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Grounding Domestic Energy Models with Empirical Data

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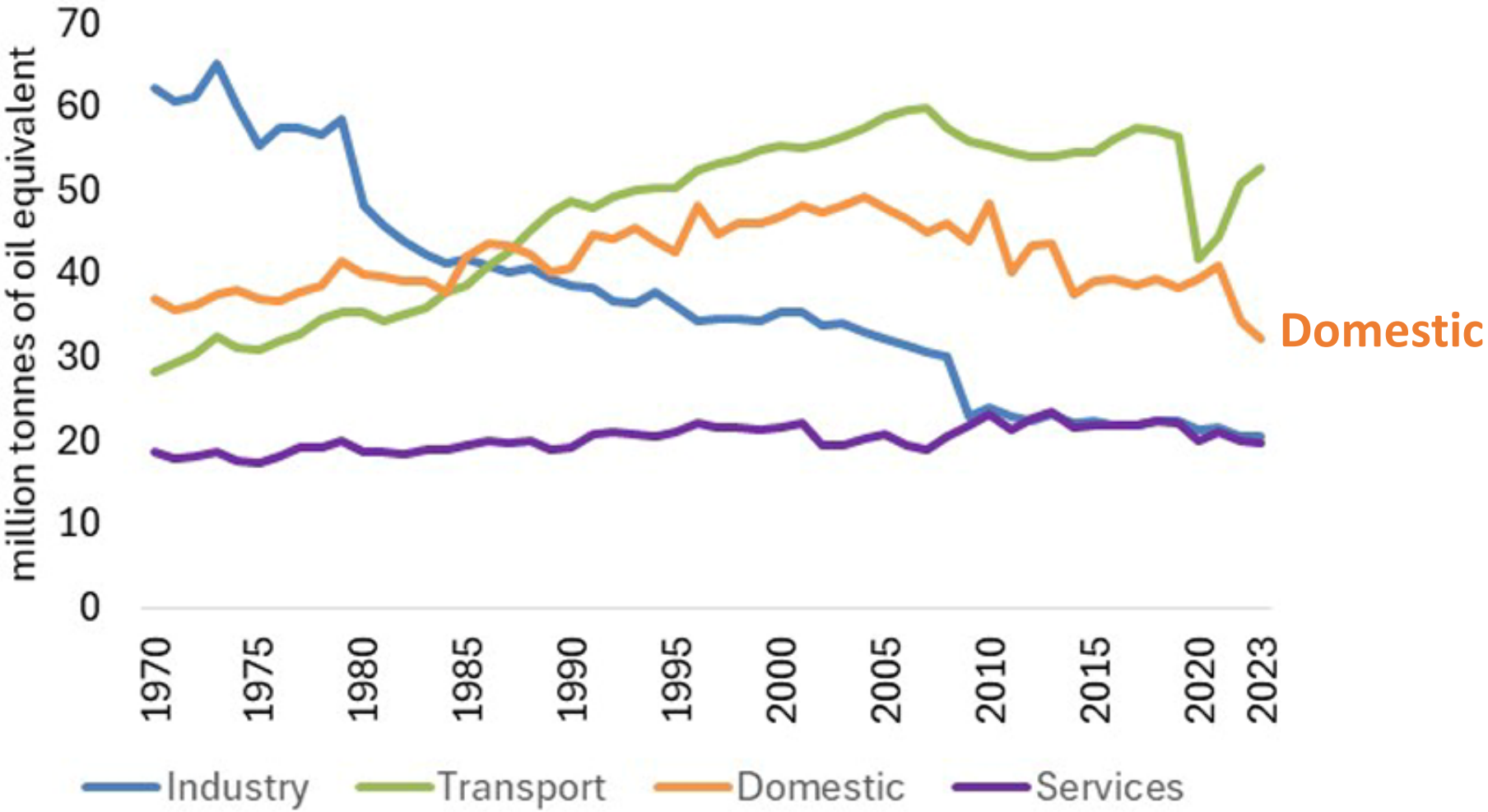
UCL Energy Institute

29th April 2025

Energy consumption by sector, 1970 to 2023 (Table C1)



DESNZ Statistical release 26 September 2024 , Energy consumption in the UK (ECUK) 1970 to 2023

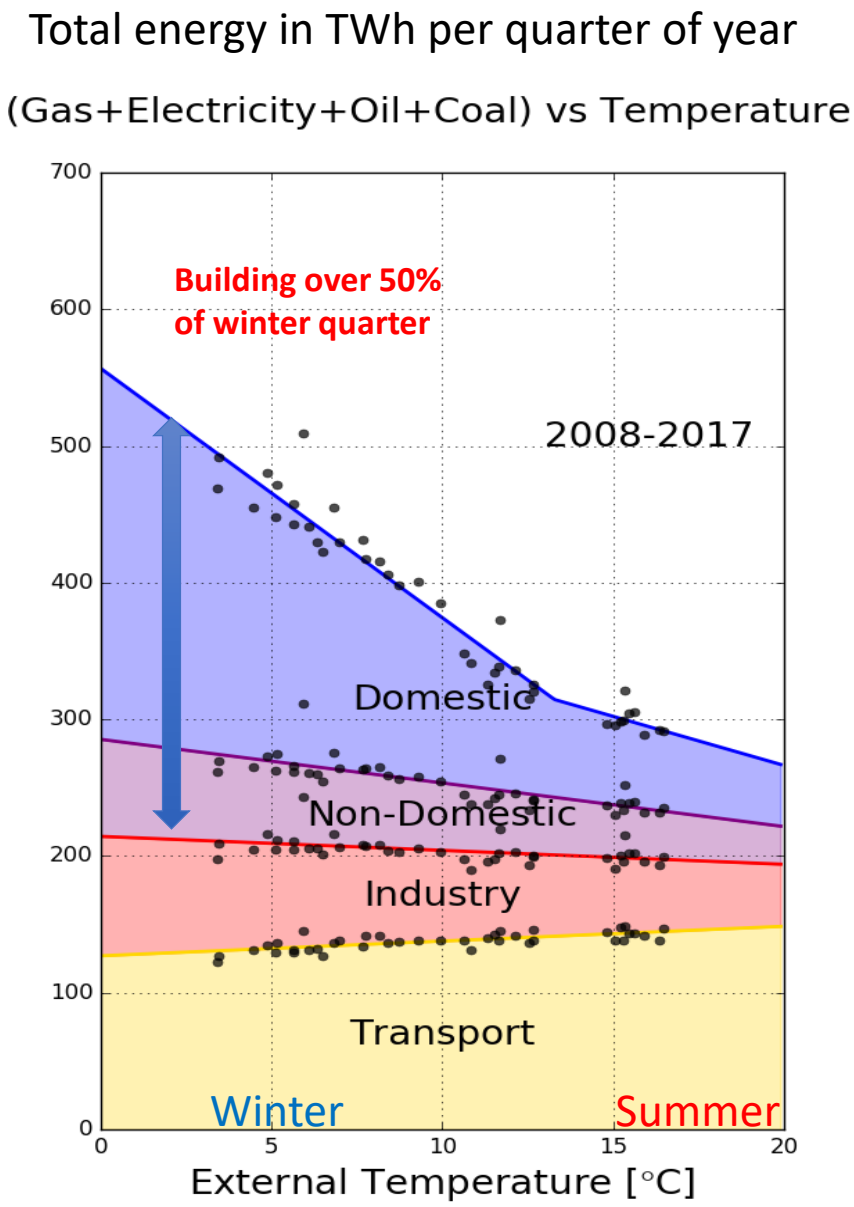
The importance of buildings: UK Energy Signature:

Domestic buildings drive UKs peak energy demand and so impact the size of the grid and storage.

Need mass deployment of 3 technologies in the UK to help achieve net zero:
1. Offshore Wind
2. EVs
3. Heat Pumps

Plus, everything more efficient, PVs storage etc

Energy Ratings (EPCs) are a key policy tool for reducing energy demand.

