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Smart Multi-Terminal DC μ-grids for autonomous Zero-Net Energy Buildings

ITT Mandi v| 14-15th December 2014 | Mandi, India

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Define and Scenarios to reflect different rural and urban representative areas in UK

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1. Agenda
2. Energy in UK
3. Demand in UK
4. Low carbon technology demand and generation profiles
   - Electric vehicle charging
   - Domestic heat pumps
   - Domestic solar photovoltaic systems
   - Small-scale wind turbines
5. Define and Scenarios

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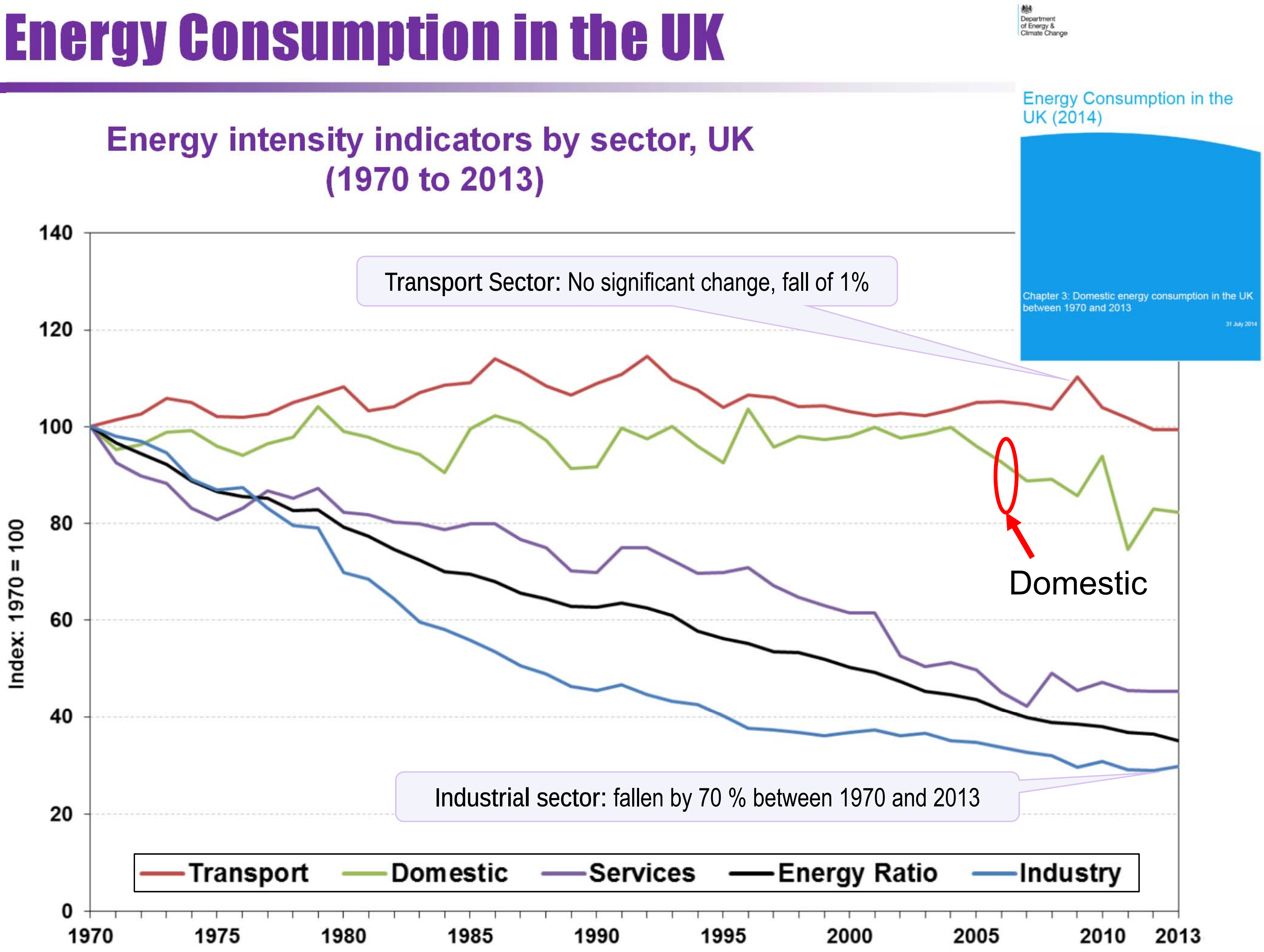
BACKGROUND
Demand UK

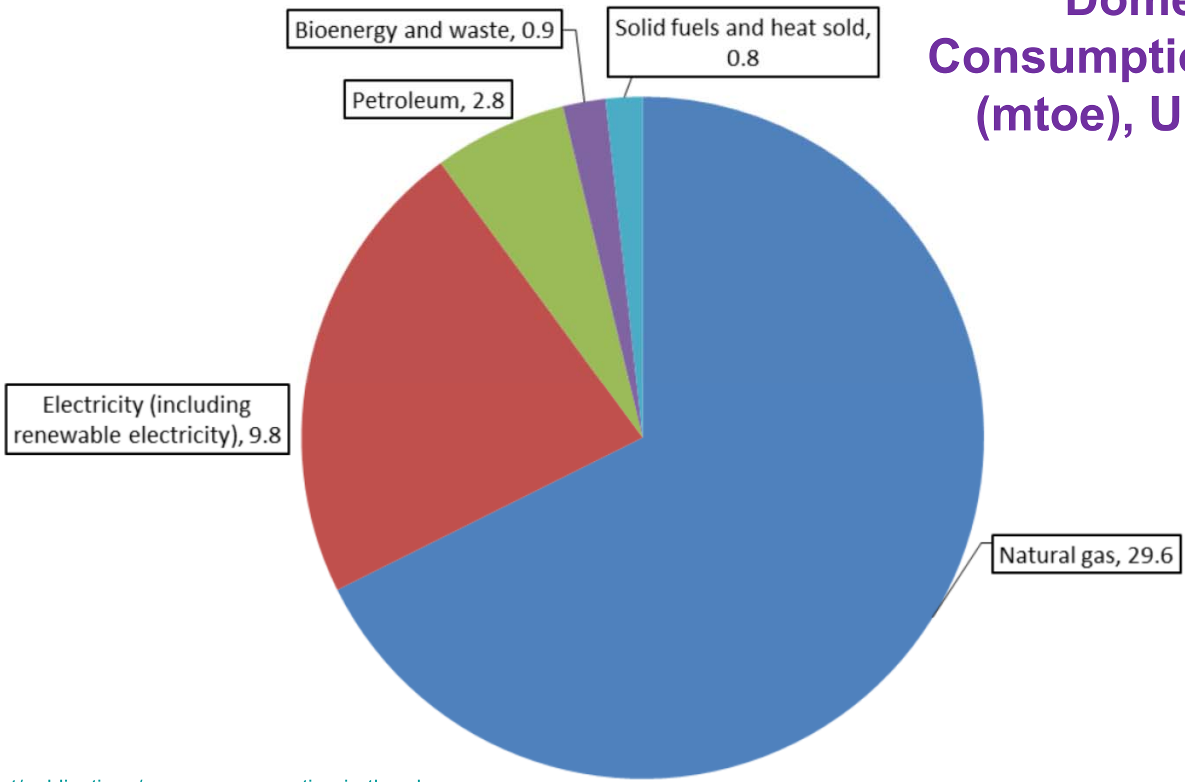
Energy Consumption in the UK



https://www.gov.uk/government/publications/energy-consumption-in-the-uk

Overall domestic sector energy consumption 2013

- Since 2000 **domestic energy use has decreased by 7%.**
- **Increase of 11% in the number of UK households** and a **9% increase in the UK population**.
- At a per household level, **energy consumption has fallen by 9%** since 2000

