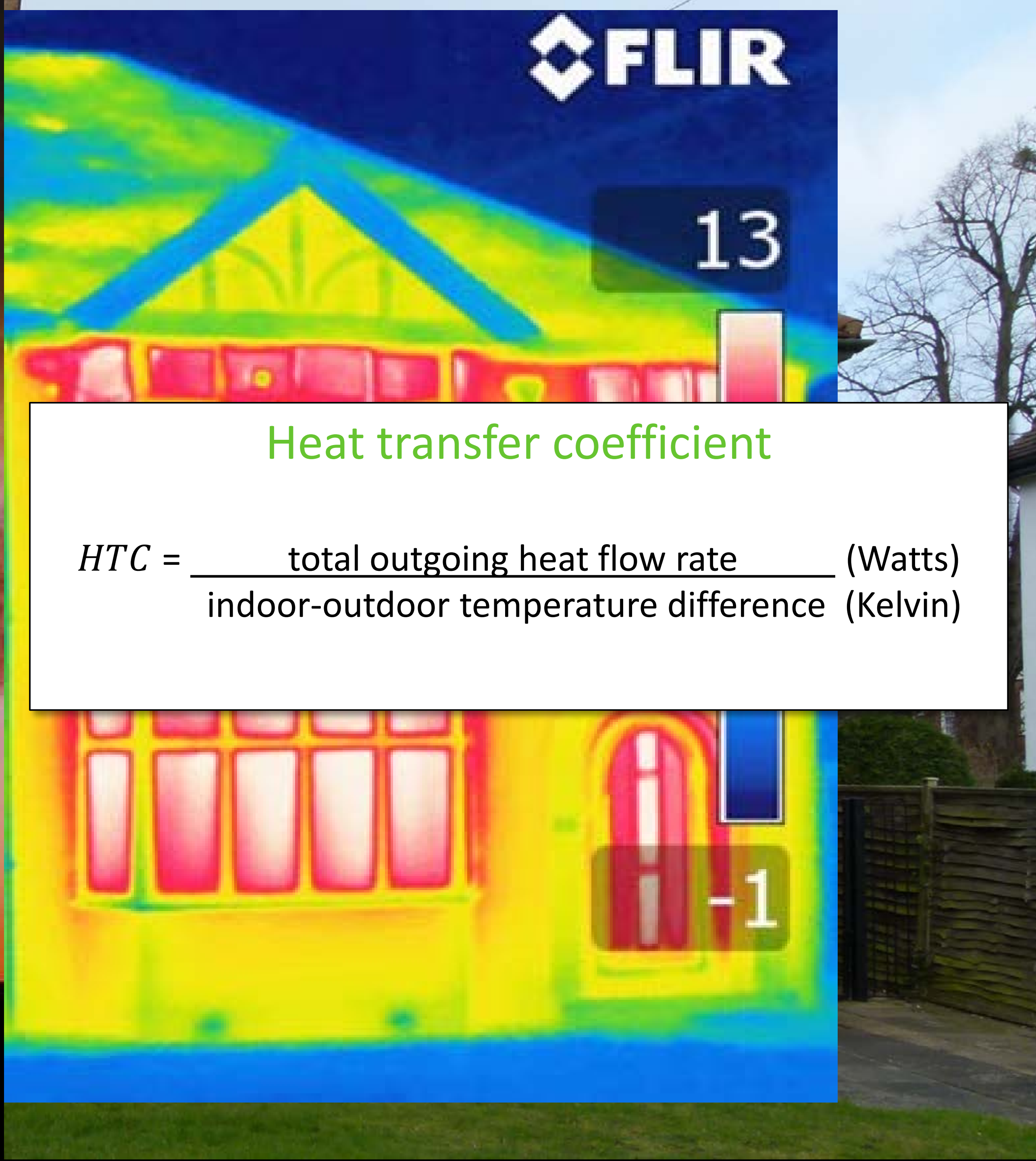
Improving thermal performance of homes identified as key for meeting emissions reduction goals