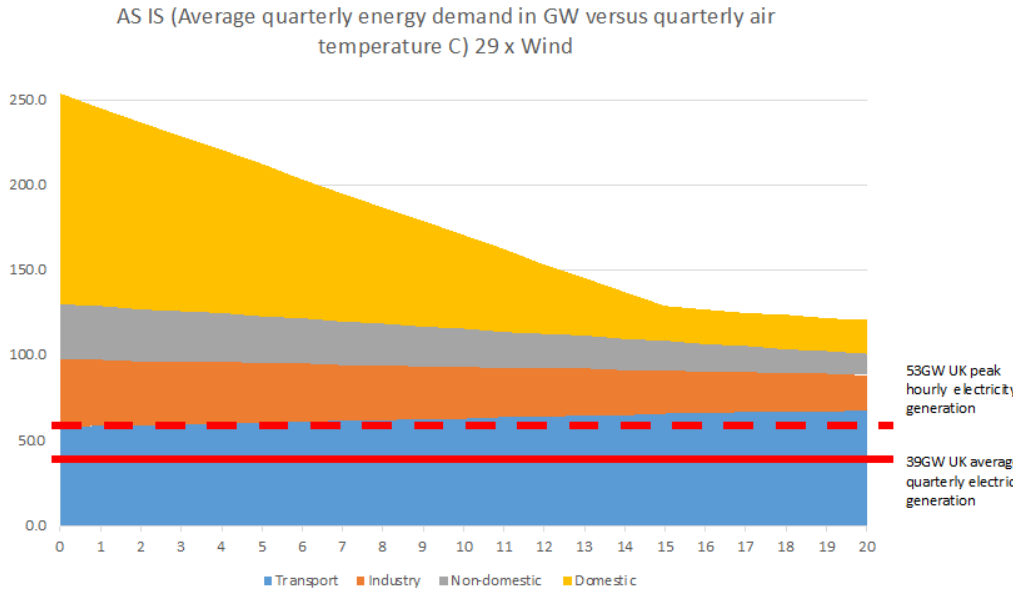


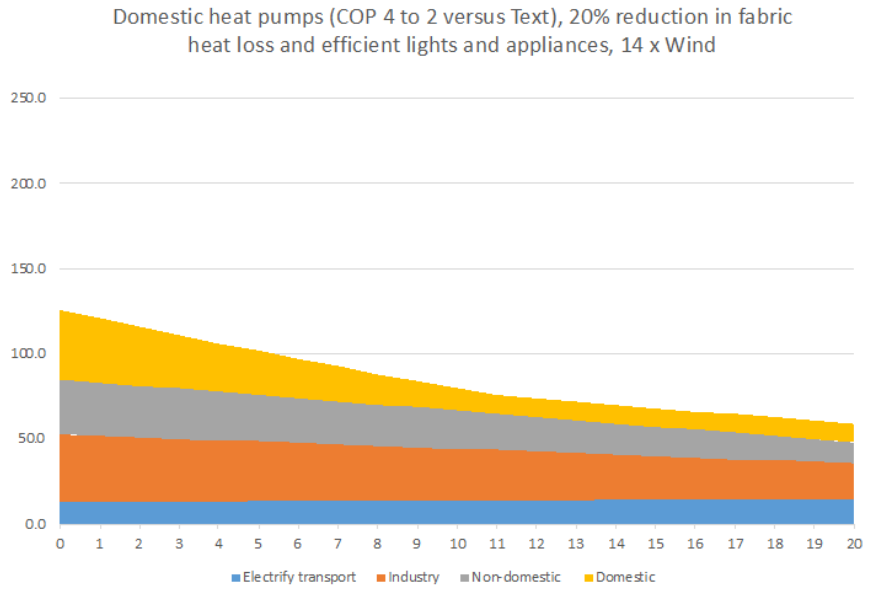
Thought experiment: What happens if we electrify all energy use?

X 29

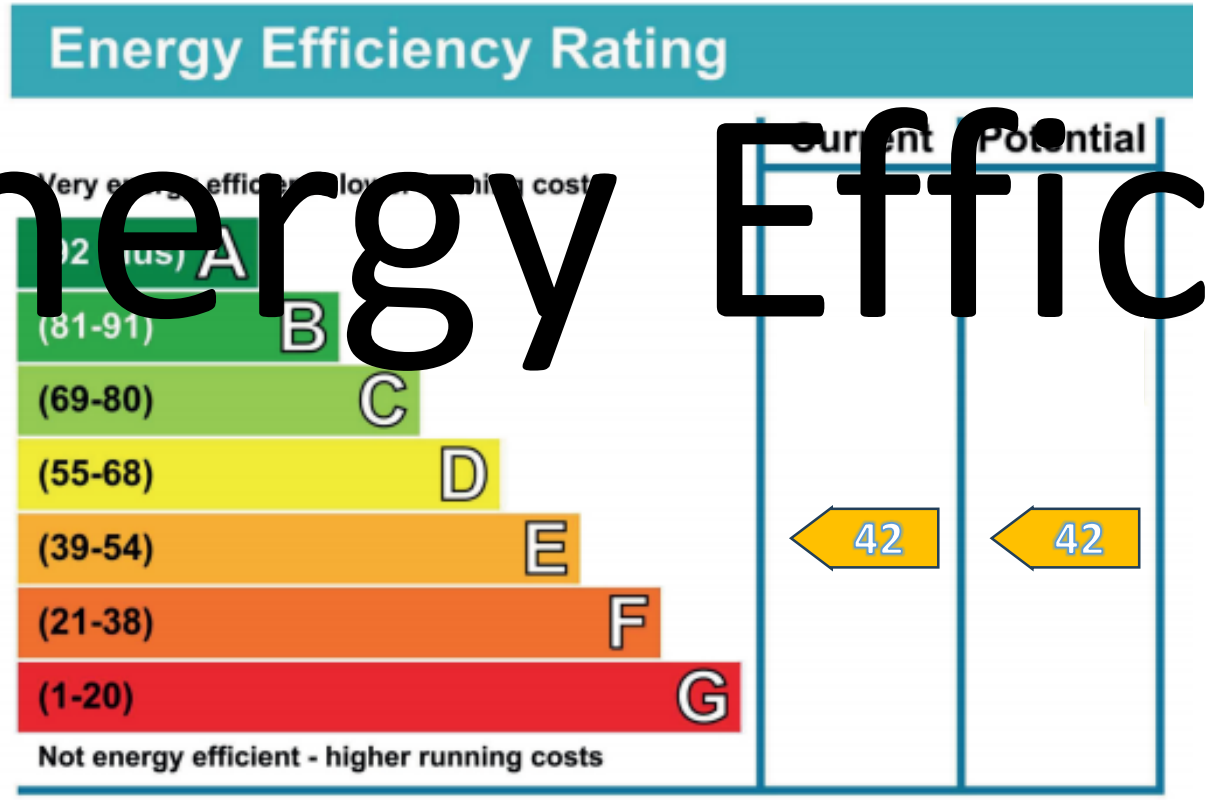
X14 +

+





I’ve just paid half a £million for a house with a SAP of 42 (EPC band –E), what is that telling me?



Energy Efficiency

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In The Hitchhiker's Guide to the Galaxy, Deep Thought is a supercomputer, built by a race of hyper-intelligent beings to calculate the Answer to the Ultimate Question of Life, the Universe, and Everything. After seven and a half million years of computation, Deep Thought finally reveals that the answer is simply:

"42"

When asked to clarify, Deep Thought explains "I think the problem, to be quite honest with you, is that you've never actually known what the question is.". To find it, you need to build an even more powerful computer, which turns out to be Earth itself.

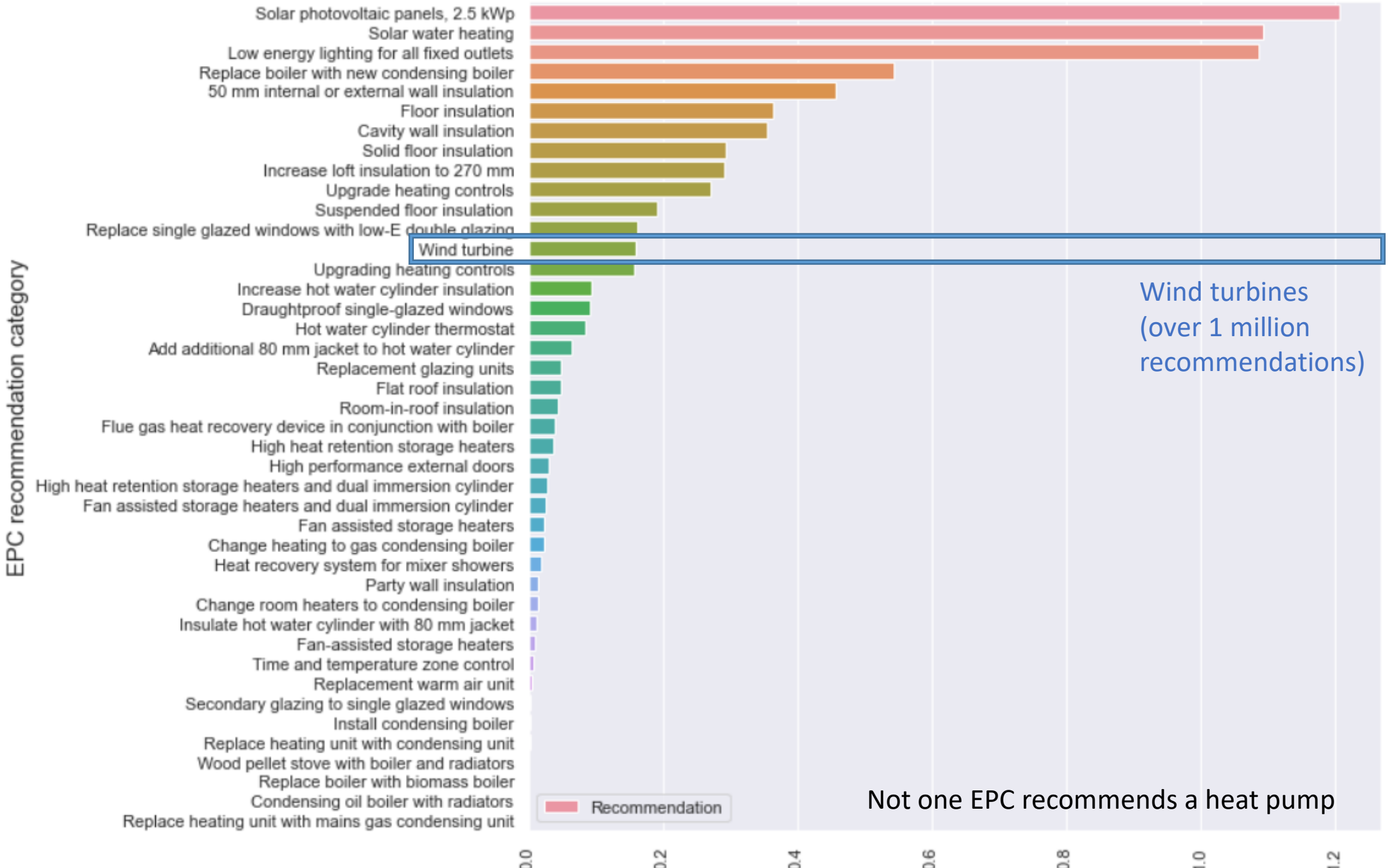
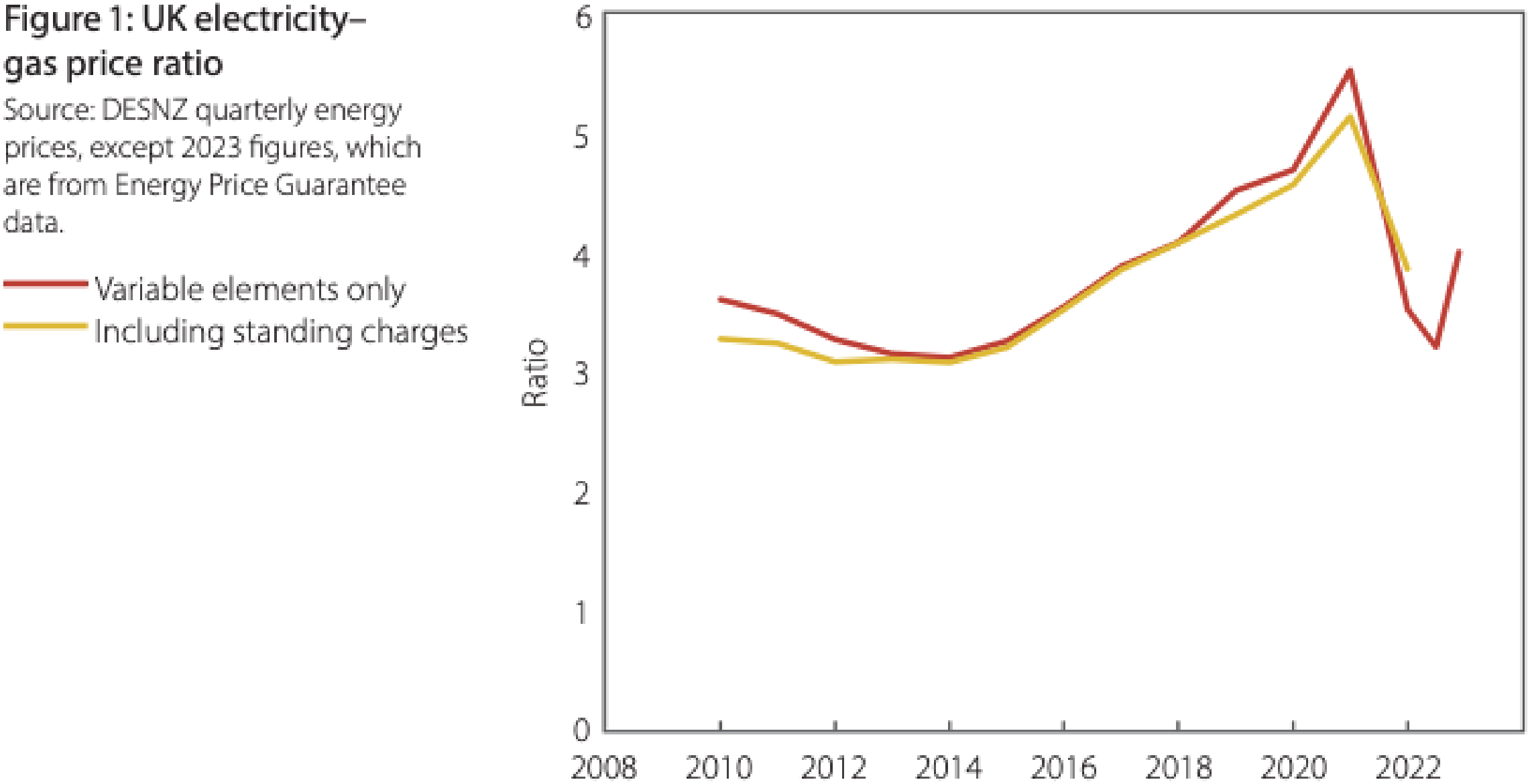