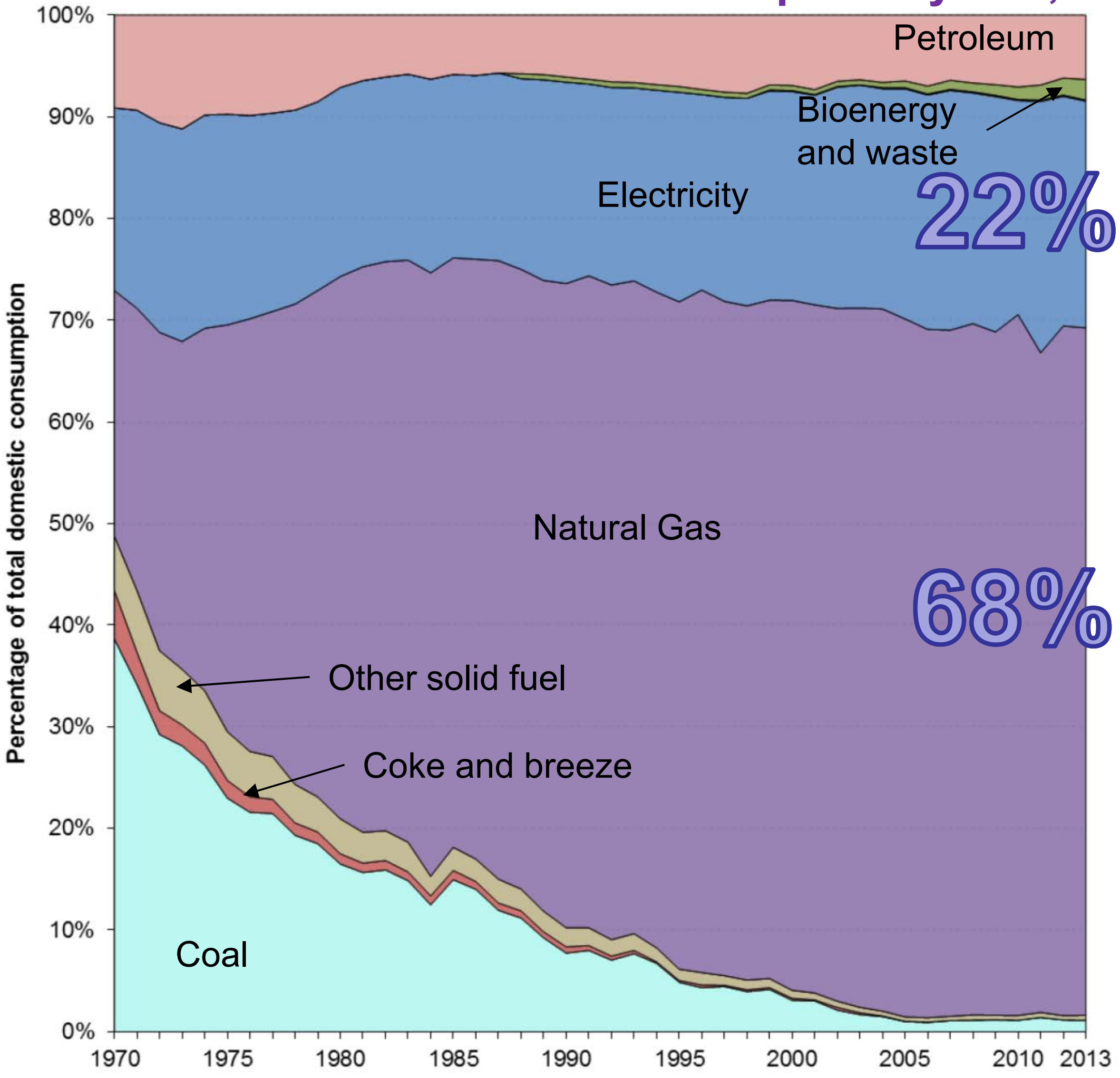


Domestic Consumption by Fuel (mtoe), UK (2013)

https://www.gov.uk/government/publications/energy-consumption-in-the-uk

Energy Consumption by Fuel Type

Domestic consumption by fuel, UK (1970 to 2013)



The fuel mix for domestic consumption has significantly changed since 1970

1970:

- 39% coal,
- 24% natural gas and
- 18% electricity;

2000:

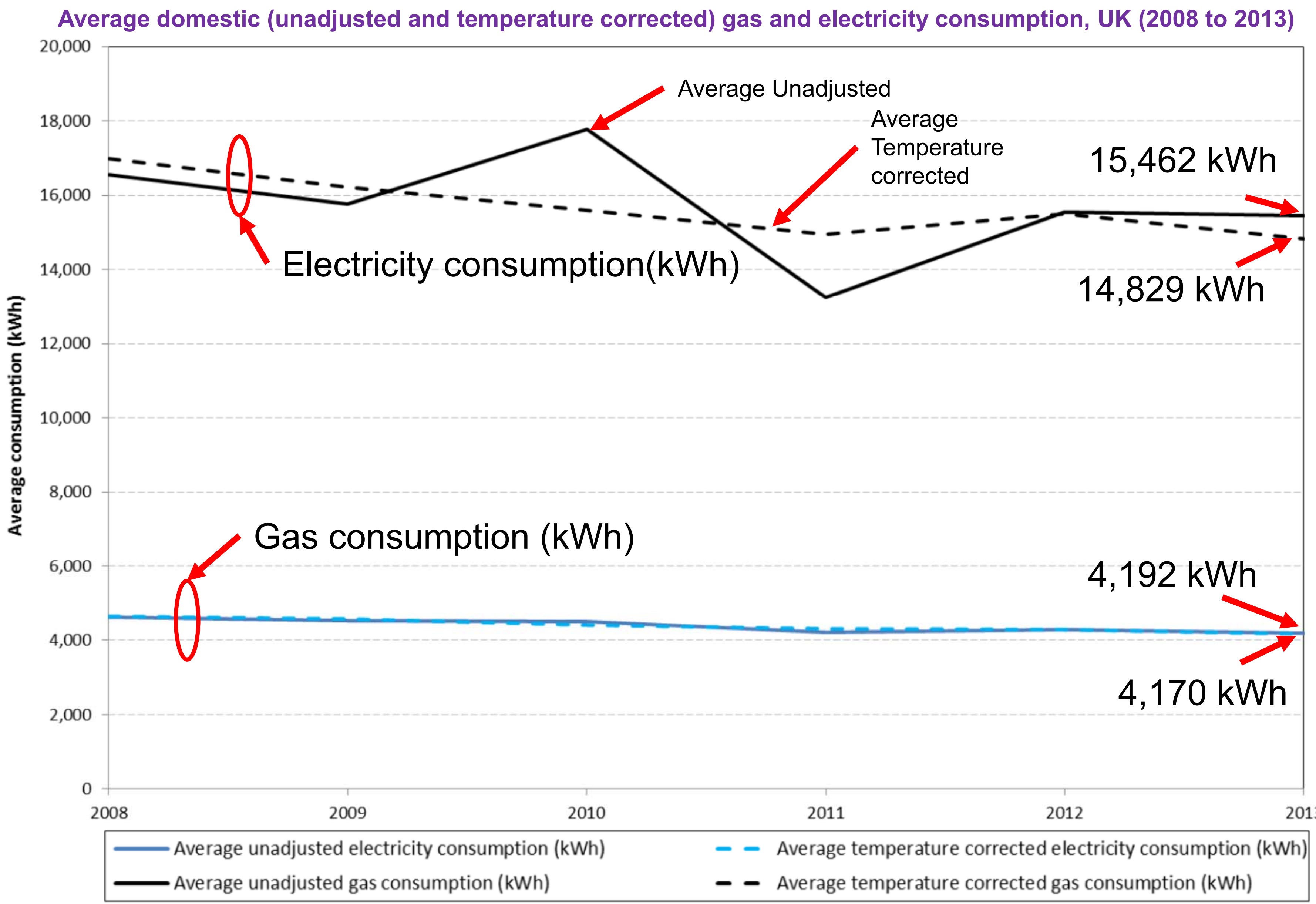
- 3% coal,
- 68% gas and
- 21% electricity

2013

- 1% coal,
- 68% natural gas and
- **22% electricity**

https://www.gov.uk/government/publications/energy-consumption-in-the-uk

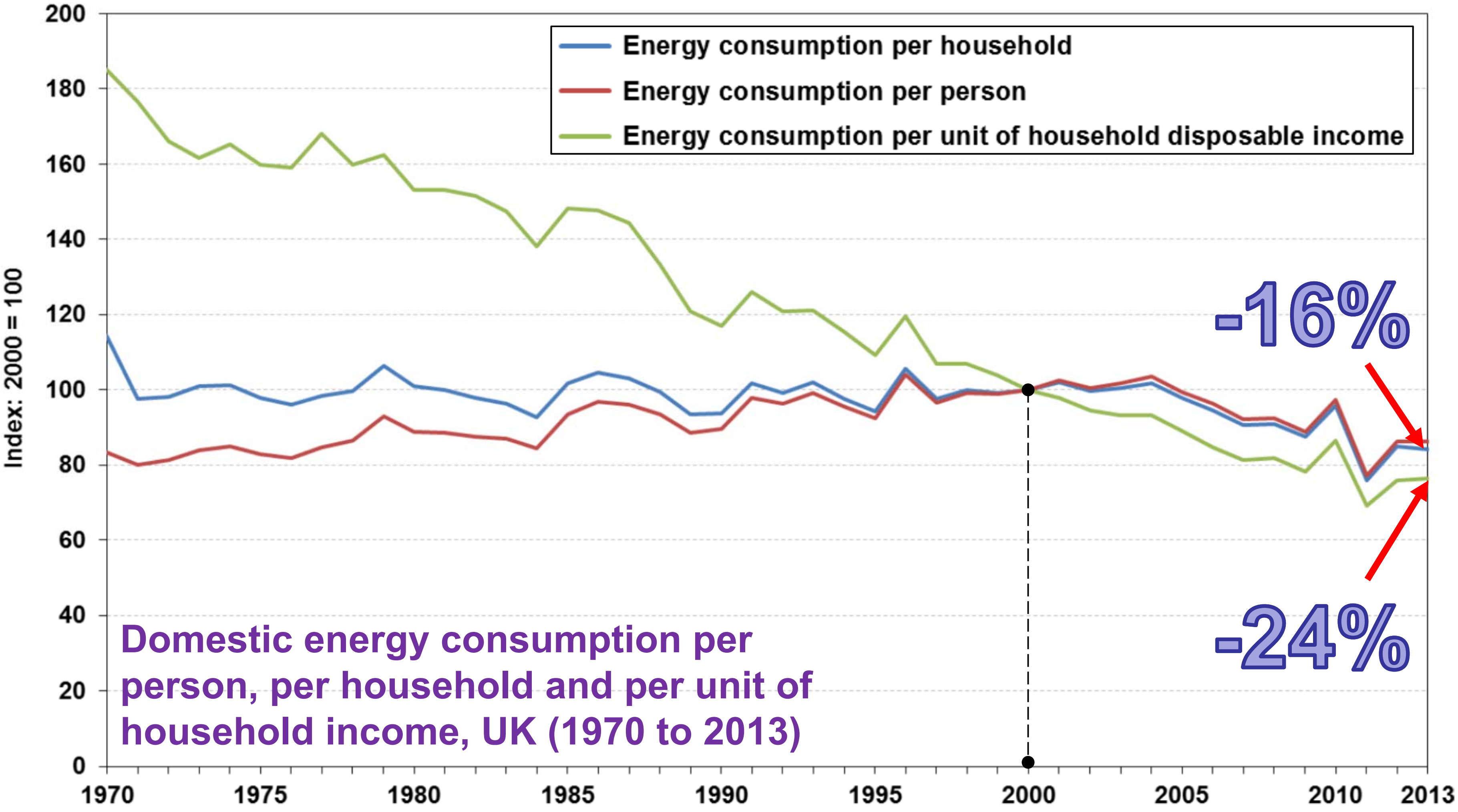
Average domestic gas and electricity consumption