Improving thermal performance

↓

Decreasing heat loss

Need to be able to measure heat loss

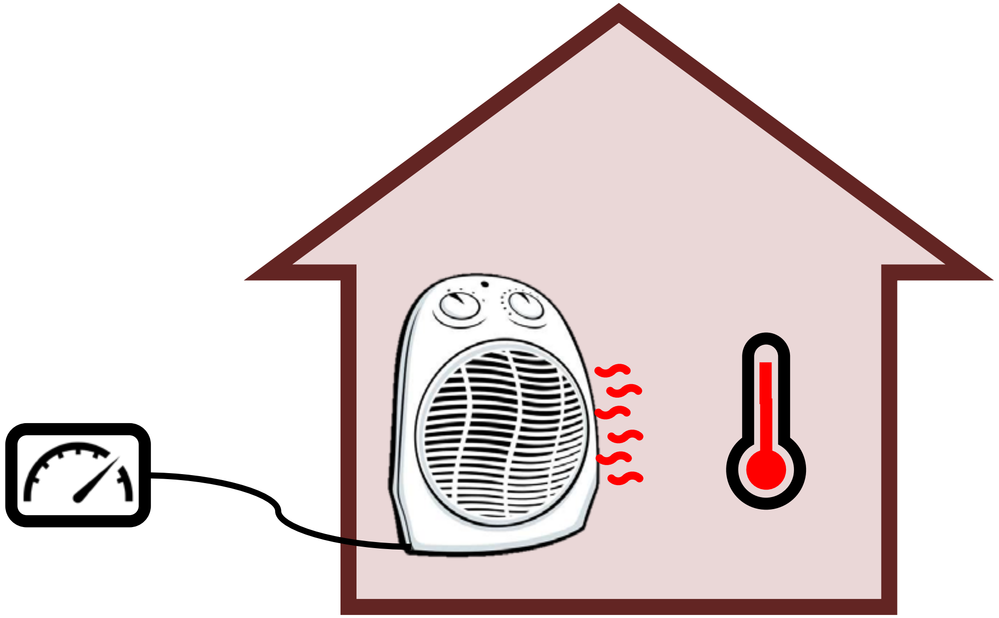


Heat transfer coefficient

$$HTC = \frac{\text{total outgoing heat flow rate}}{\text{indoor-outdoor temperature difference}} \quad \frac{(\text{Watts})}{(\text{Kelvin})}$$

Measuring the HTC: coheating test

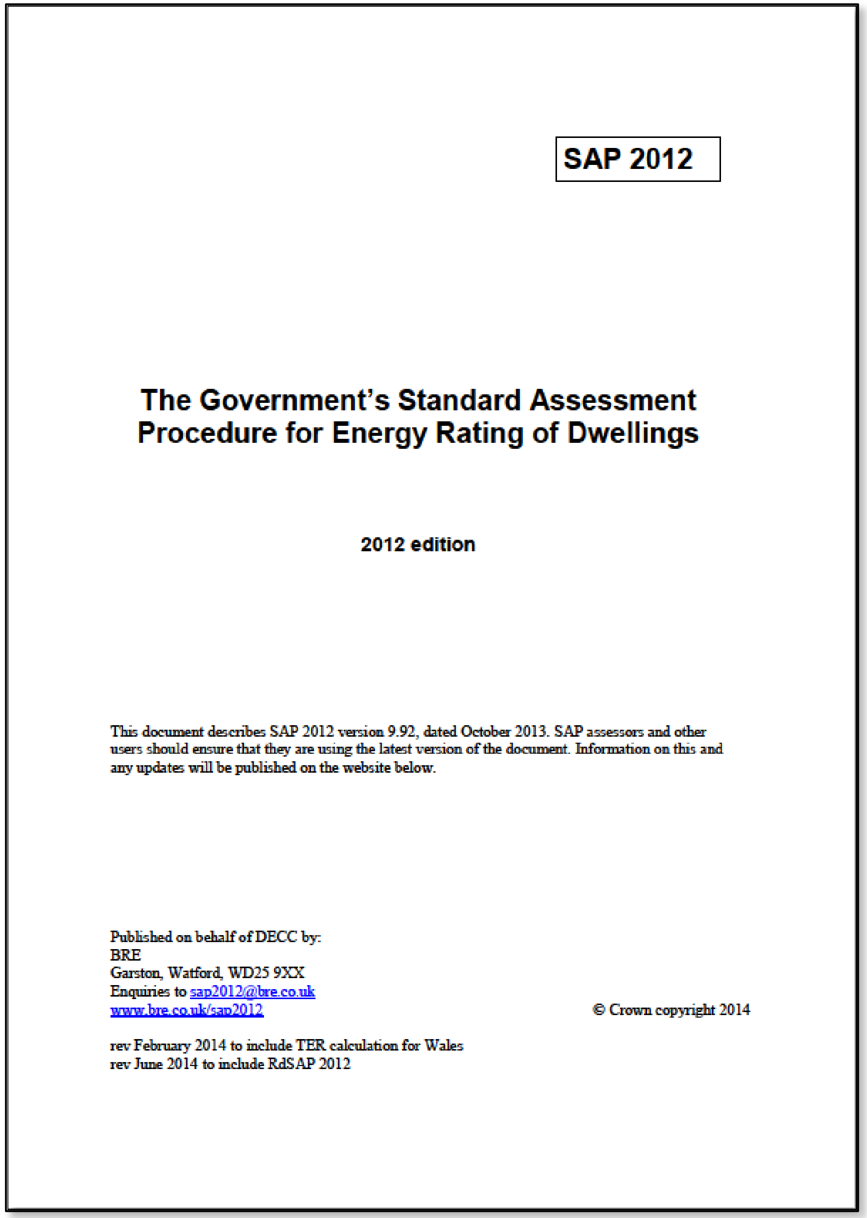
Uses electric heaters to maintain a fixed internal temperature (typically 25°C) in an **empty home**.