EPC recommendation category
Solar photovoltaic panels, 2.5 kWp
Solar water heating
Low energy lighting for all fixed outlets
Replace boiler with new condensing boiler
50 mm internal or external wall insulation
Floor insulation
Cavity wall insulation
Solid floor insulation
Increase loft insulation to 270 mm
Upgrade heating controls
Suspended floor insulation
Replace single glazed windows with low-E double glazing
Wind turbine
Upgrading heating controls
Increase hot water cylinder insulation
Draughtproof single-glazed windows
Hot water cylinder thermostat
Add additional 80 mm jacket to hot water cylinder
Replacement glazing units
Flat roof insulation
Room-in-roof insulation
Flue gas heat recovery device in conjunction with boiler
High heat retention storage heaters
High performance external doors
High heat retention storage heaters and dual immersion cylinder
Fan assisted storage heaters and dual immersion cylinder
Fan assisted storage heaters
Change heating to gas condensing boiler
Heat recovery system for mixer showers
Party wall insulation
Change room heaters to condensing boiler
Insulate hot water cylinder with 80 mm jacket
Fan-assisted storage heaters
Time and temperature zone control
Replacement warm air unit
Secondary glazing to single glazed windows
Install condensing boiler
Replace heating unit with condensing unit
Wood pellet stove with boiler and radiators
Replace boiler with biomass boiler
Condensing oil boiler with radiators
Replace heating unit with mains gas condensing unit
Recommendation
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Wind turbines (over 1 million recommendations)
Not one EPC recommends a heat pump

Figure 1: UK electricity–gas price ratio

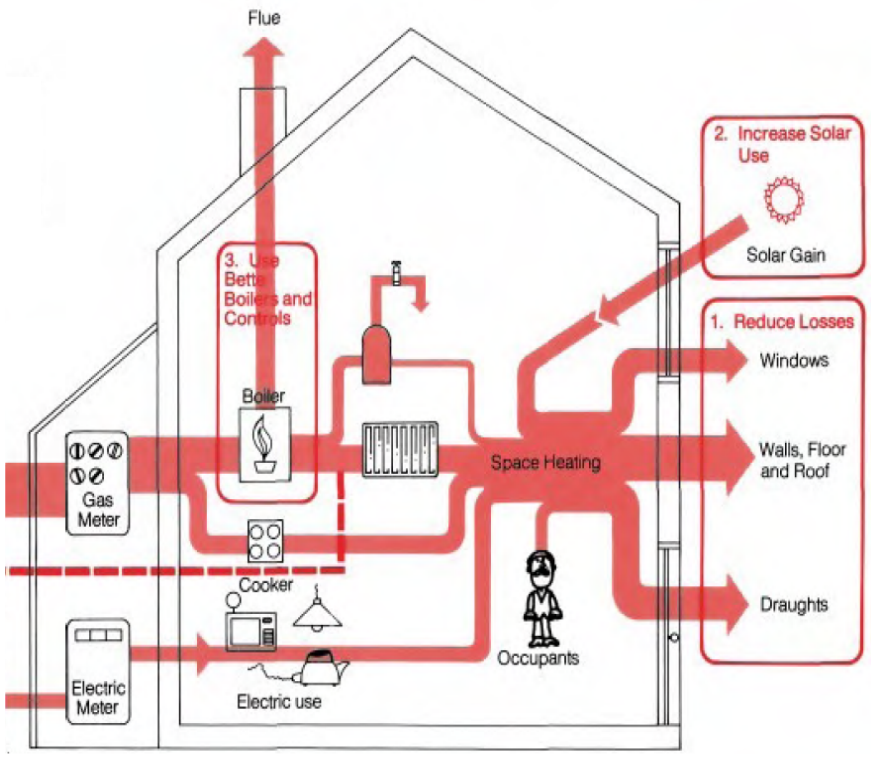
Source: DESNZ quarterly energy prices, except 2023 figures, which are from Energy Price Guarantee data.



https://www.thegwpf.org/content/uploads/2023/07/Montford-Heat-Pumps.pdf

Energy Rating: Background and History

- Almost everything has an energy rating (cars, homes, fridges, light bulbs etc)
- Building energy rating challenges:
  - not mass produced to high standards,
  - multiple uses (car gets you from A to B).
  - modelled not physical testing for design rating
- Rate the technology, not the building plus occupants
- The first energy rating is now 40 years old, Milton Keynes Energy Cost Index 1984 (used BREDEM) evolved into NHER system and then SAP/EPC
- Calibration, BRE homes, New build (Pennylands, Linford, Milton Keynes Energy Park), English Housing Survey.



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Milton Keynes Energy Cost Index (MKECI)

- Clear aims and objectives: Inform homeowners when comparing one house against another, regulate homes built in Milton Keynes.
- Metric: Not energy, but energy cost as the key performance metric – its what homeowners are interested in.
- Philosophy,
  - only model significant factors, no point knowing the window overhang to +/-10% , if you don't know the ventilation rate to +-50%.
  - Reduced data input: accuracy versus complexity.
  - Not everybody had a computer when SAP was invented?

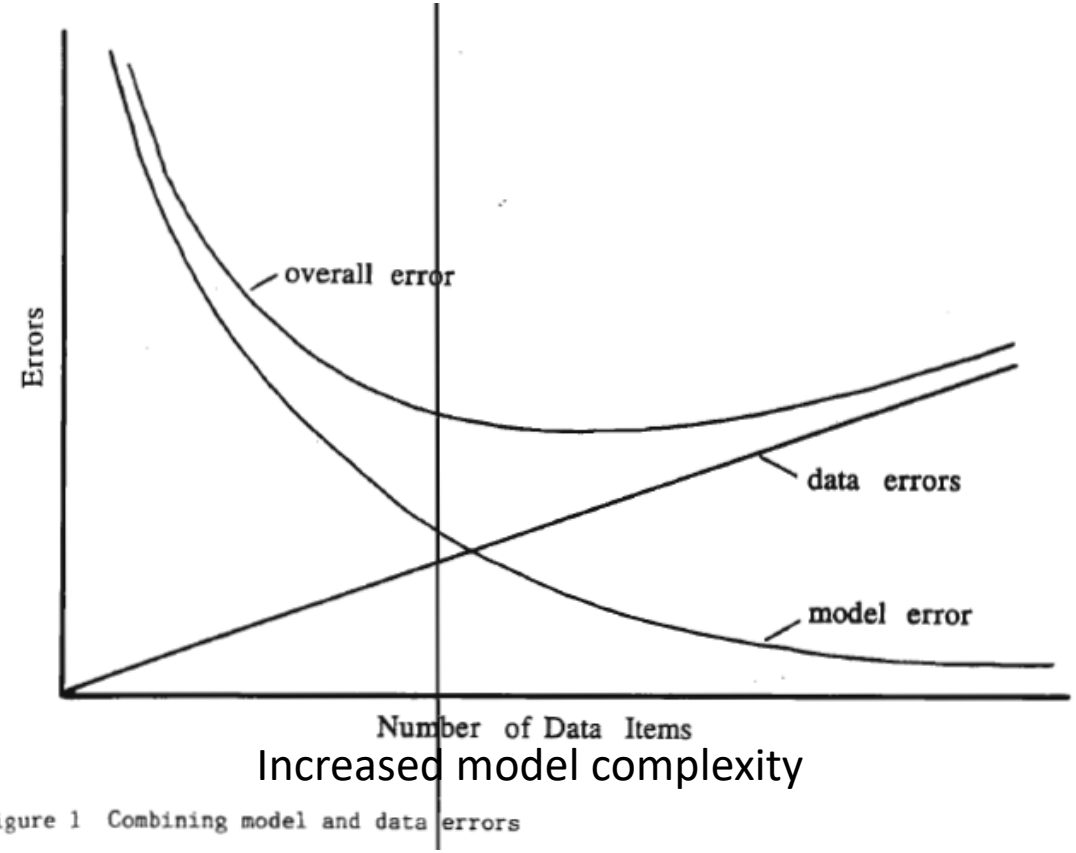

Figure 1 Combining model and data errors

Chapman, P, The Milton Keynes Energy Cost Index, Energy and Buildings 14(1990) 83-101

Chapman, J, Data Accuracy and Model Reliability, BEPAC, Canterbury Conference, 1991.