https://www.gov.uk/government/publications/energy-consumption-in-the-uk

Energy consumption per head and by income

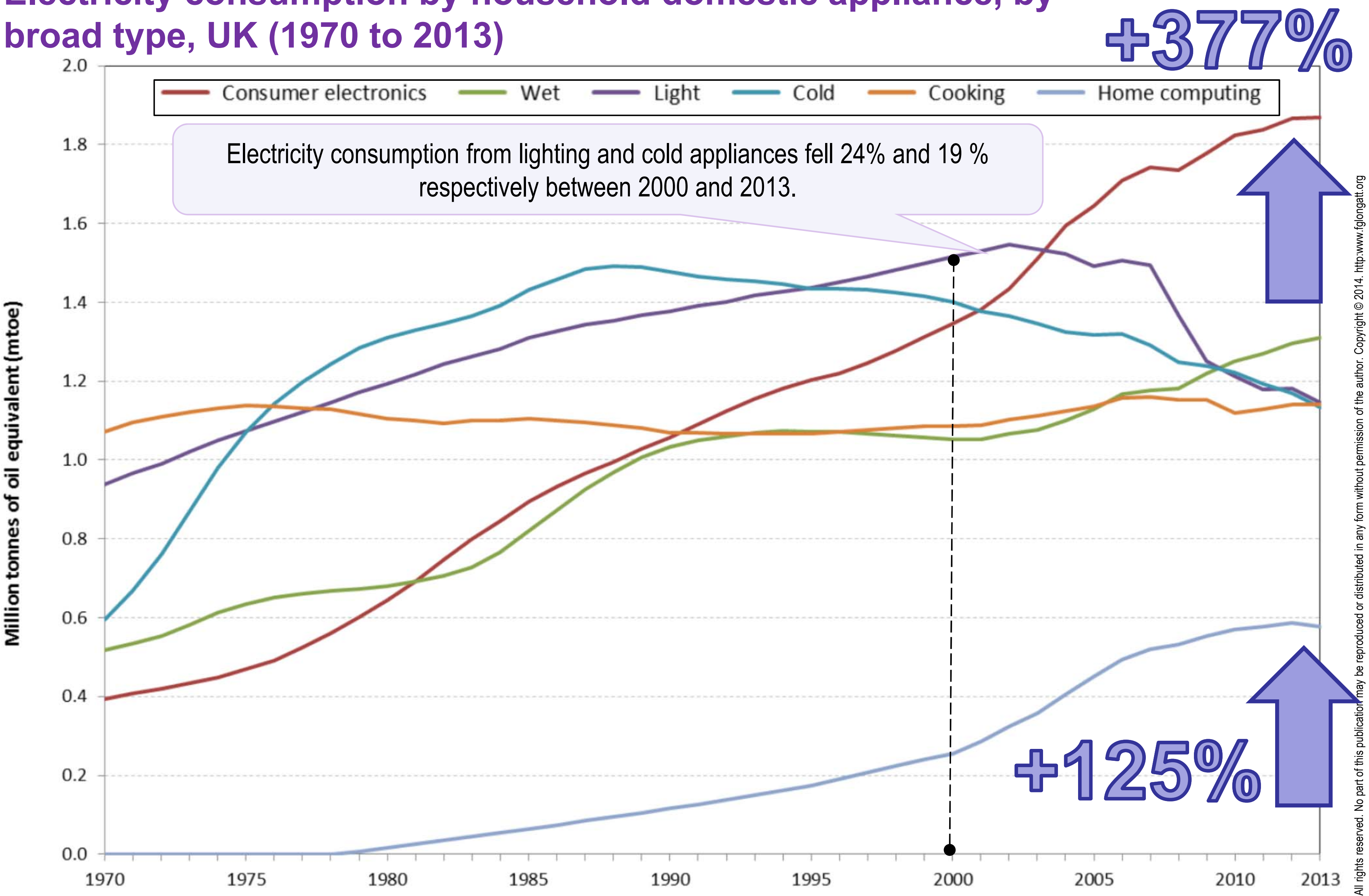
Energy consumption per unit of household disposable income has fallen by 24% since 2000, whilst **energy consumption per household has fallen by 16%** and energy consumption per person fallen by 14%, reflecting an increase in energy efficiency.



https://www.gov.uk/government/publications/energy-consumption-in-the-uk

Use of electricity by appliance type

Electricity consumption by household domestic appliance, by broad type, UK (1970 to 2013)



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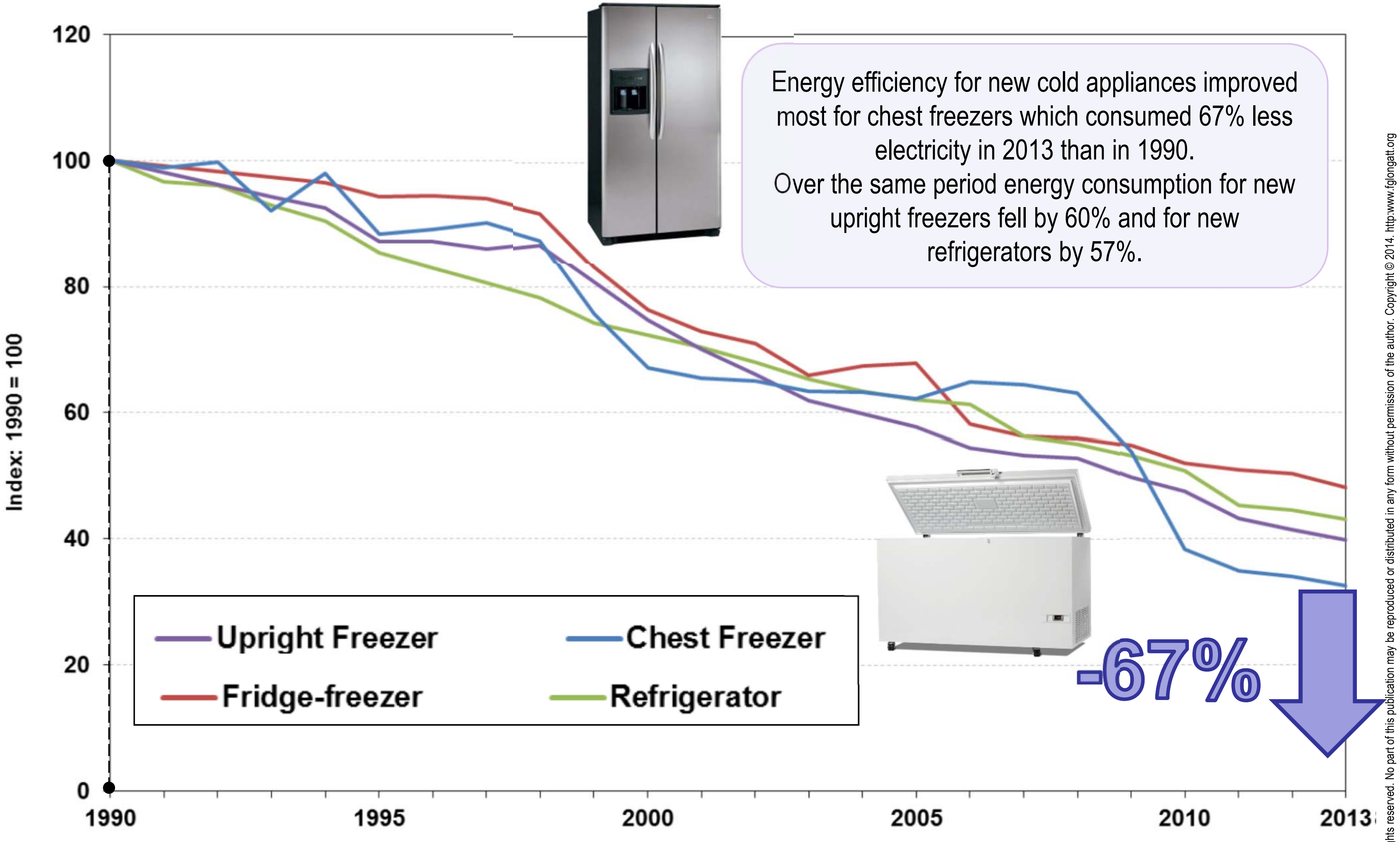
Energy efficiency improvements in appliances

Average energy consumption of new cold appliances, UK (1990 to 2013)