- Can be accurate to within ±10%
- Expensive & energy intensive
- Must be conducted during winter
- House must be empty for ~3 weeks

Jack et. al (2017) First evidence for the reliability of building co-heating tests. *Building Research & Information*, 46:4, 383-401

Predicting dwelling performance



SAP 2012

The Government's Standard Assessment Procedure for Energy Rating of Dwellings

2012 edition

This document describes SAP 2012 version 9.92, dated October 2013. SAP assessors and other users should ensure that they are using the latest version of the document. Information on this and any updates will be published on the website below.

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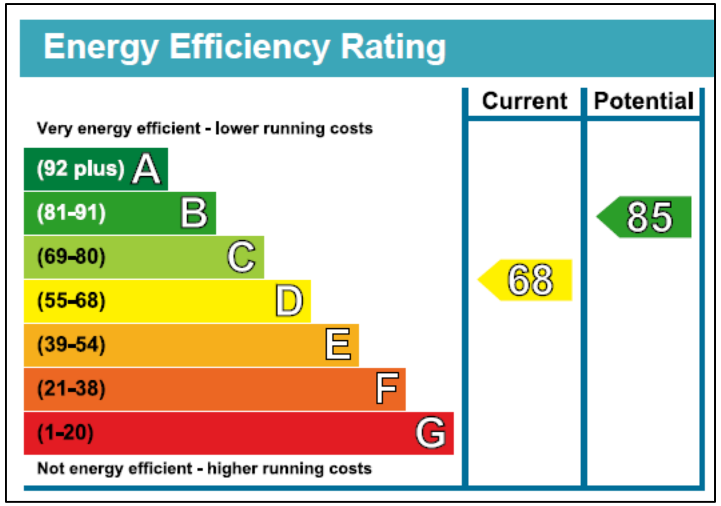
rev February 2014 to include TER calculation for Wales
rev June 2014 to include RdSAP 2012