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Four decades of energy rating evolution: MKECI to SAP-10 (EPCs)

- 26 million EPCs in England and Wales (50% of homes), £billion cost of collecting the data.
- Energy Cost Index labelled as Energy Efficiency Rating (EER) – confusing – most people using EPCs think they are mostly about efficiency (A-B have PVs, F&G expensive (non-gas) heating fuel).
- Use expand beyond original objective: fuel poverty, MEES, ECO, all homes EPC C. EPCs key tool for delivering building net zero.
- Core model has evolved from variable base degree-days calculation to monthly semi-steady state calculation.
- Added complexity with more technical systems, heat pumps, etc.
- Polarised views; essential for saving the planet, concerns about accuracy. After 4 decades how accurate are EPCs?

SERL Observatory Dataset

Electricity data

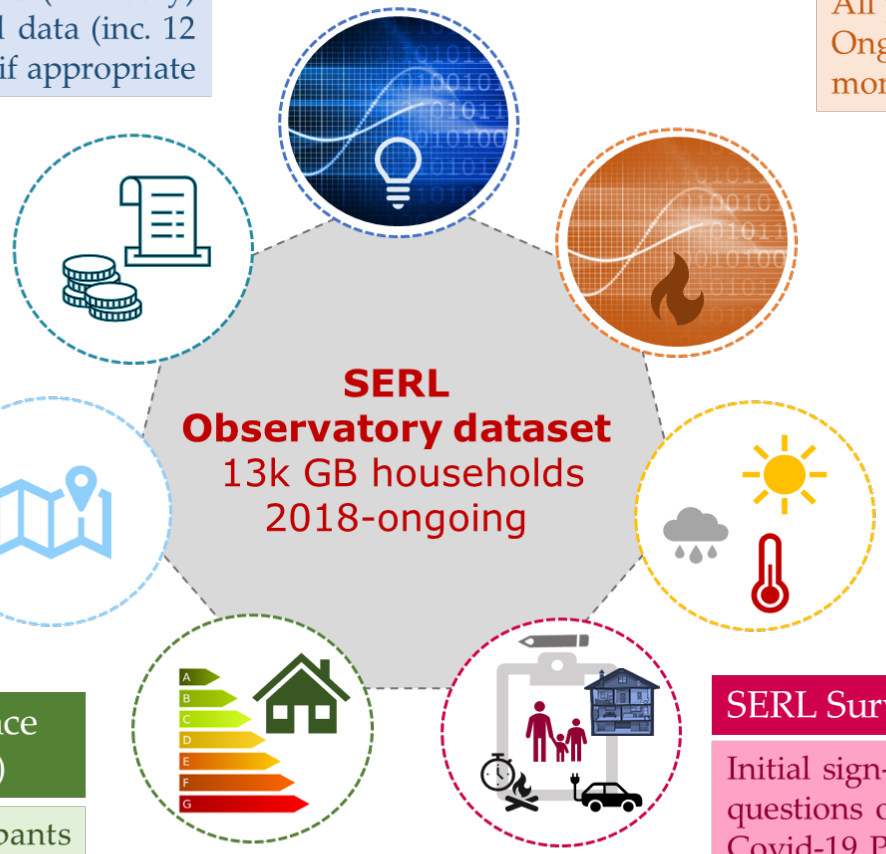
Energy data: Daily, half-hourly
All participants (in theory)
Ongoing longitudinal data (inc. 12 months historic data, if appropriate

Gas data

Energy data: Daily, half-hourly
All participants with gas meter
Ongoing longitudinal data (inc. 12 months historic data, if appropriate)

Tariff data

Unit and standing charges for electricity and gas
All participants (in theory)



Location data

Region, LSOA, IMD quintile
All participants

Weather data

ECMWF ERA5 data
Hourly longitudinal data
30km resolution
24 variables

Energy Performance Certificate (EPC)

~50% of participants
Sourced from EPC Register

SERL Surveys

Initial sign-up survey (2019-2021): 40 questions on the dwelling and household
Covid-19 Pandemic survey (2020)
Cost of living / energy costs survey (2023)

UKDS study number 8666
Data descriptor paper: Webborn *et al.* (2021)
Statistical reports: Few *et al.* (2022), Few *et al.* (2024)

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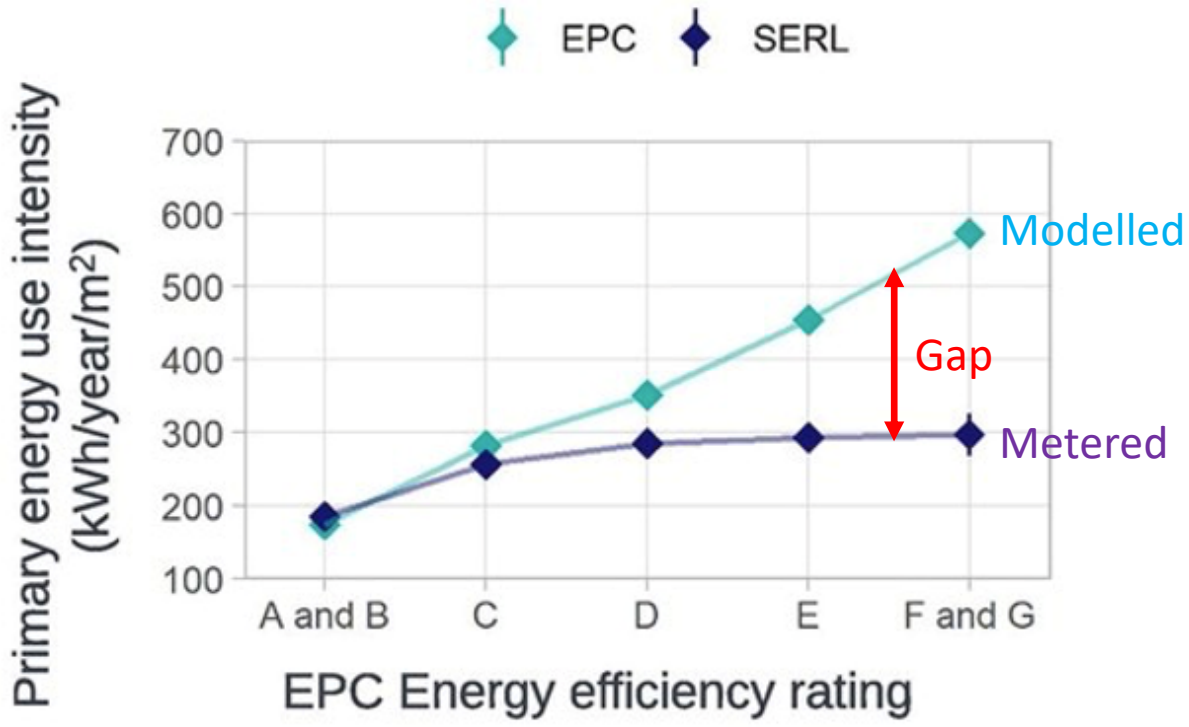
EPCs overpredict energy use

- EPC F- and G-rated homes predict 50% more energy use than metered.
- Little difference in metered energy use between bands C to G.

Note, only gas heated homes with no PV or EV.

Compare: EPC modelled energy use with metered energy use



Conclusion: EPCs increasingly overpredict energy use as EPC band worsens.

J. Few, et al, *The over-prediction of energy use by EPCs in Great Britain: A comparison of EPC modelled and metered primary energy use intensity*, Energy & Buildings (2023), doi: https://doi.org/10.1016/ j.enbuild.2023.113024

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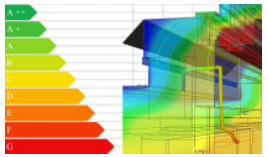
Whose gap?