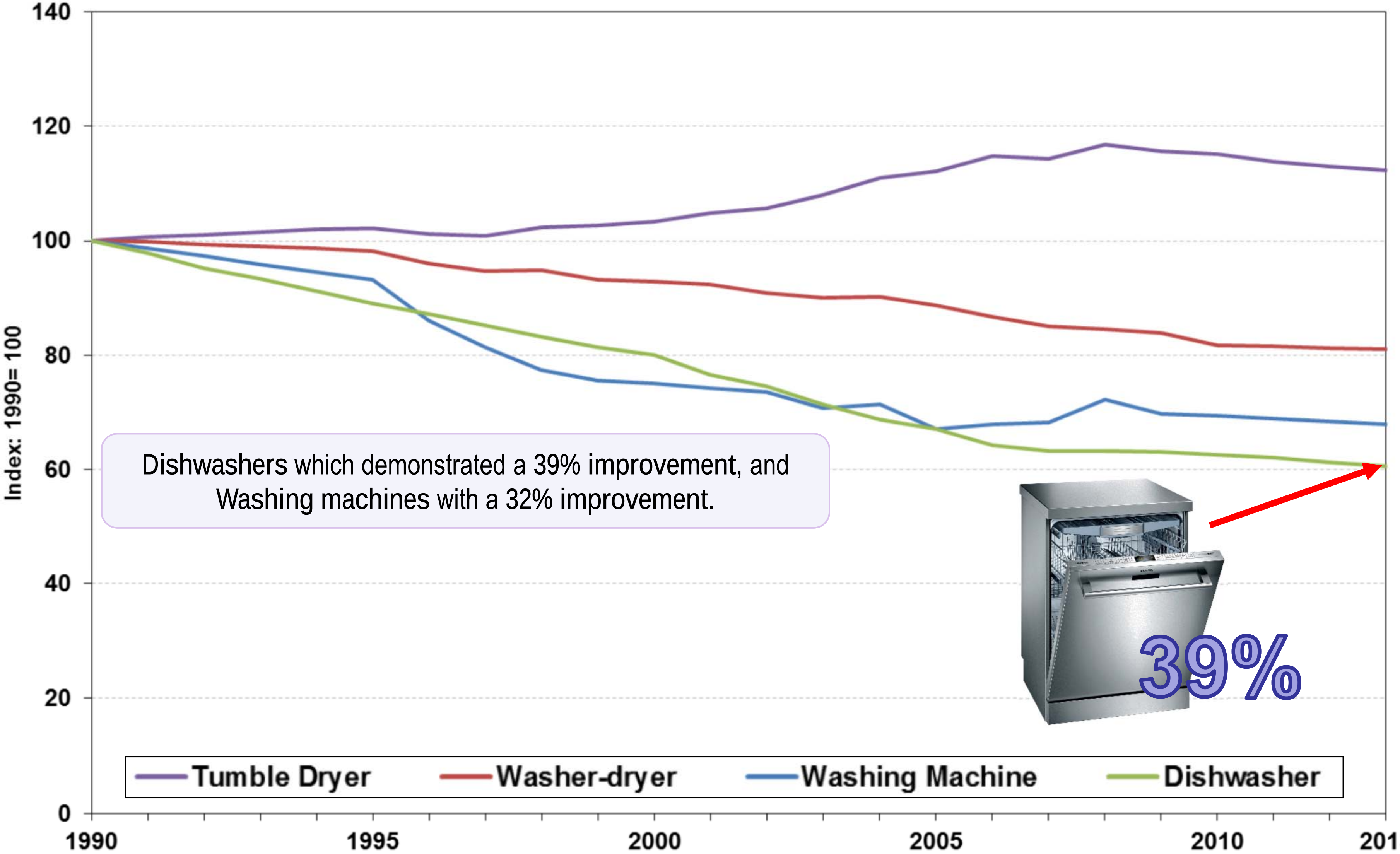


Energy efficiency for new cold appliances improved most for chest freezers which consumed 67% less electricity in 2013 than in 1990.
Over the same period energy consumption for new upright freezers fell by 60% and for new refrigerators by 57%.

https://www.gov.uk/government/publications/energy-consumption-in-the-uk

Use of electricity by appliance type

Average energy consumption of new wet appliances, UK (1990 to 2013)



https://www.gov.uk/government/publications/energy-consumption-in-the-uk

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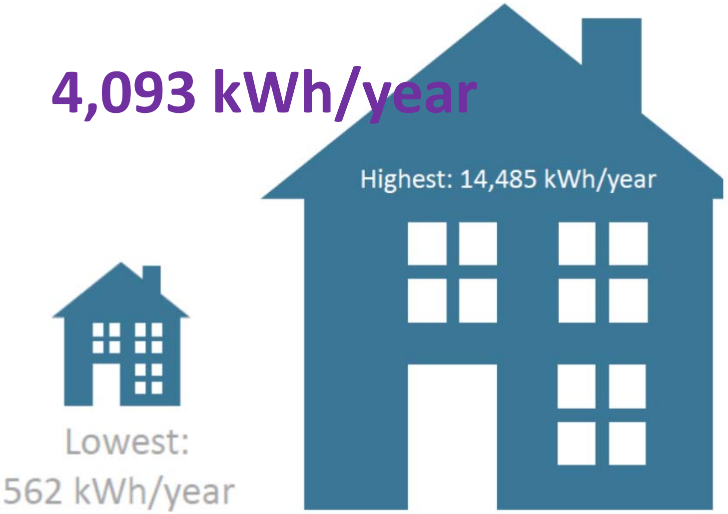
BACKGROUND
Demand UK

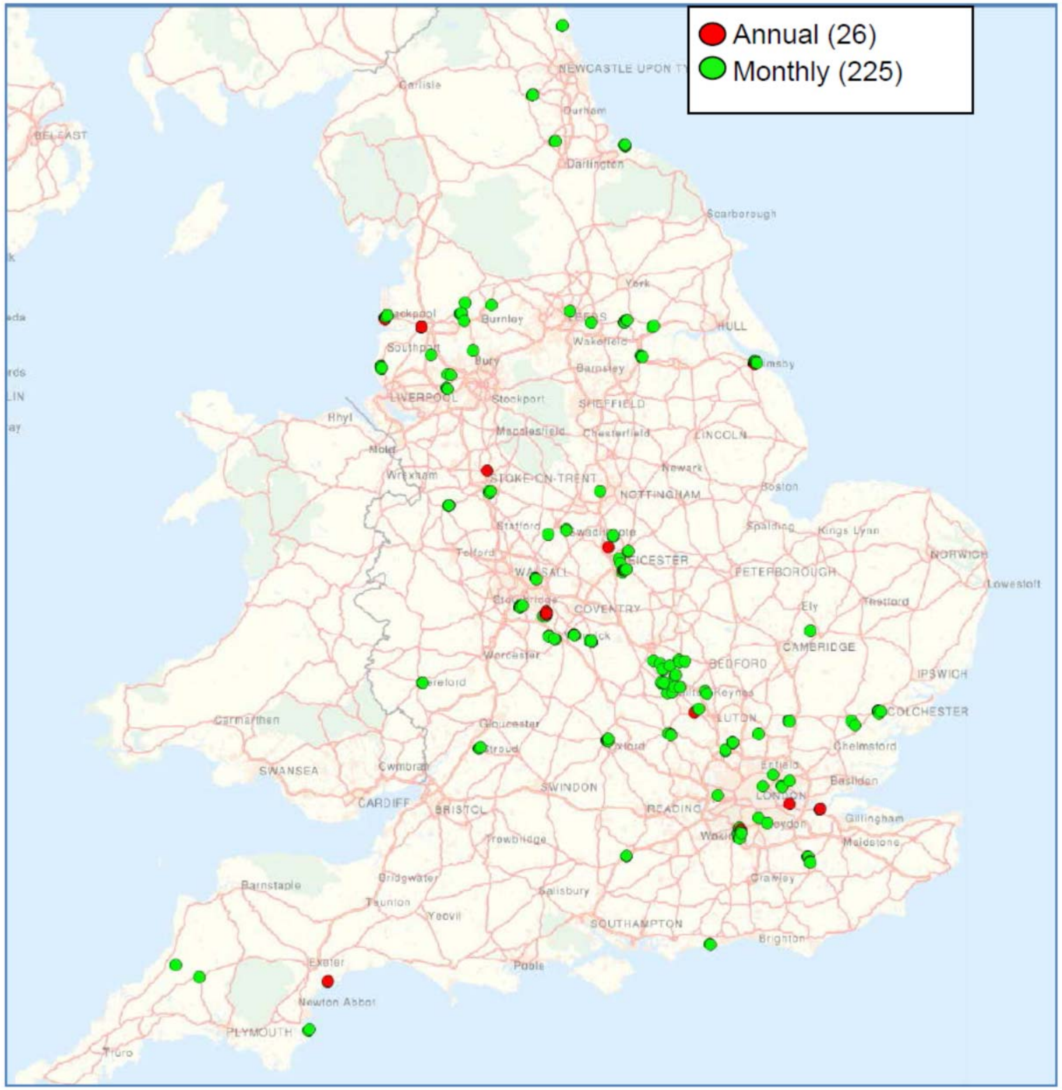
Household Electricity Survey (HES)

- The **Household Electricity Survey** monitored a total of 250 owner-occupier households across England from 2010 **to 2011.**

Average (mean) electricity use across homes in the sample was **4,093 kWh/year**, against a mean of **4,154 kWh** across all UK home.