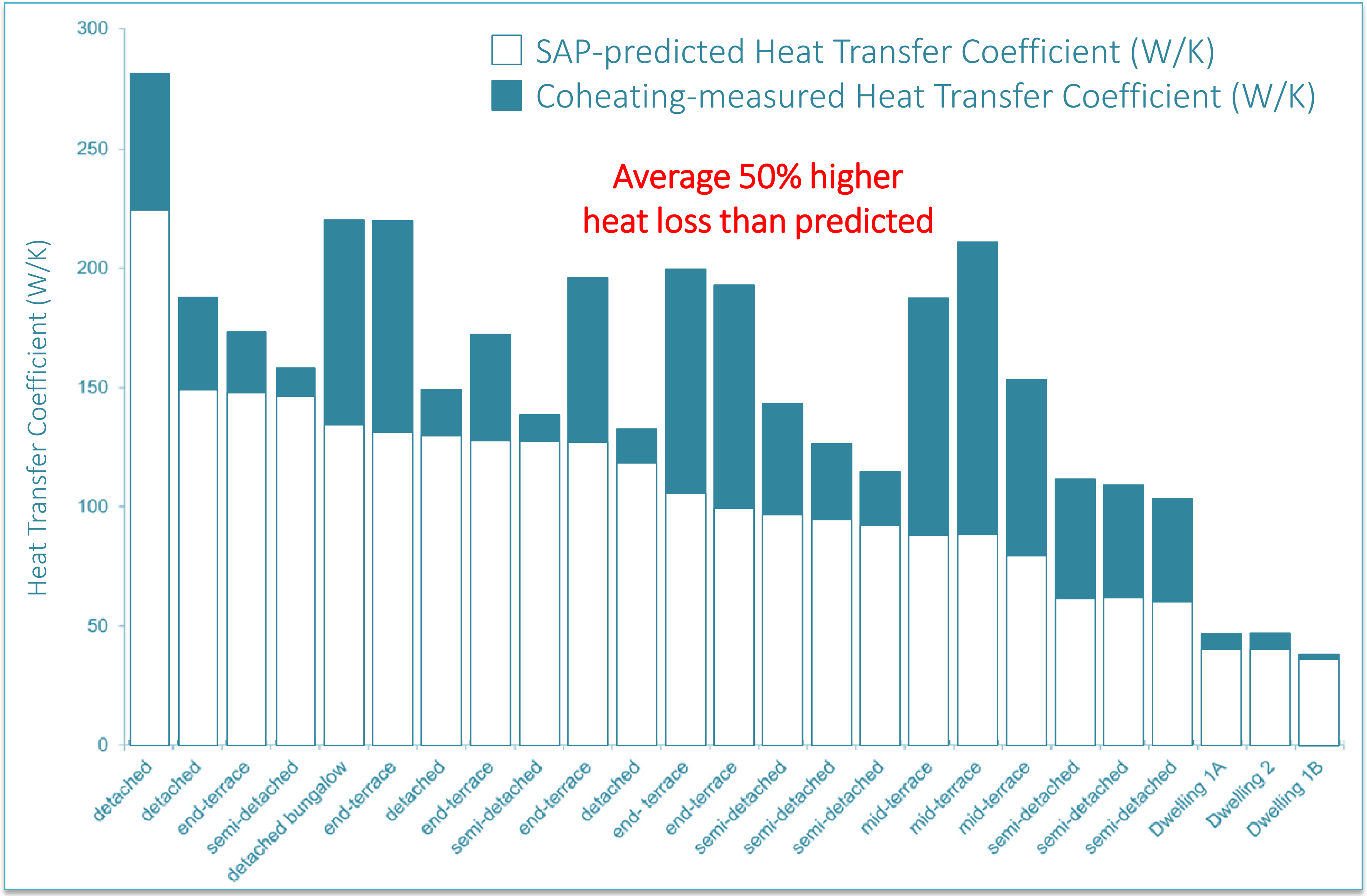
Estimated energy costs of this home

	Current costs
Lighting	£ 123 over 3 years
Heating	£ 1,371 over 3 years
Hot Water	£ 267 over 3 years
Totals	£ 1,761



Thermal performance can be predicted using the UK Standard Assessment Procedure (SAP)

The fabric thermal performance gap



Adapted from Johnston et al (2016) Bridging the building fabric performance gap. *Building Research & Information* 44, 147-159

Thermal performance can be predicted using the UK Standard Assessment Procedure (SAP)

Whenever the HTC has been measured by coheating, it has exceeded predicted heat losses.

Q: Is this the case across the UK domestic stock?

Q: Is there a way to determine the HTC of an occupied, in-use house – without moving occupants out?

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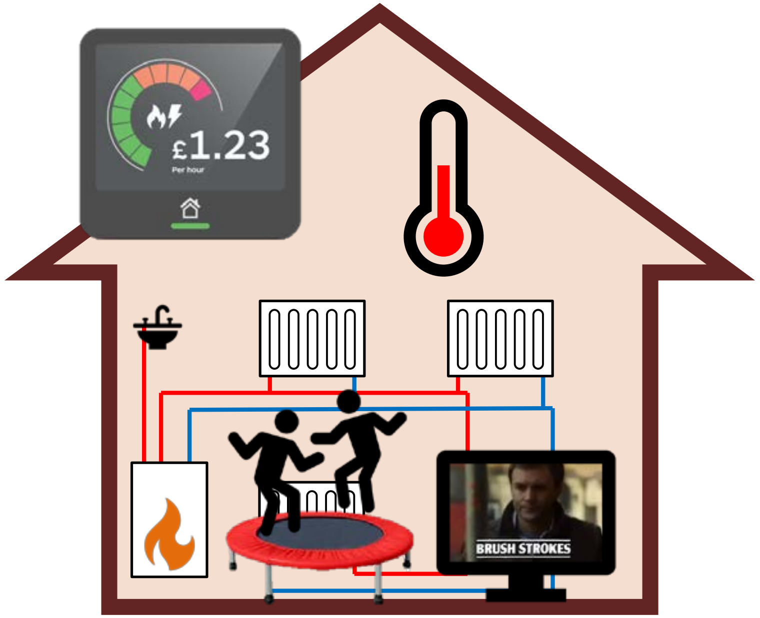
PhD project outline

Aim

To quantify the fabric thermal performance gap in UK homes **using in-use data from on-board monitoring**



Approach

Identification of potential methods for estimating the heat transfer coefficient (HTC) of an in-use house

Establishing accuracy and characterizing uncertainty through application to well-characterized case studies