•The **building physicist** who developed the wrong core model

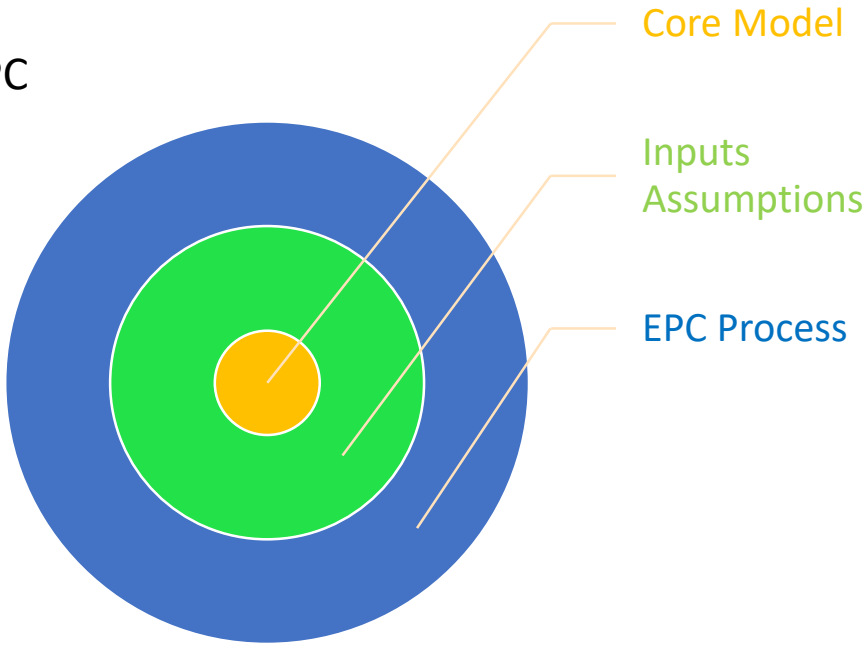
•The **government** who set the method for implementation, and EPC metrics, and defaults

•The **EPC assessor** who made errors

•Energy efficiency **installers** who did not install the technology properly

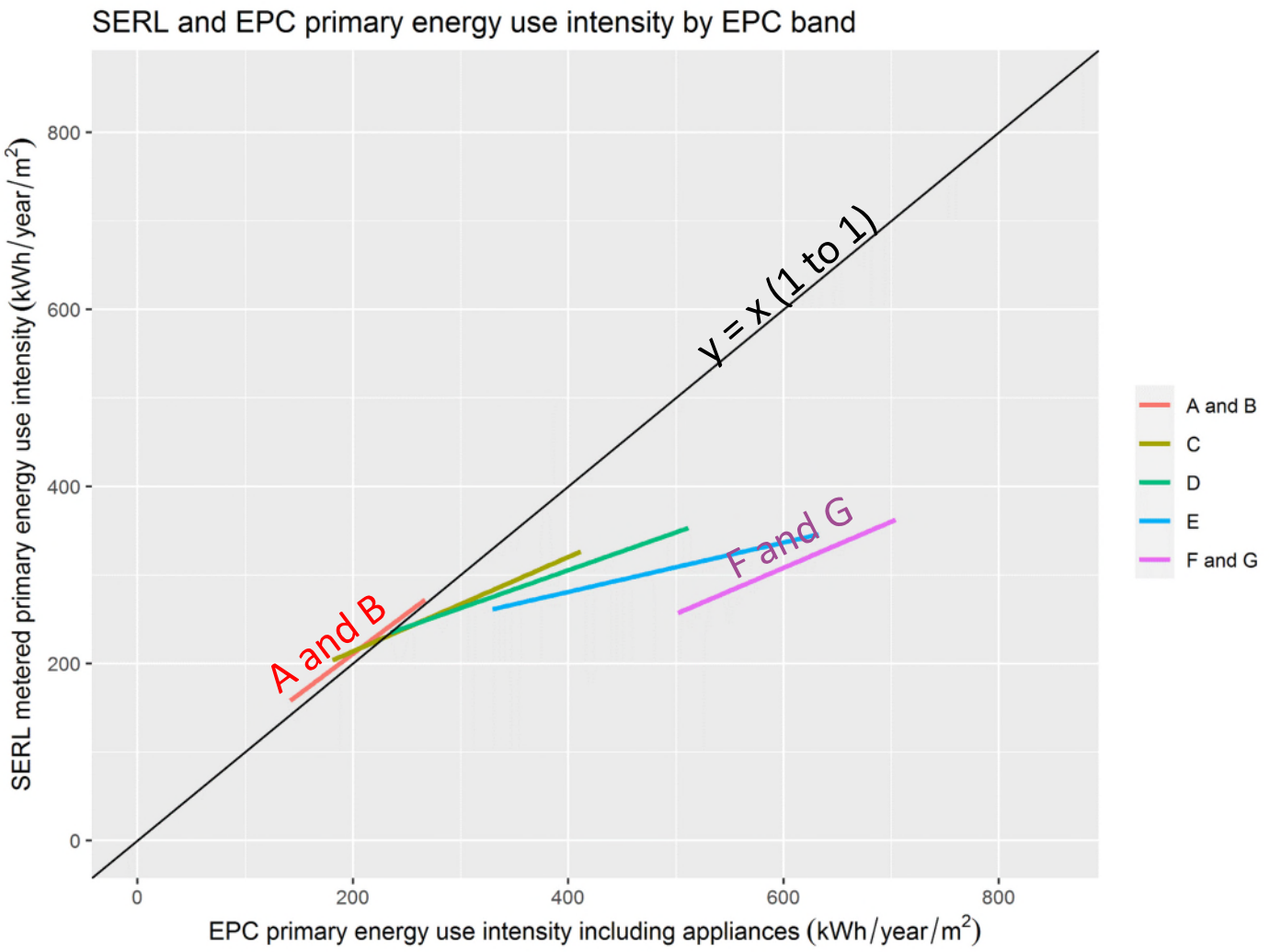
•The **occupants** – who don't use the building as specified or took the benefits as comfort

•The scientists/**analysists** who did not do the energy measurement correctly or incorrectly compared apples with oranges.



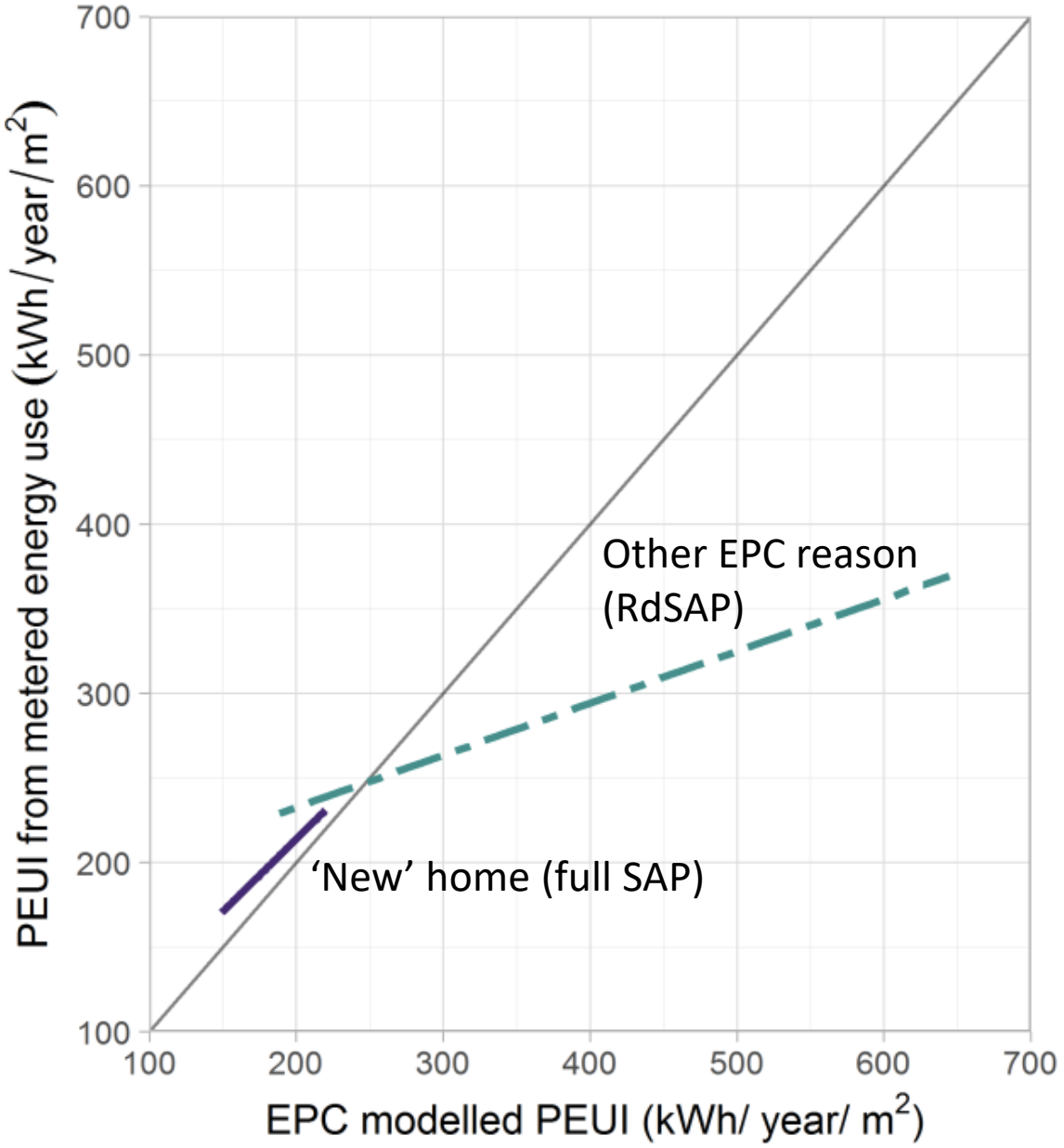
Good agreement between theory and metered for A&B