Highest and lowest users



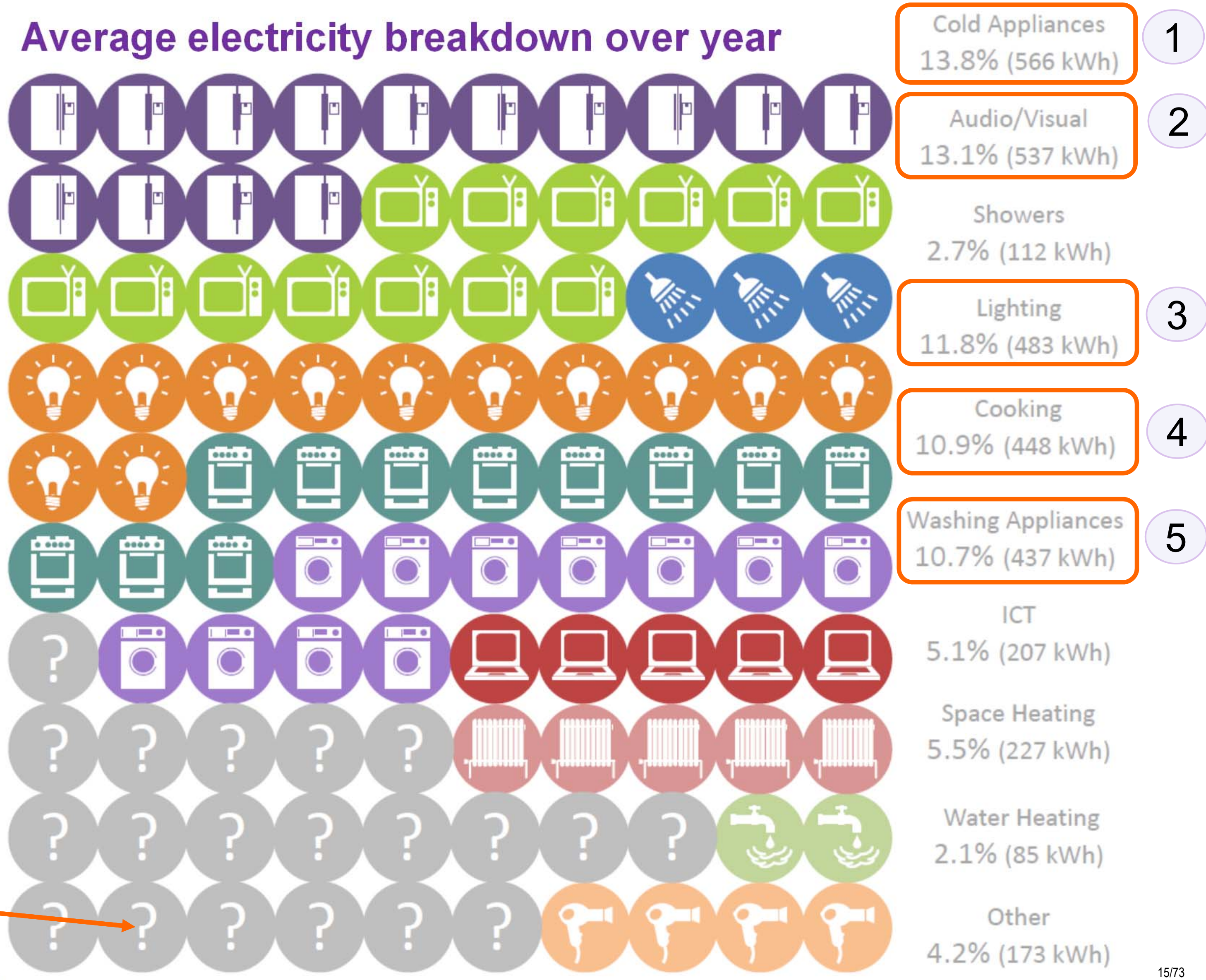


https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/208097/10043_R66141HouseholdElectricitySurveyFinalReportissue4.pdf

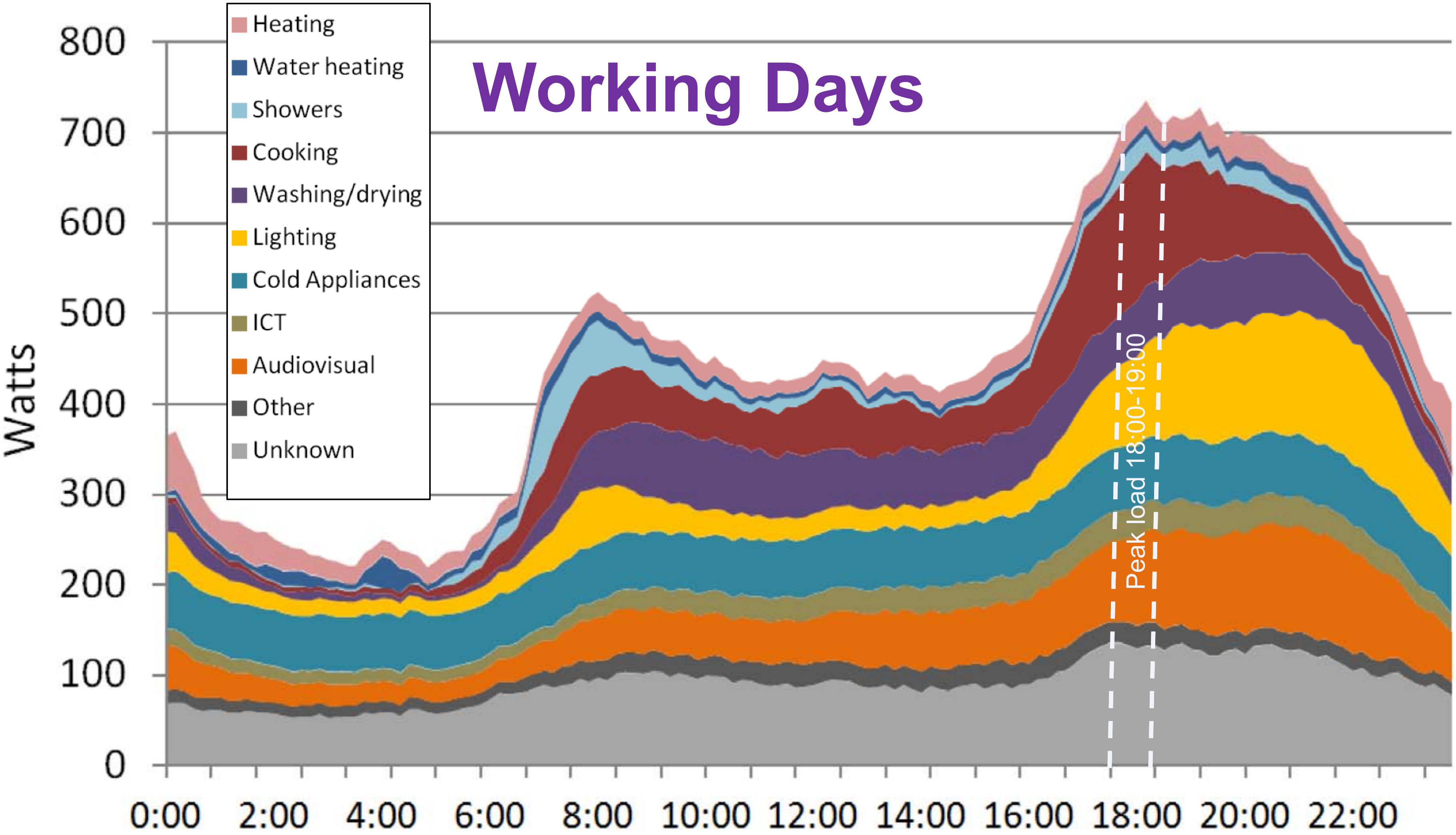
- **Ten appliance types** are included in this analysis.

- Dishwashers
- Washing machines
- Tumble dryers
- All cold appliances
- Refrigerators
- Freezers
- Fridge-freezers
- Televisions
- Microwaves, and
- Kettles

Average peak load breakdown



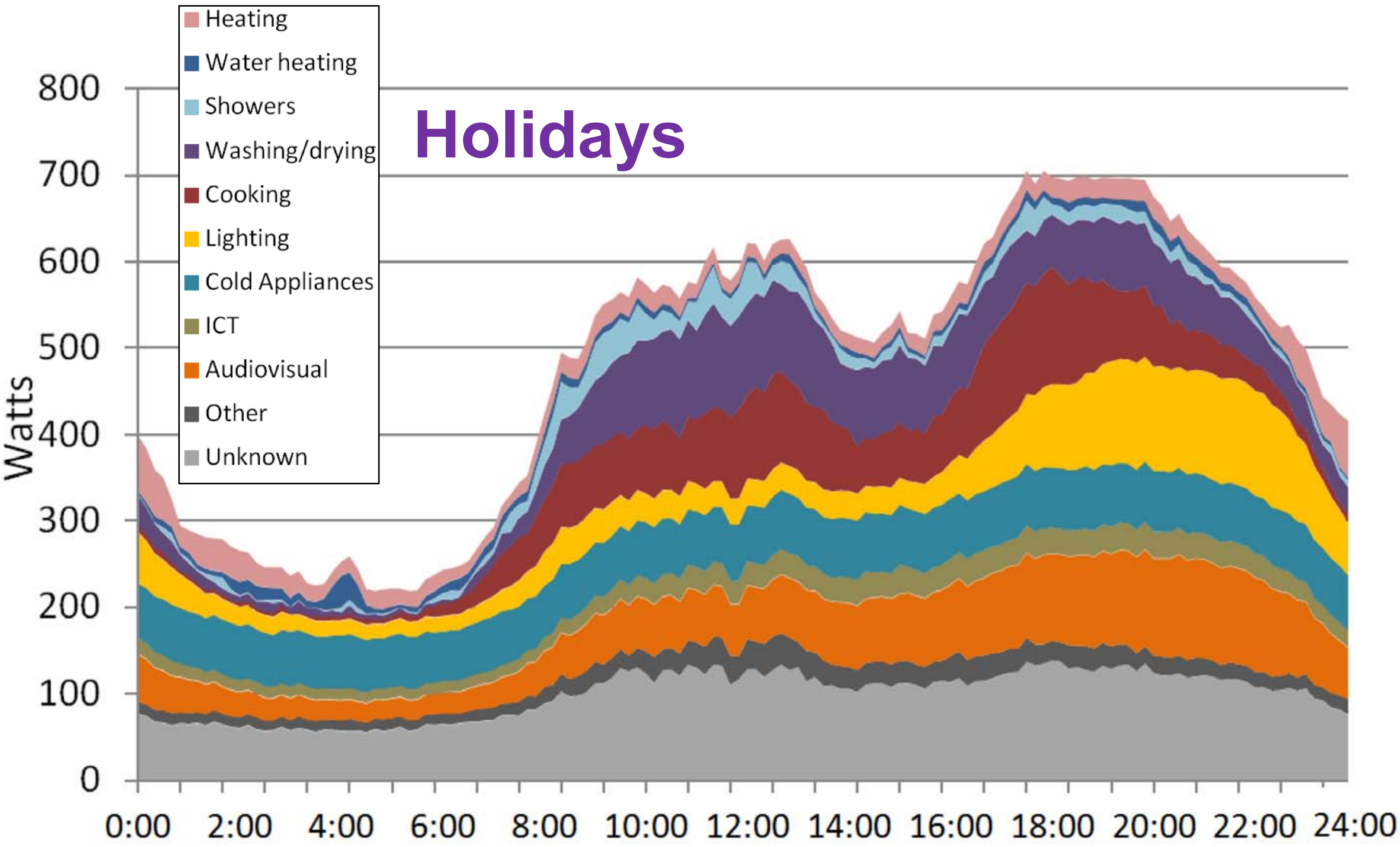
Average 24-hour profile for 250 homes



http://www.mdpi.com/buildings/buildings-04-00737/article_deploy/html/images/buildings-04-00737-g003.png

The **evening peak is very pronounced**, and made up largely of electricity used for **cooking** in the early evening, transferring to **lighting** and **audiovisual** later in the evening.