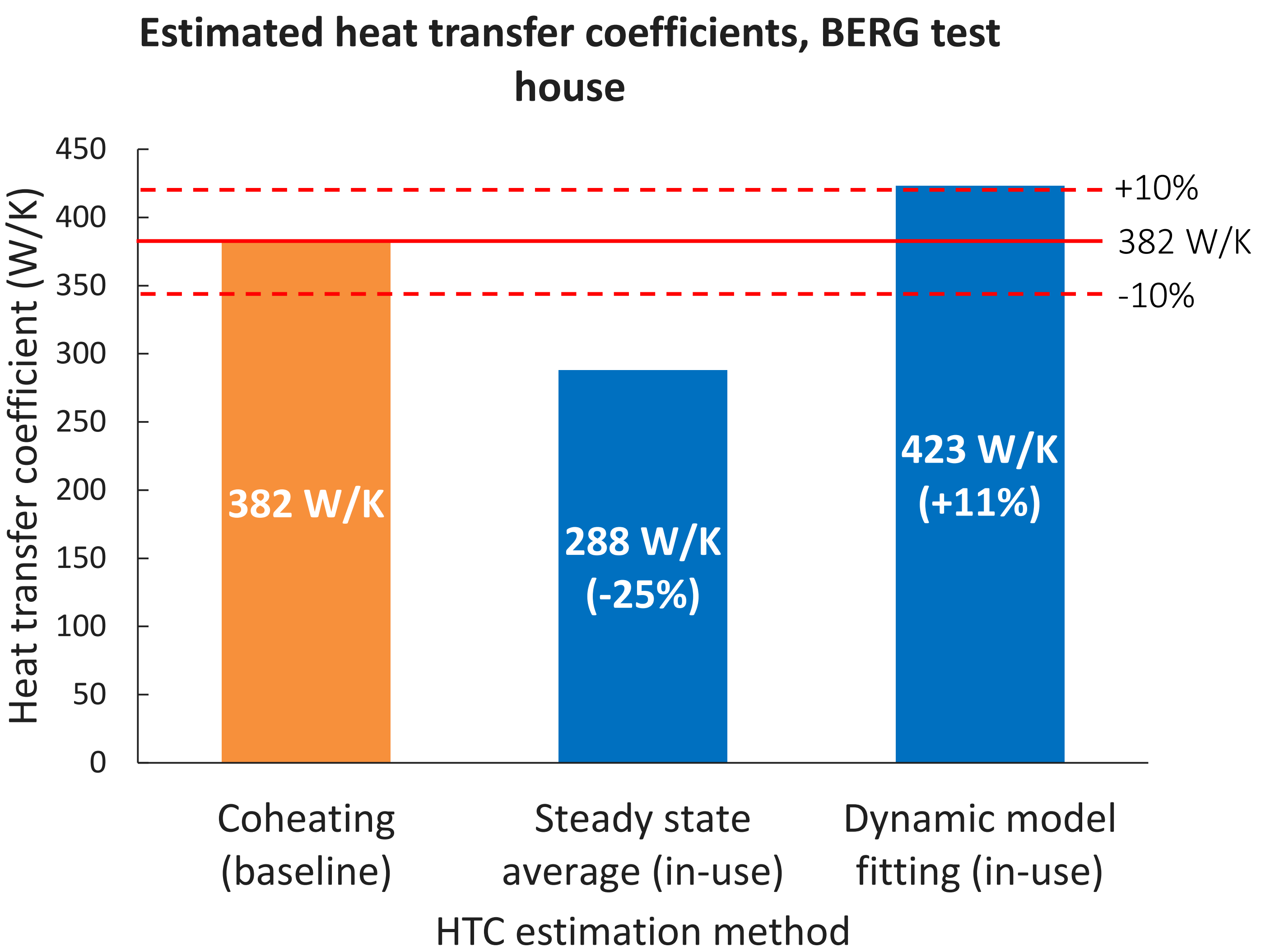
Analysis of monitored data gathered from a sample of 172 in-use UK dwellings

Findings to date

Steady-state and dynamic methods identified and applied to a case study dwelling.

BERG matched pair test houses, Loughborough
Equipped with simulated occupancy
Direct measurement of:

- Electrical power
- Central heating power
- Indoor & outdoor air temperatures



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Findings to date

Steady-state average method applied to data from 172 semi-detached homes in the UK Midlands.

Half-hourly data for:

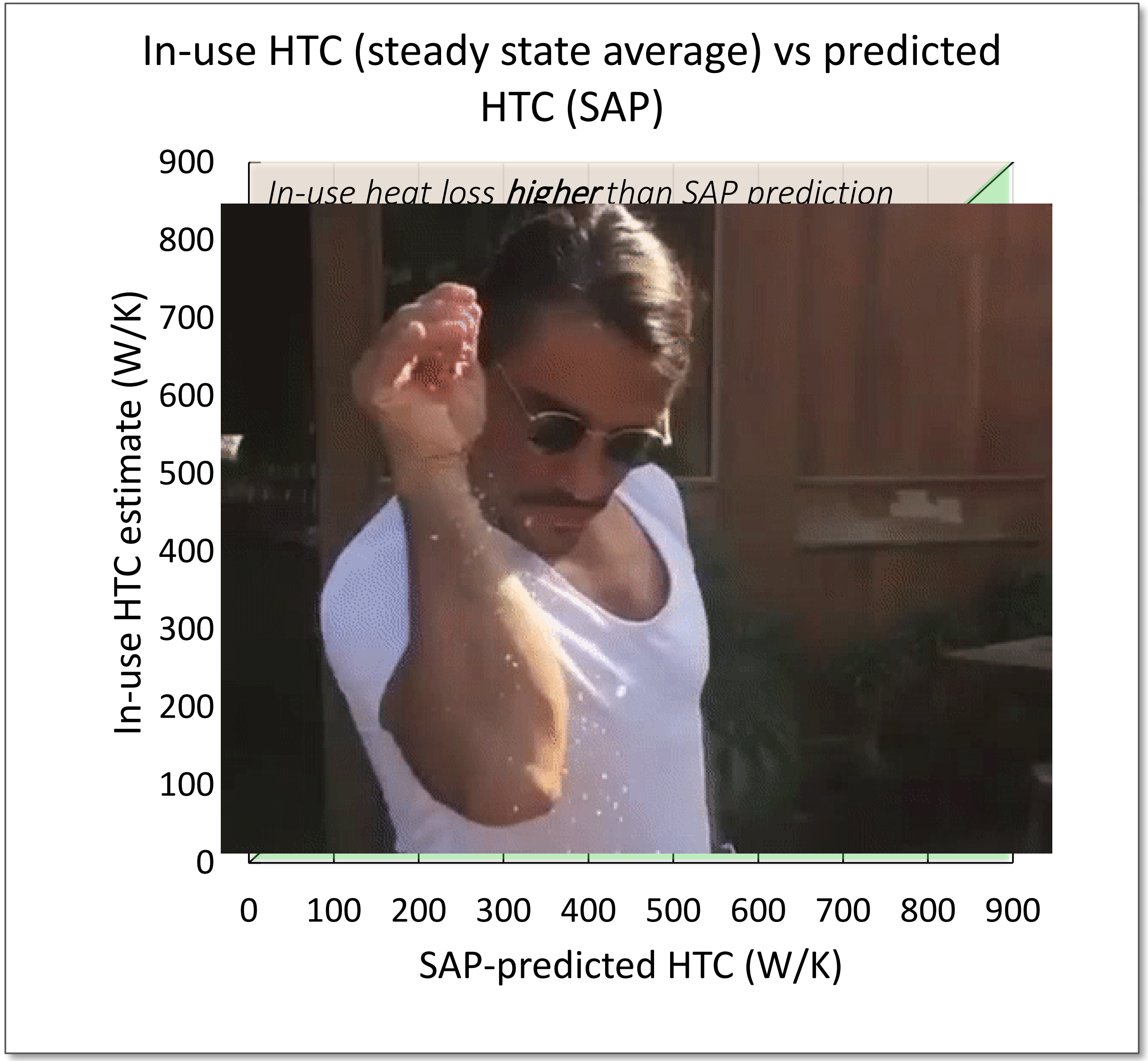
- Electrical energy demand (kWh)
- Gas demand (m^3)
- Indoor air temperature (°C, multiple rooms)

Additional data:

- Outdoor temperature and solar radiation from Met Office weather stations
- Predicted HTC calculated using UK SAP method

Early and incomplete analysis to be taken with large pinch of salt!

This method underestimated the HTC by 25% in previous case study



Next steps

- To have confidence in the results, we need to understand the uncertainty in the methods applied
- To characterize this uncertainty, data representing the diversity of UK homes is required (rather than just one case study)
- The reported case study is one of the only currently available in-use datasets for a home where we know the HTC
- But collecting suitable data from a sufficient range of in-use homes is not feasible for this project
- A simulation approach is to be adopted

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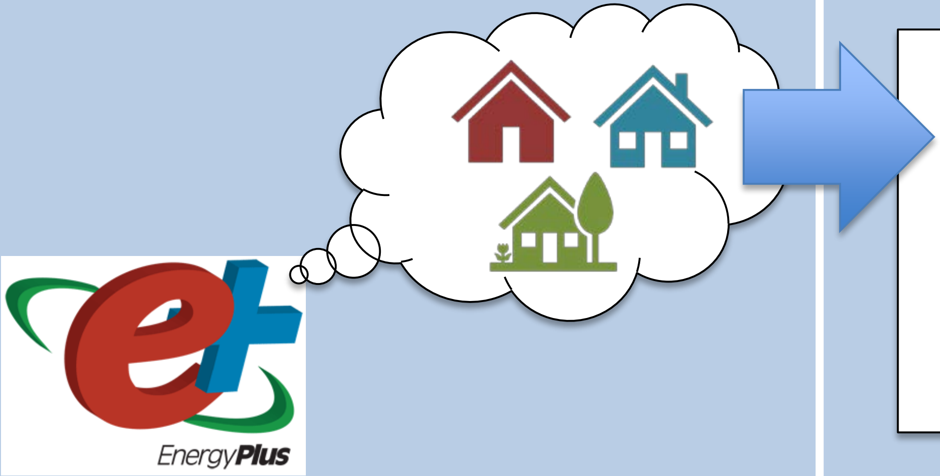
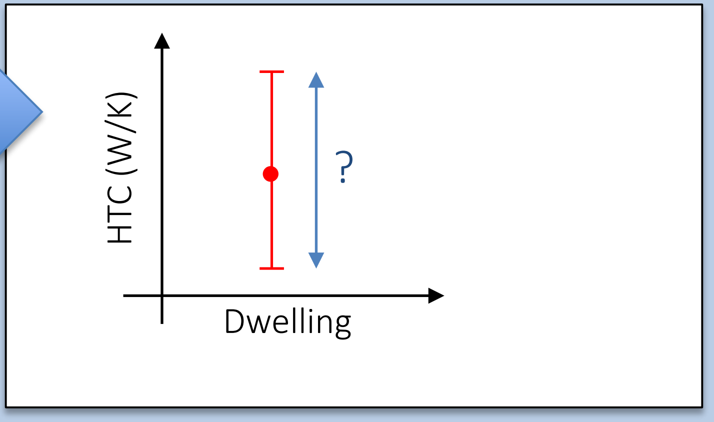
The next year