Measured



Modelled

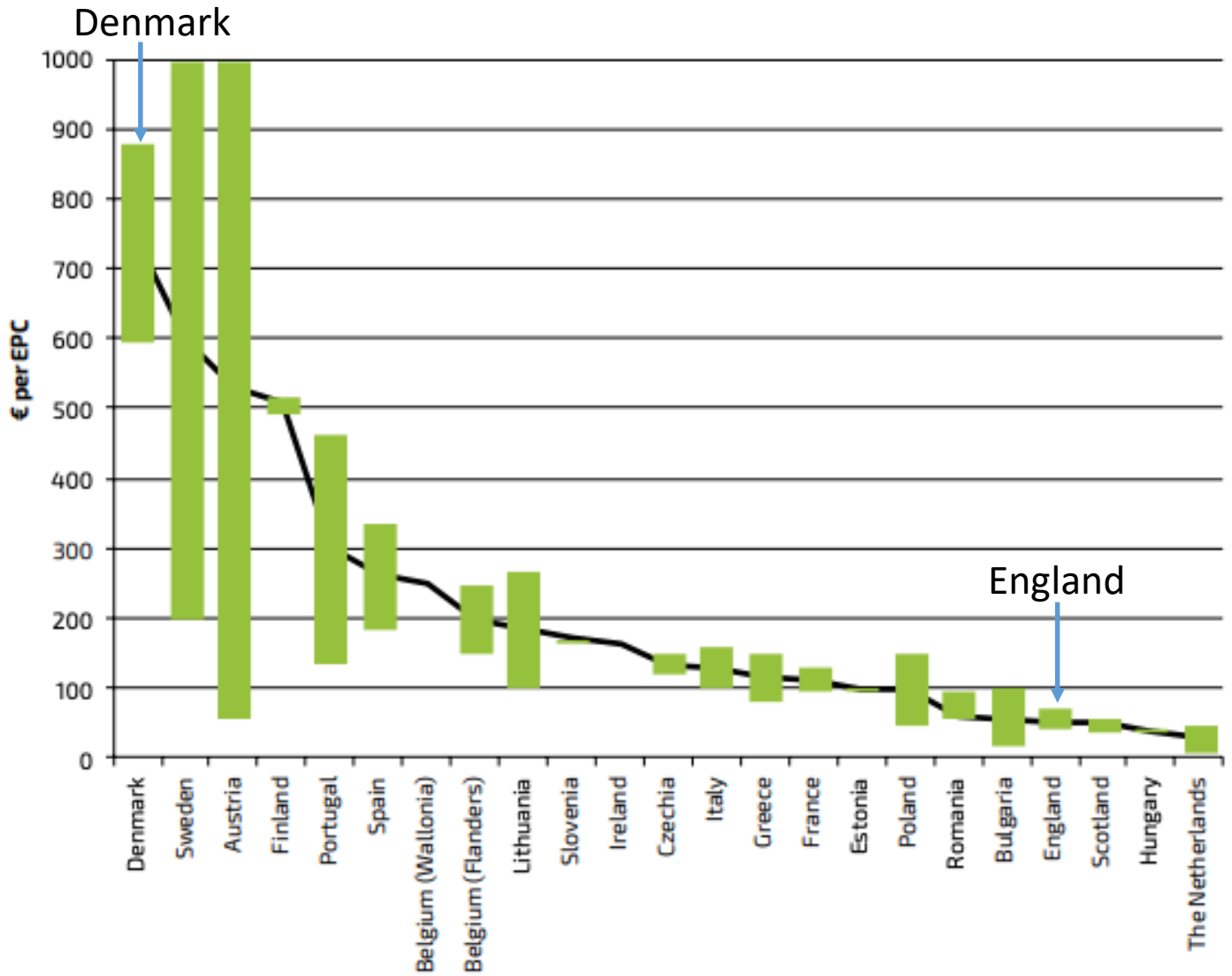
Reason for Gap – The EPC Assessor?



70% of homes EPC rated B when 'new' were rated as C or lower when they were 'marketed' for sale.

The average cost of an EPC in Denmark is more than 10 times that in the UK.

You get what you pay for?



Cost range for an EPC for a single-family house

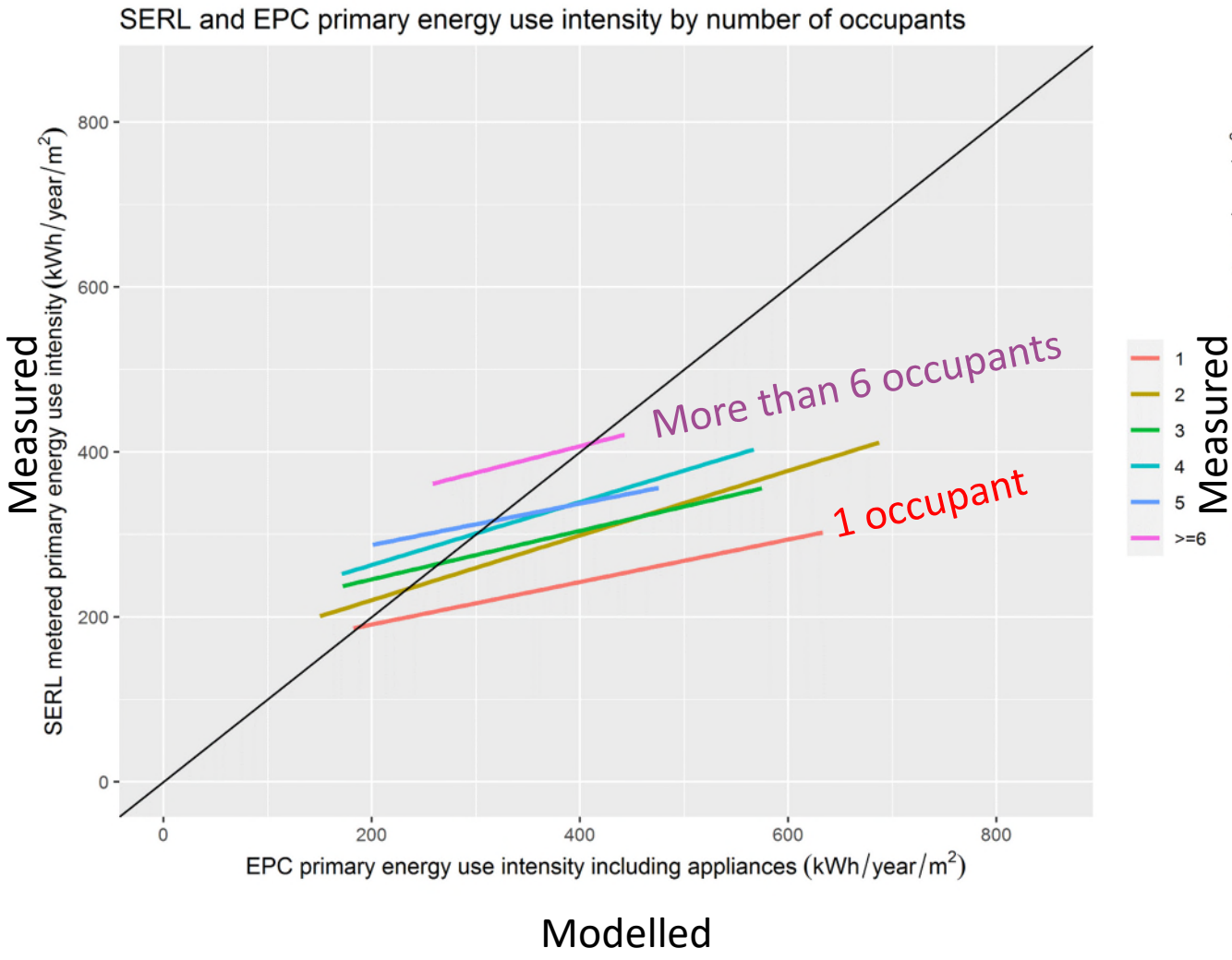
Original data sources: X-tendo partner provided information

See, "Making SAP and RdSAP 11 Fit for Net Zero" a report for DESNZ June 2021, for a review of international ratings and calculation methods.

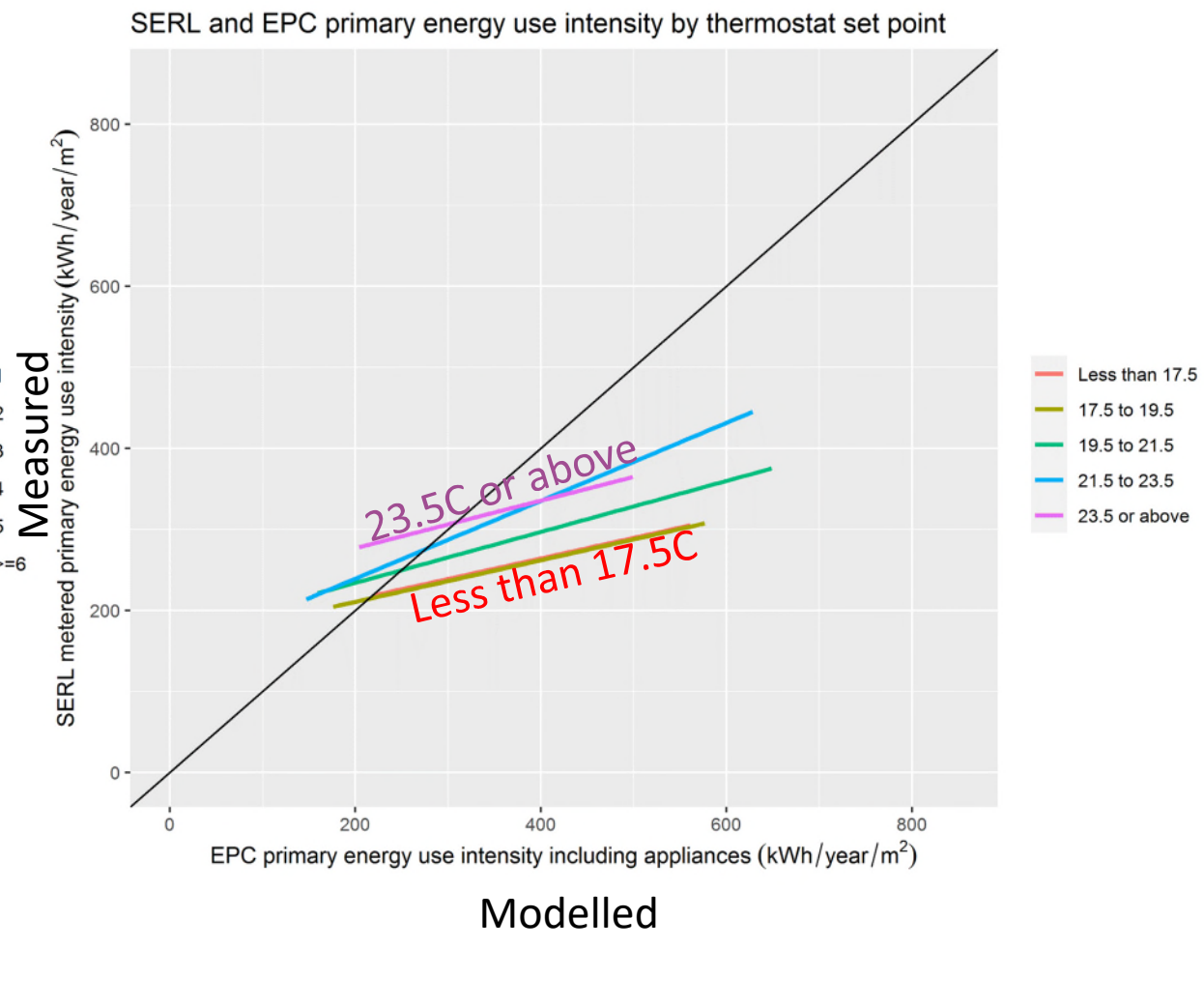
Building Performance Institute Europe(BPIE), X-tendo report, Energy Performance Certificates: Assessing their status and potential, March 2020.