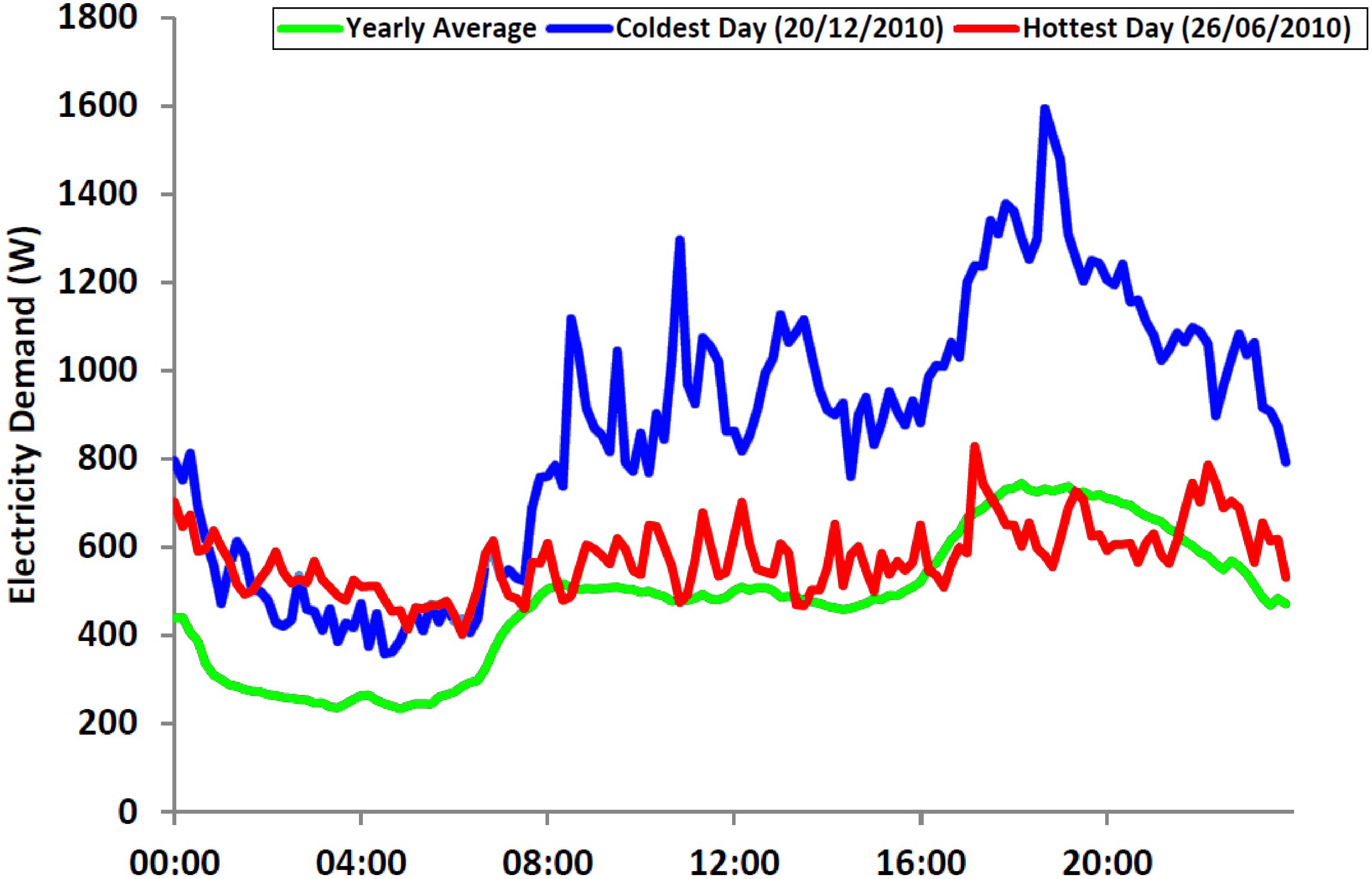
Average 24-hour profile for 250 homes



http://www.mdpi.com/buildings/buildings-04-00737/article_deploy/html/images/buildings-04-00737-g003.png

The hottest and coldest days of the year

Electricity demand profile of the average HEUS household as a function of time of day



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Low carbon technology demand and generation profiles

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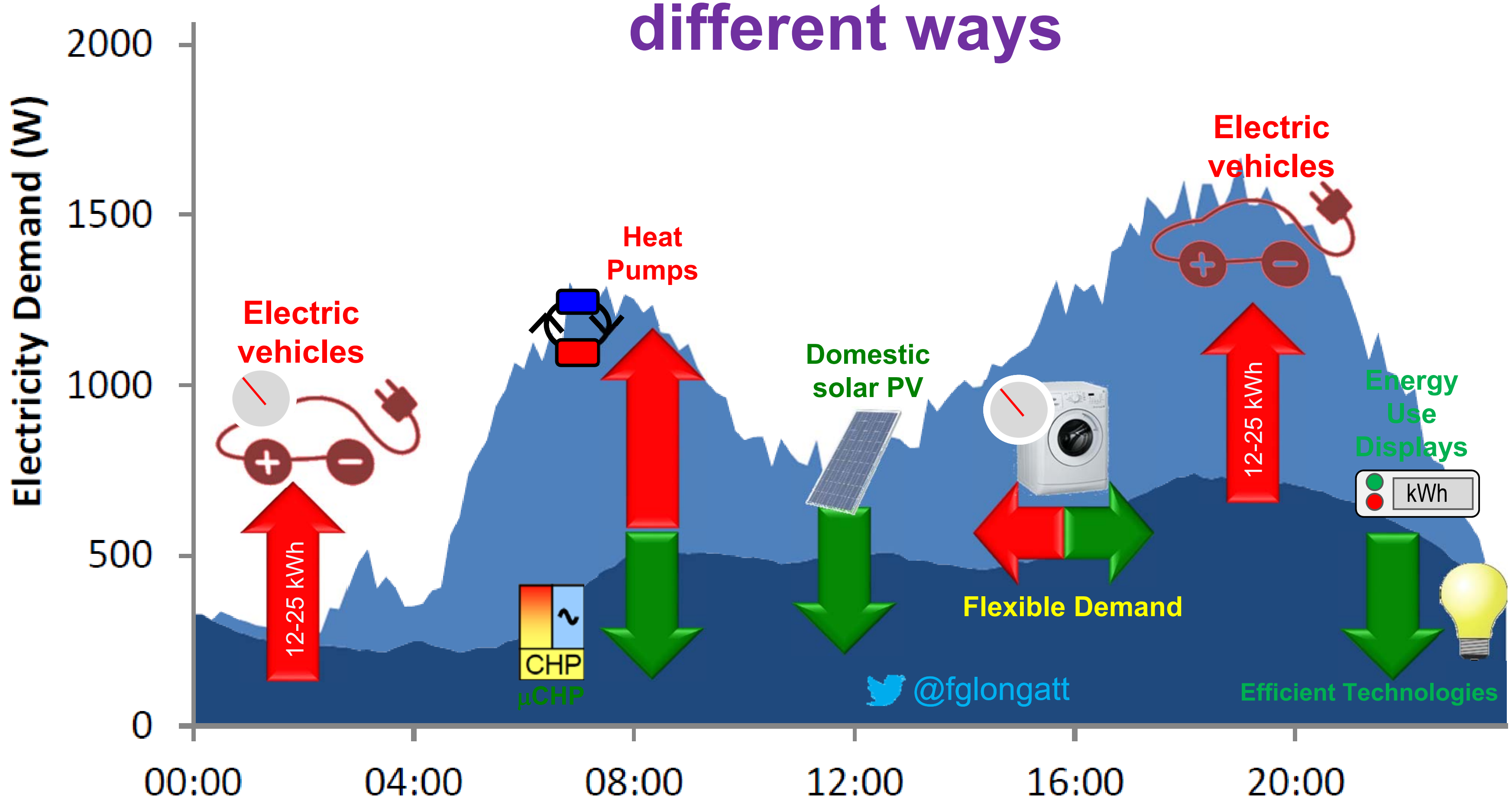
Low carbon technology demand and generation profiles

- Increasing the amount of energy the UK gets from low-carbon technologies such as **renewables** and nuclear, and **reducing emissions** through **carbon capture** and storage (CCS), will help us to:
  - make sure the UK has a secure supply of energy
  - reduce greenhouse gas emissions to slow down climate change
  - stimulate investment in new jobs and businesses
- **Low Carbon technologies:**
  - Electric Vehicle Charging
  - Domestic heat pumps
  - Domestic Photovoltaic Systems

Low Carbon Technologies

Different low-carbon technologies affect demand in different ways



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BACKGROUND: Demand UK -Prospective-