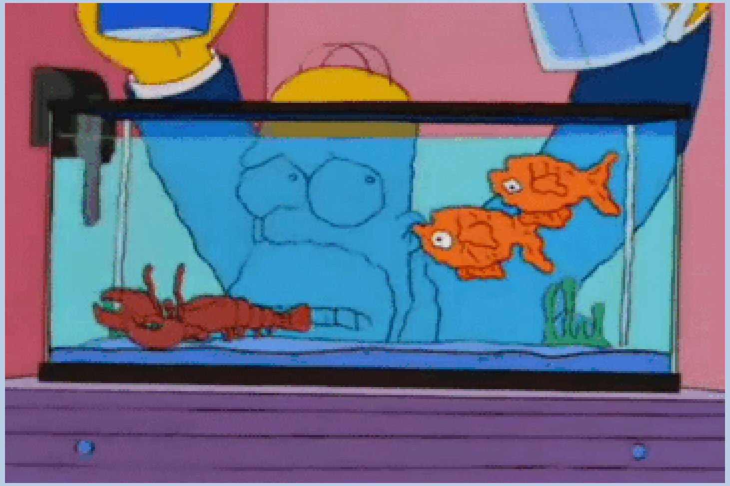
1) Generation of simulated data representing in-use homes



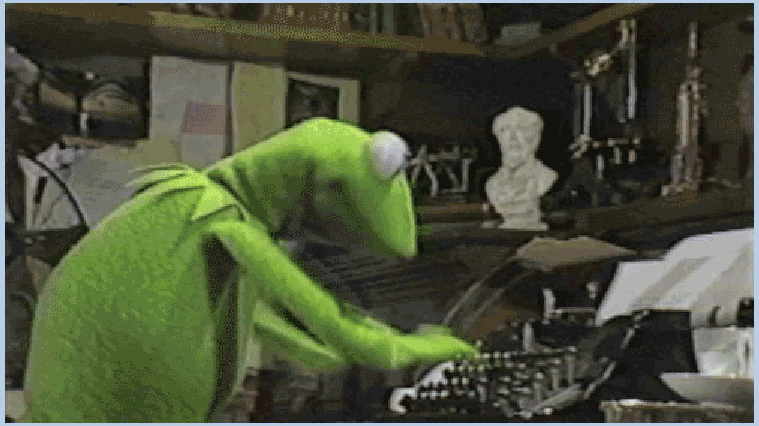
2) Characterization of uncertainty of in-use HTC estimation



3) Refining in-use HTC estimation methods



4) Analysis of in-use homes



5) Writing up

6) Final results in a poster next year!

(Potential) Insights

Industry

- Findings may aid identification of target dwellings for retrofit
- Methods may be of use in quality assurance

Academia

- Work will demonstrate a framework for evaluating in-use HTC estimation approaches
- Comparison of performance between steady state and dynamic methods

Policy

- Adding value to present and future smart-metering
- May indicate the suitability of in-use HTC estimation for compliance testing

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Vision and leadership for a sustainable built environment

QUANTIFYING IN-USE THERMAL PERFORMANCE OF UK HOMES

Matthew Li (2nd year PhD, LU)

Supervisors: Dr David Allinson (LU), Prof Kevin Lomas (LU)

LoLo/ERBE Annual Colloquium 2019

7 November 2019

UCL · Loughborough University · EPSRC Engineering and Physical Sciences Research Council

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Loughborough
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in Energy Demand

Vision and leadership for a
sustainable built environment

HOW FLEXIBLE IS UK HOME HEATING?