Occupancy makes a difference, but not to the gradient

Number of Occupants



Thermostat set point

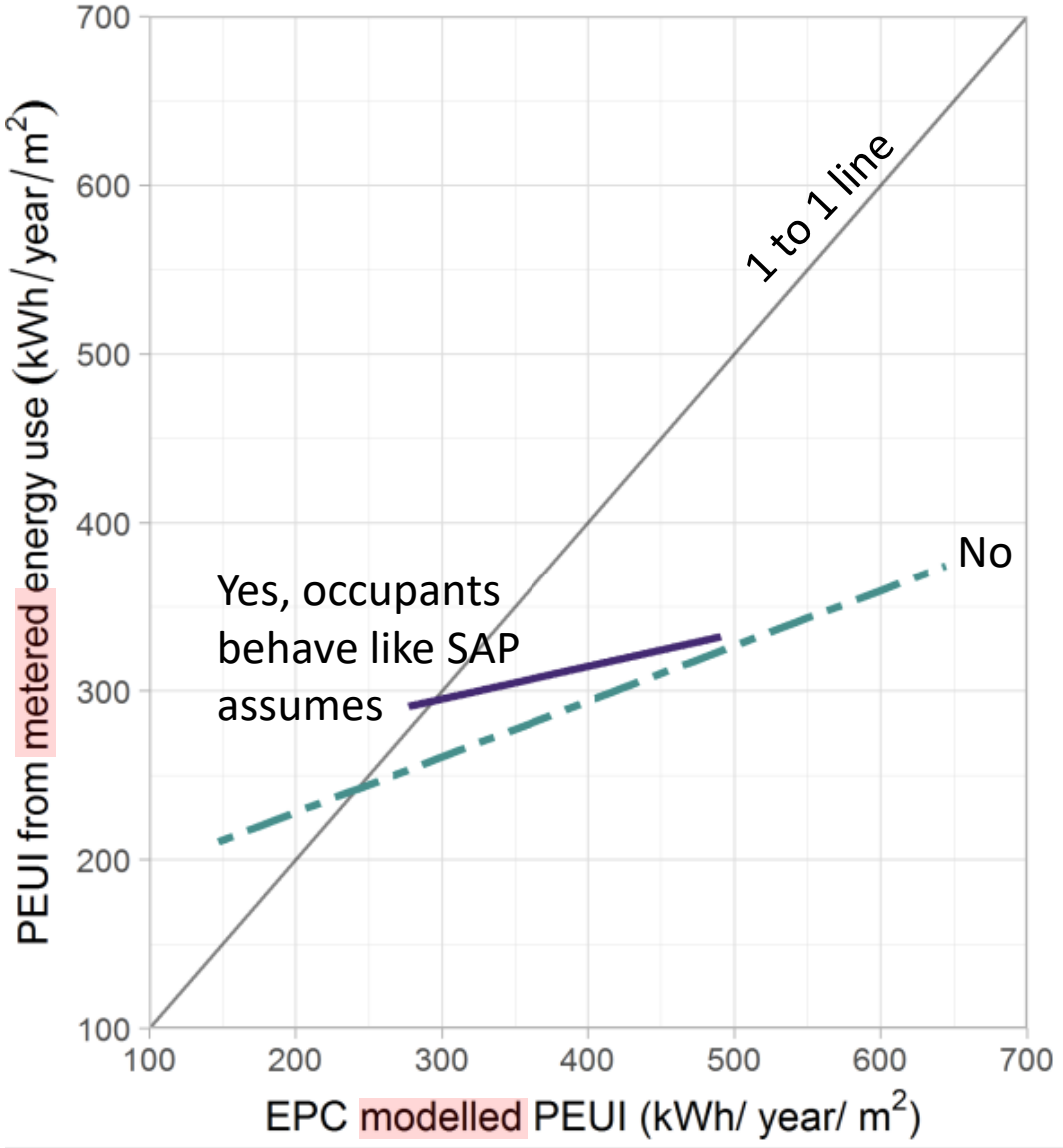


Occupancy makes a difference but not in gradient

'Yes' means:

- the number of occupants is similar to what SAP calculates.
- the temperature set point is 20.5-21.5 (SAP models 21C)
- The occupants heat their whole house and can keep living room comfortably warm.
- Occupants are not struggling financially.

'No' is the rest of the sample



Best Guess Narrative (following 2023 analysis)

1. Homes are not achieving SAP levels of comfort? But this does not fully explain the gap.
2. Homes improved since rated; more low energy lights, new regulated windows and combi boilers, reduced ventilation e.g. fitted carpets?
3. Less electrical power for light and appliances than predicted by SAP? Impacts primary energy analysis and incidental heat gains?
4. The SAP algorithms for internal temperature (MIT) may need improving?
5. SAP optimistic about efficiency, RdSAP pessimistic?
6. Wrong age assumptions in RdSAP for U-values and efficiency?

New Project - EPC Accuracy (DESNZ funded)

Build SAP model of each SERL home, so we can :

1. Update model (EPC) to current version of SAP
2. Run model with meted weather data
3. Add efficiency improvements post EPC, but pre metering.
4. Actual occupancy (number and set point thermostat).

This has proven ‘Living EPC’ and ‘MyEPC’ are feasible low-cost additional tools.

Plus, **compare monthly disaggregated energy** use by fuel (gas and electricity separately) and by month

Forensic investigation of 40 homes, resurveyed, full SAP. Impact of assessor error, change in conventions and modifications post EPC assessment.

Also, compared modelled and measured **Mean Internal Temperature** for EHS (EFUS) homes to see if temperature assumptions in SAP were cause of error.

Combined methods provide the most detailed explanation of the cause of the gap.

Energy Data & Analysis

DATA for 700 gas-heated homes

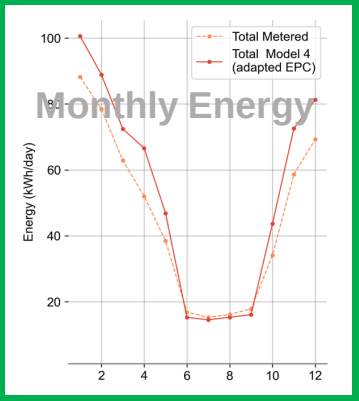
- Metered 2021 Monthly Gas and Electricity (SERL)
- Building and system data (MHCLG EPC Input data)
- EPC vintage (EPC Registry)
- 2021 Weather (ECMWF-SERL)
- Efficiency Improvements (NEED-DESNZ)
- Behaviour Data (SERL)

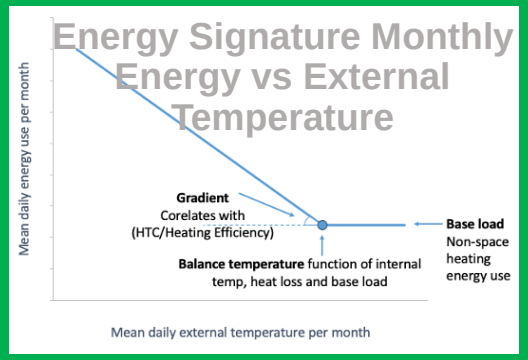
National Building Model (NBM-SERL)

- Model 0 (as per EPC)
- Model 1 (Update to RdSAP 9.94)
- Model 2 (M1 + real weather)
- Model 3 (M2+NEED upgrades)
- Model 4 (M3 + real occupancy & thermostat temp)

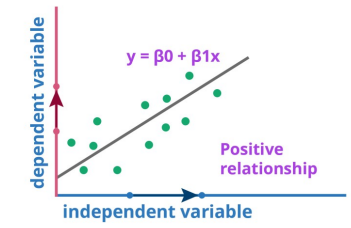
Output - Modelled Monthly Gas and Electricity