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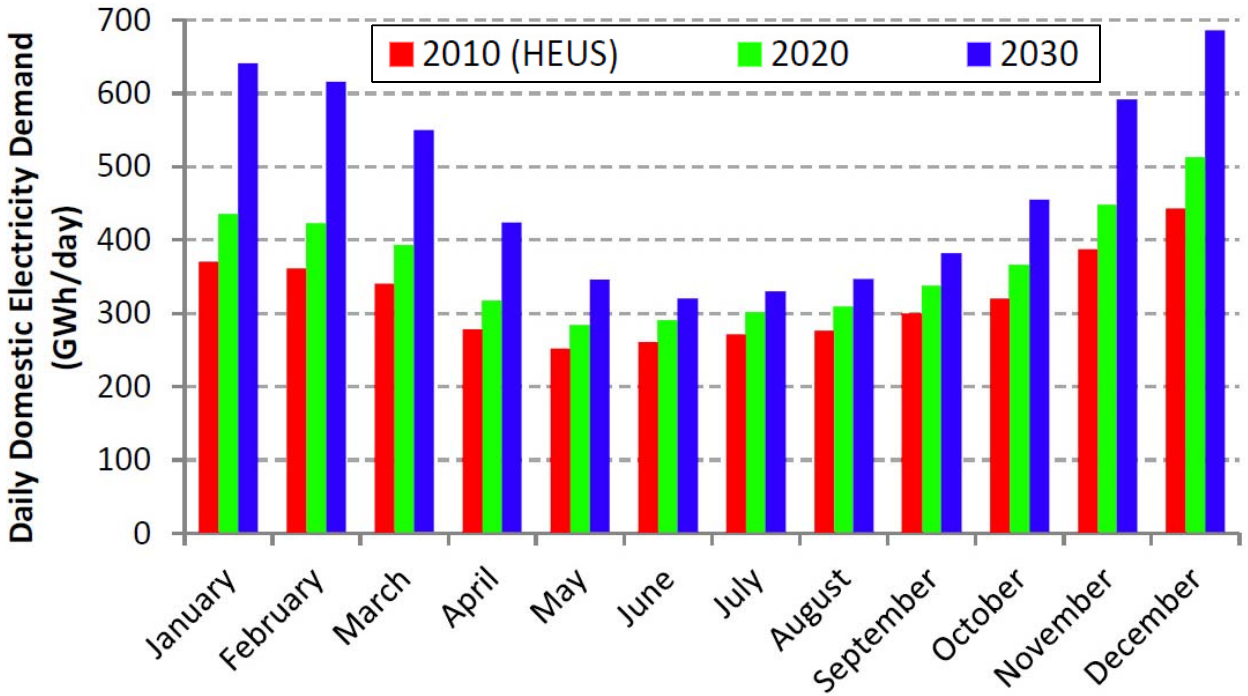
Demand UK -Prospective-

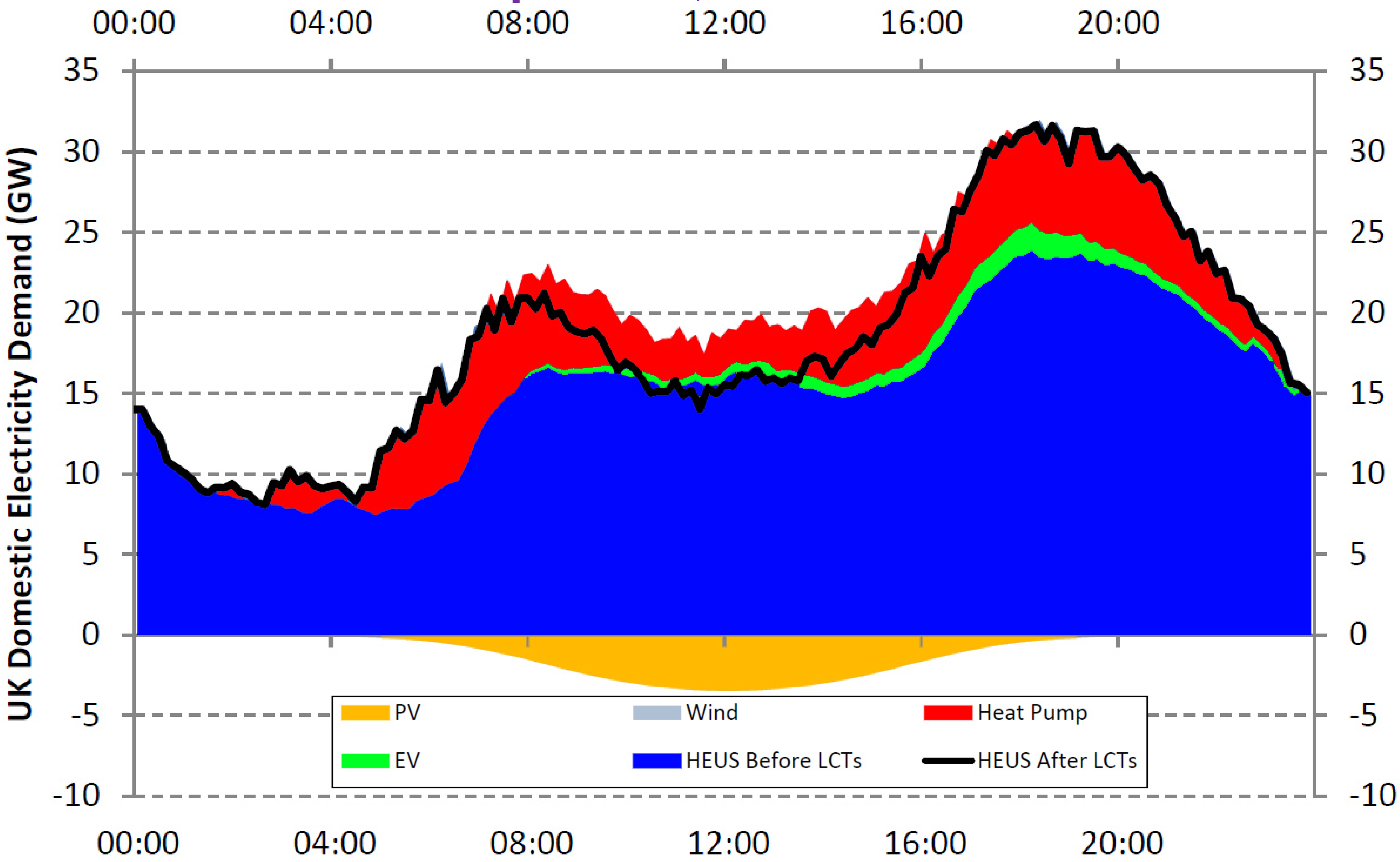
- UK domestic electricity demand from the grid is likely to rise substantially, to as much as **48% over current levels**, by 2030 driven by a **combination of population growth** and **demand from heat pumps** and **electric vehicles**, which are offset to some extent by embedded small scale wind and solar generation.