Clare Hanmer

Supervisors: D Shipworth, M Shipworth, C Johnson

Industry partner: PassivSystems Ltd

LoLo/ERBE Annual Colloquium 2019

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UCL
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EPSRC Engineering and Physical Sciences Research Council

Introduction: transition to low carbon heating in the UK

- 90% of UK homes have central heating with fossil fuel boiler, most supplied by natural gas
- Heating typically operated intermittently, current gas demand shows clear peaks morning and evening
- Electric heat pumps likely to play a major role in decarbonisation.
  - Efficient when run for long periods at steady, low temperature outputs (contrast with customary boiler operation)
- Requirement for flexible demand to move heating energy consumption away from peak electricity demand periods:
  - Heating ahead of demand periods
  - Algorithmic smart control
  - Disconnect between when heat source operates and when residents have requested warmth

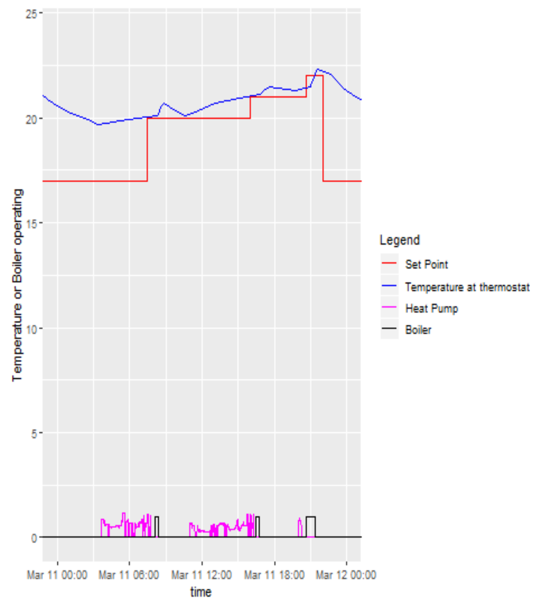
Overview of research

Research questions

- What output do households want from their heating systems?
- How do residents interact with their heating system to get their desired outputs?
- How do households react to a change in heating system characteristics?

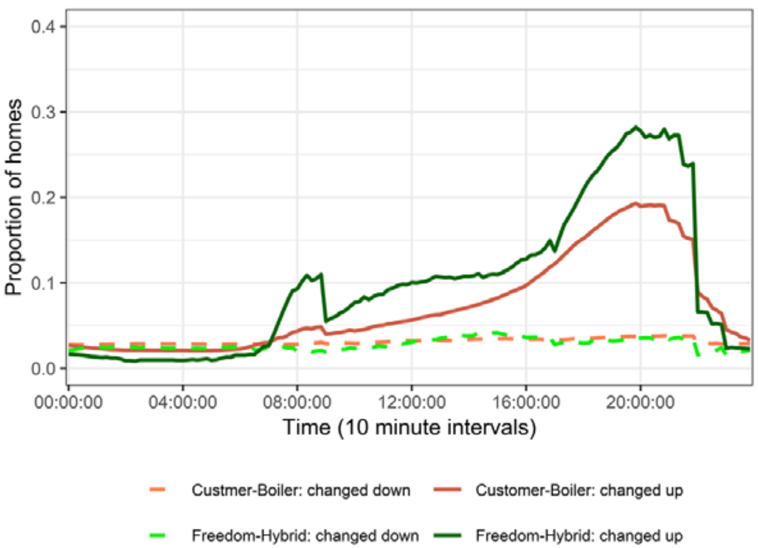
Case study

- Trial in 75 homes in Wales in 2017-2018 heating season
- 5kW/8kW air source heat pump with "combi" boiler
- Algorithm chose heat source based on price
  - lowest cost of gas boiler or electric heat pump
  - testing time shifting of electricity with ToU and carbon pricing
- Quantitative data from heating controllers in all homes in trial
- Qualitative data from 11 homes while trial was in progress



Findings

- Many households in the Freedom trial were happy with the new system
- But aspects of new running patterns unwelcome to some:
  - Disturbance at night: warmth and noise
  - Wish for direct response to requests to start / stop
- Variable temperature preferences over the day
- Importance of feeling in control
- High levels of manual operation
- Challenges of understanding



Proportion of homes with setpoint changed since beginning of heating period. Weekdays, 8 January 2018 to 2 March 2018.

Insights for industry / policy

- This research aims to inform controller / algorithm design providing a clearer picture of what people actually want from their heating system:
  - Variable temperature preferences (including for coolness)
  - Overrides for instant response
  - Information about operating patterns and contribution to network

- Some limits to flexibility were identified households which want:
  - Low temperatures at night.
  - Direct response to requests to start / stop heat source.

- Households which persist with “burst” operating patterns will not save carbon or contribute to demand management

Insights for researchers

- Investigate pattern of heating operation as well as temperature: how do residents adapt to unfamiliar patterns?
- Analysis of manual setpoint changes to investigate residents' goals
- Importance of "practical understanding" about how to operate heating
- New relationship between network and homes: ensuring cooperation from residents