Analysis





Linear Regression Model



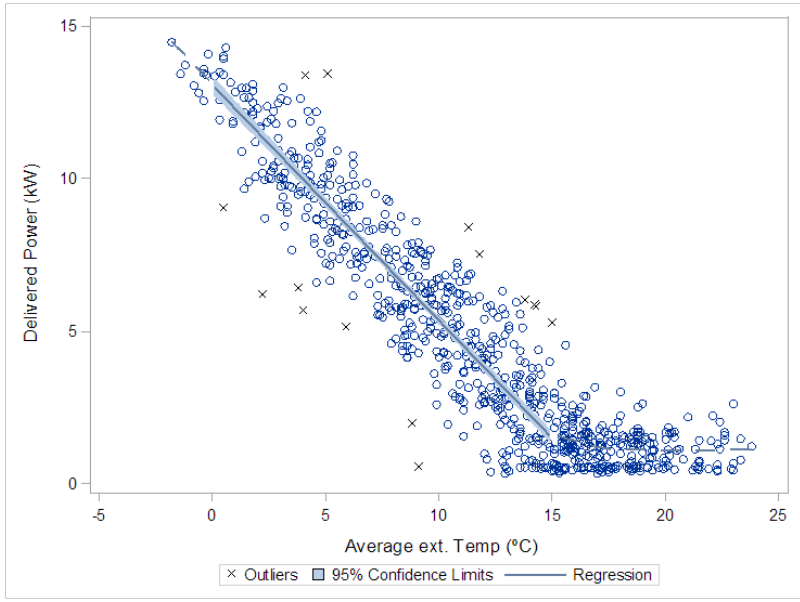
Energy signature

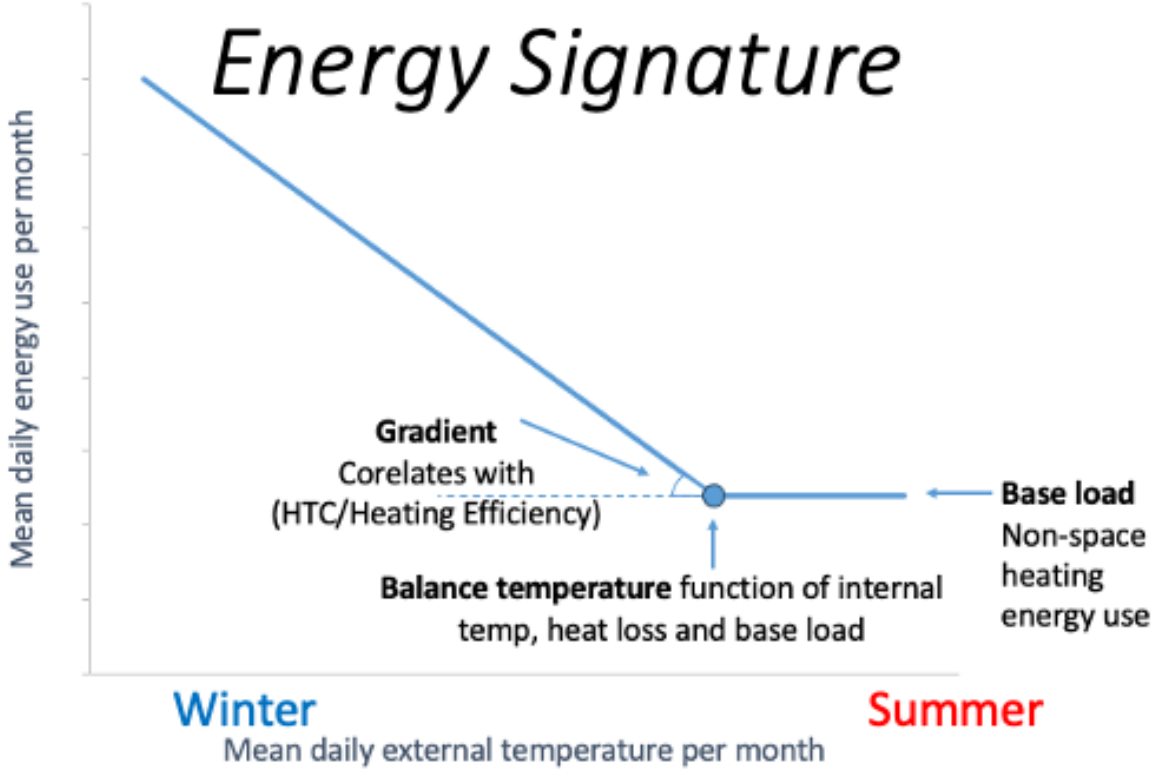
- Used to help disaggregate heating season and non-heating season gas and electricity energy use and provide an indication of the heat efficiency of the building. By comparing the modelled with the monitored energy signatures, it is possible to gain insights as to the cause of the performance gap.

Produced by fitting a model of the form shown in the graph using NBM monthly outputs, and the 2021 monthly metered energy use.

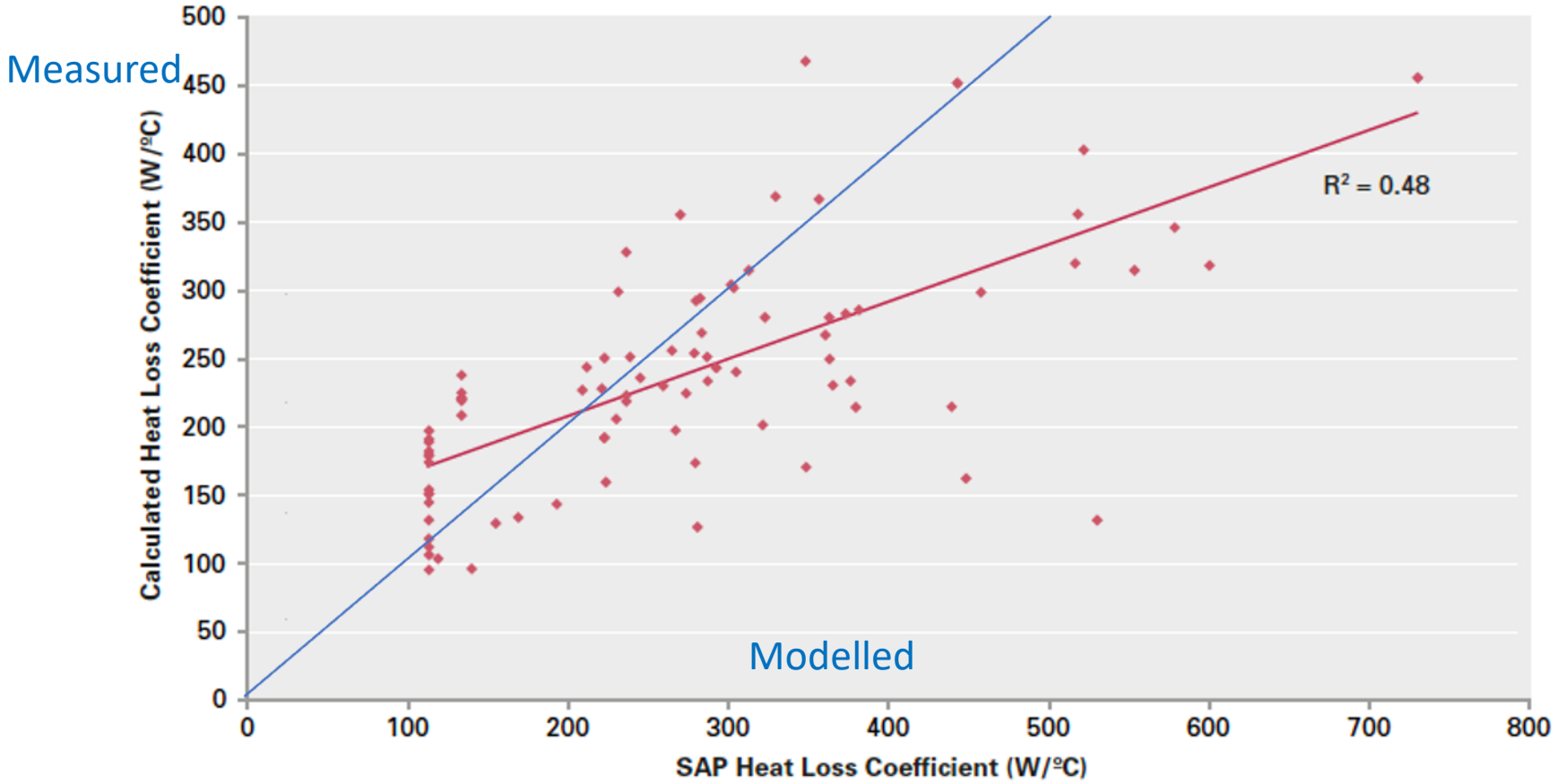
The energy signature methods produces three outputs:

1. **Base Load**: this is the average non-space heating energy use during the summer, for gas heated homes the gas base load is mostly hot water, and electricity is lights and appliances.
2. **Gradient**: The steeper (larger) the gradient, the more energy the building requires for heating as the external temperature drops. Buildings with better insulation and more efficient heating will have lower gradients.
3. **Balance Temperature**: This is the outside temperature when the space heating system turns on. It is impacted by the thermostat temperature, the building incidental and solar gains and heat loss.





We have known that SAP heat loss may be wrong for over two decades



Hypothesis: Building constructions have gaps:

- In buildings with no insulation air gaps can be good.
- In insulated buildings gaps create thermal bypass

Calculated heat loss coefficient from metered heat input into the building versus SAP modelled heat loss for a range of different heating systems. Each point is a single house. Red line is best fit, blue line, one to one , i.e. all data would lie on this if SAP modelled data predicted measured data. Homes with high heat loss are better preforming than modelled and well insulated homes do not perform as well as expected. Source: Carbon Trust, Micro CHP Accelerator Interim report, 2007.

Concluding personal reflections

1. Good news - GB housing stock better than we think (from EPCs).
2. The less efficient older properties are generally even better – in part because they have had more upgrades since they were last rated.
3. Occupants can make a big difference to energy use – but are not the only explanation for a gap.
4. Modellers and analysists get things wrong. Occupants' behaviour is normally the soft target for unexplained results (e.g. paper saying energy efficiency improvements all disappear after 4 years because of rebound)!
5. EPC gap has many causes – model, assumptions and EPC process all at the same time.
6. No gap no problem – model validated? Errors cancel each other out! Model validation needed across all user space.
7. Difference between research and business/policy models. Balancing between accuracy, reliability, value and cost. Reliability has been a key focus – send 10 assessors around the same house. The greater the value the more likely it is gamed. (MEES, pressure testing, SMETERS).

Concluding personal reflections - continued

8. Key metric changes over time, what is the role of energy efficiency in a decarbonised world? No model is good at everything.
9. Validation is not just for Xmas. Technologies, practices (COVID and cost of living crisis), and climate all change.
10. The more complex a model the more assumptions you need to validate.
11. Access to administrative linked data is revolutionising metered (in-use) variables, and contextual data (National Buildings Database, SERL 1,000 variables per house). This data can improve our models and help us to transition to net zero.
12. AI is a game changer but needs feeding with good data. Don't assume all data is good for everything, e.g. NEED electricity data does not measure exports.
13. When science is under threat we must double down on rigour, reproducibility and challenging each other.

Acknowledgement & Further Details

Analysis undertaken by Jessica Few, Minnie Ashdown and Daniel Godoy with support from the SERL team at UCL Energy Institute

This work is funded by EPSRC under the SERL and EDOL grants and DESNZ EPC Accuracy contract .

Further details

- J. Few, et al, *The over-prediction of energy use by EPCs in Great Britain: A comparison of EPC modelled and metered primary energy use intensity*, Energy & Buildings (2023), doi: https://doi.org/10.1016/ j.enbuild.2023.113024
- SERL Stats report https://serl.ac.uk/key-documents/reports/
- Energy Demand Observatory Lab (EDOL). .

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