Forecast average daily electricity demand from domestic consumers



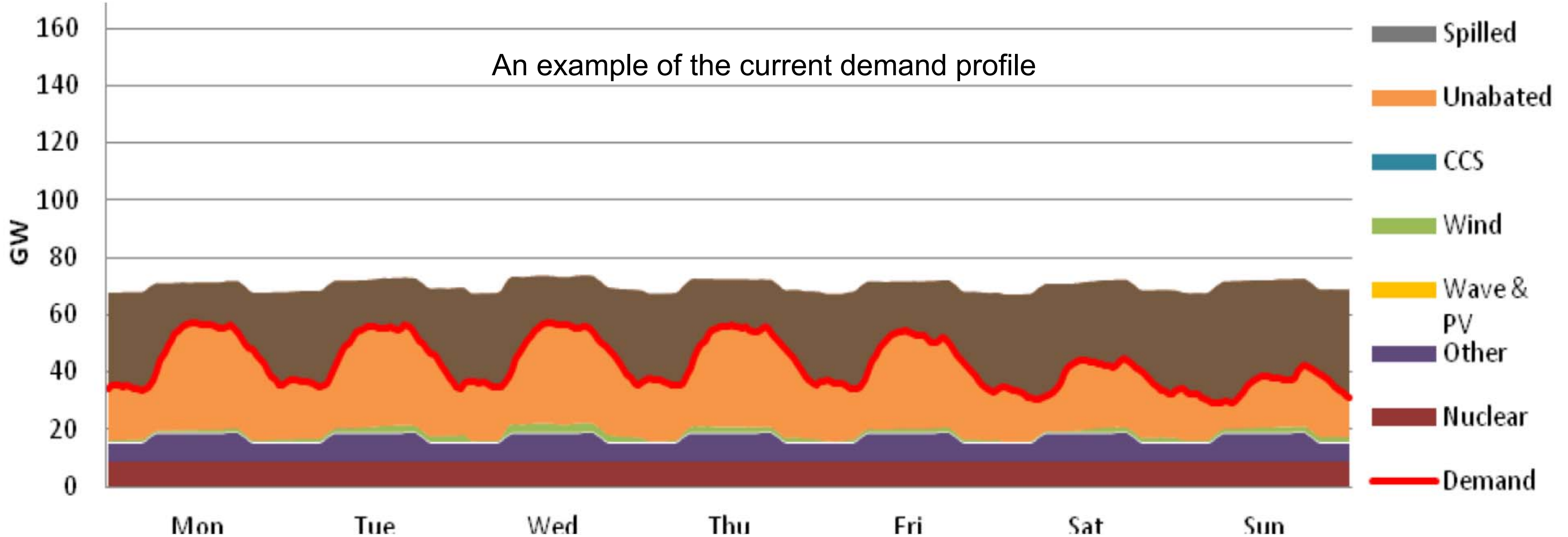
Demand UK -Prospective-

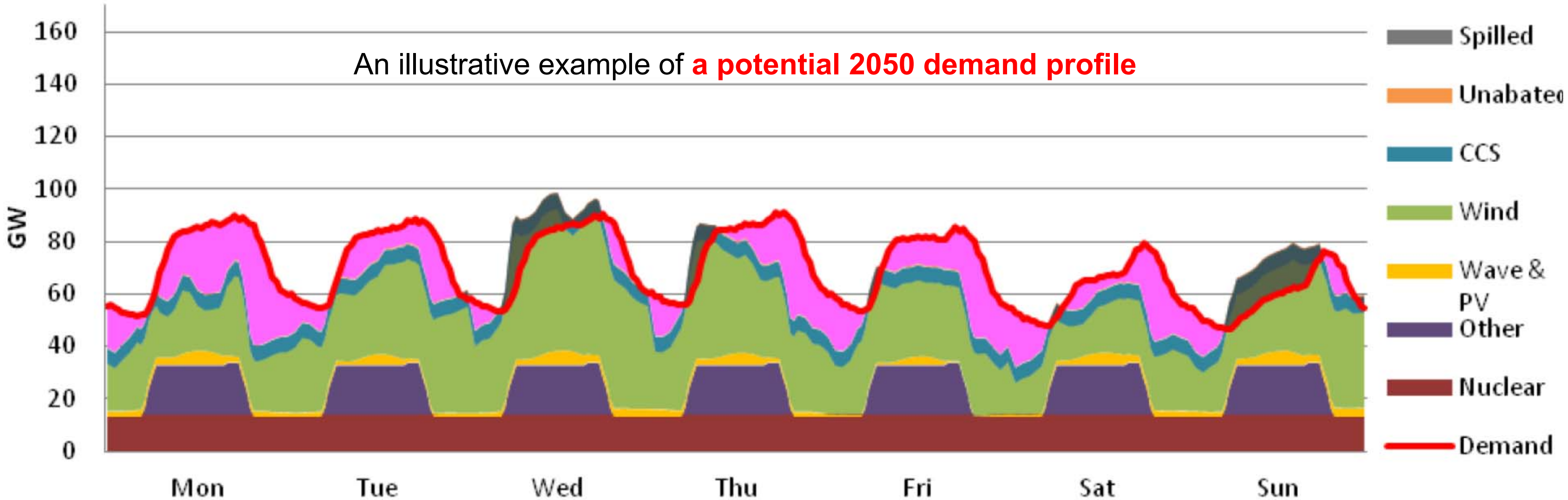
UK annual average electricity demand and generation profiles, in 2030



Issue: Balancing the System

- Balancing the system





Electric vehicle charging

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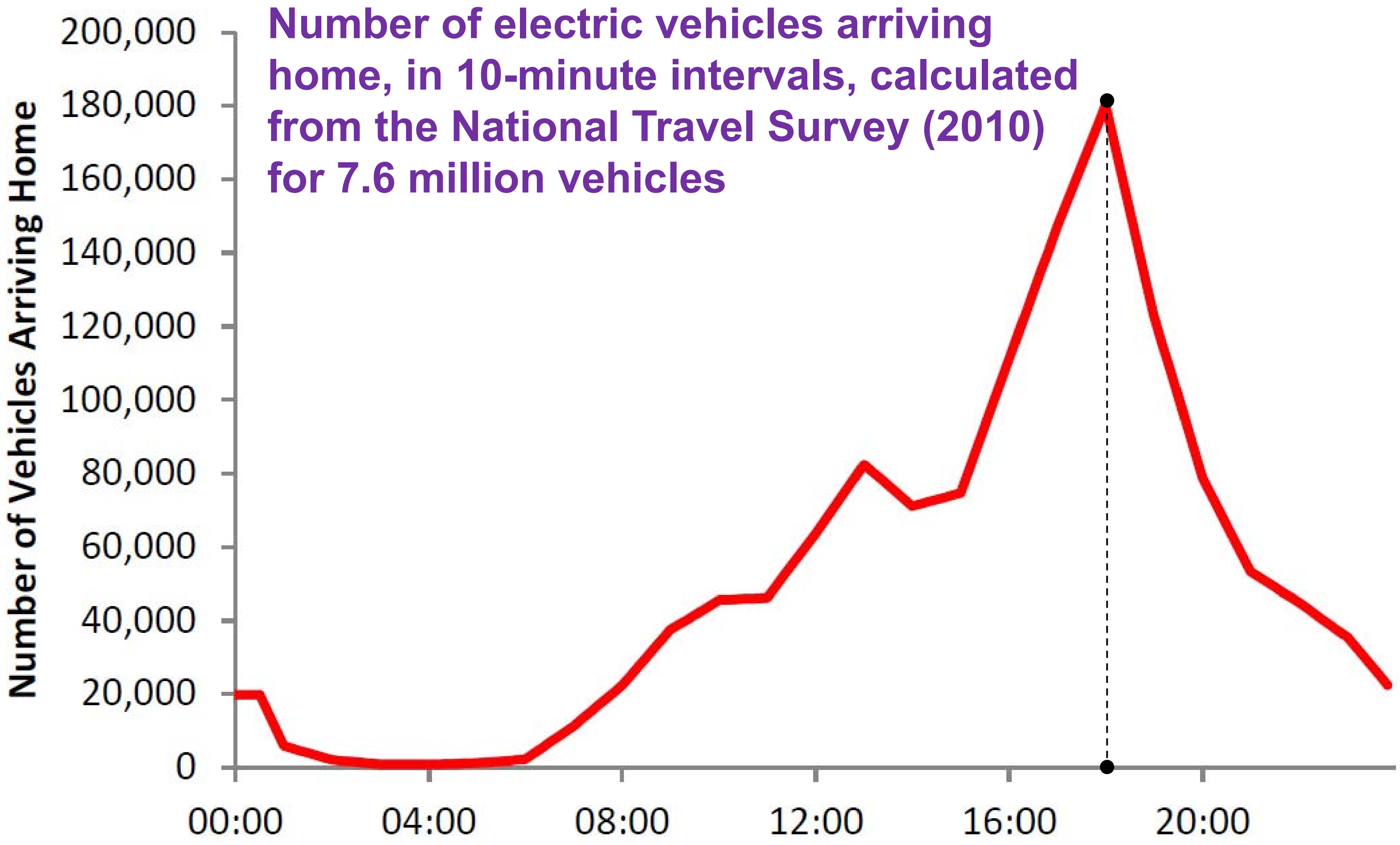
Electric vehicle charging

- Electric vehicle charging profiles have been constructed from data on time-of-arrival for drivers at their home destination, from the **National Travel Survey**.



http://www.element-energy.co.uk/wordpress/wp-content/uploads/2014/07/HEUS_Lot_II_Correlation_of_Consumption_with_Low_Carbon_Technologies_Final.pdf

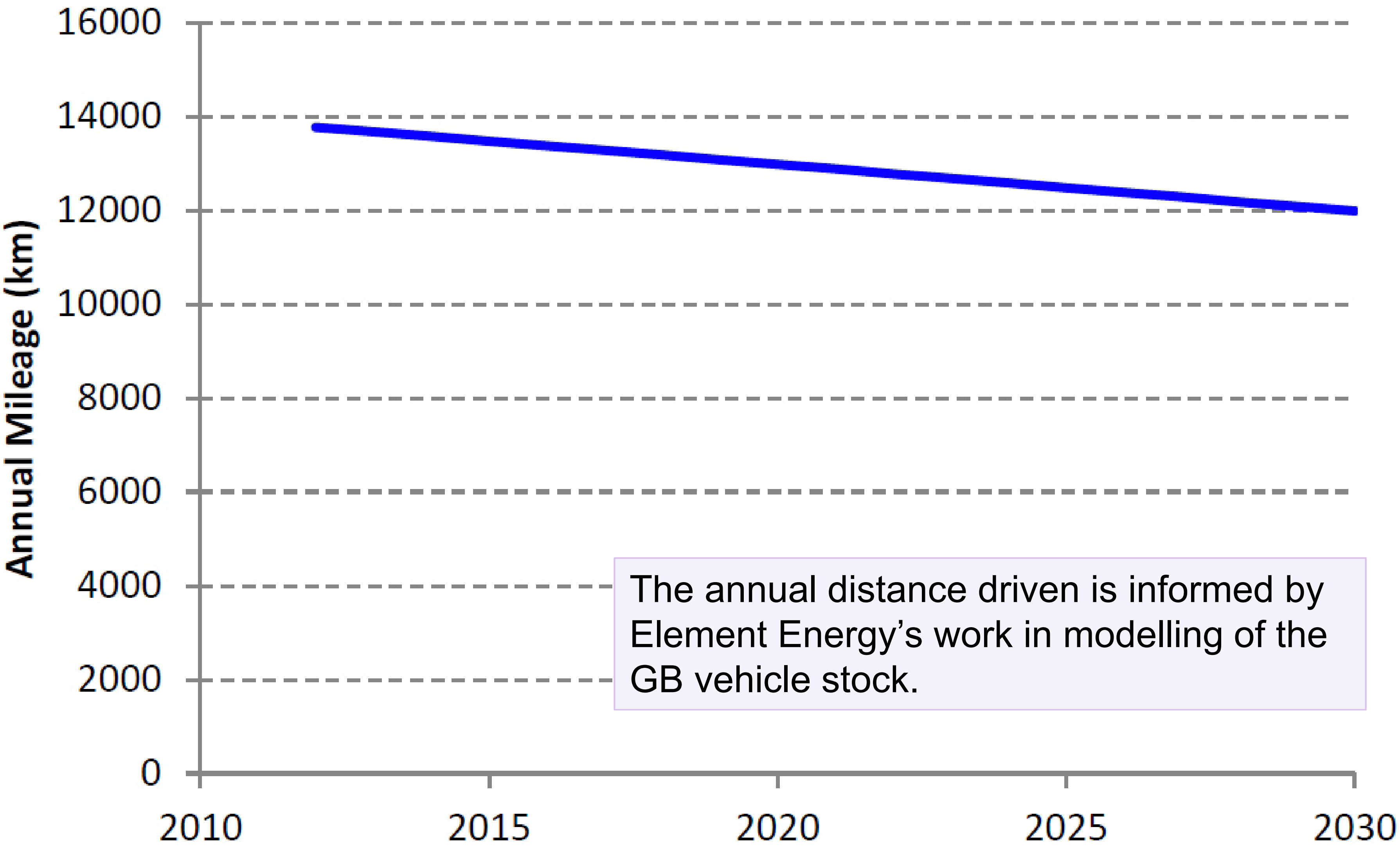
Electric vehicle charging

- For simplicity, it is assumed all drivers travel the same distance every day, 365 days per year

- The **charging profile** of a typical electric vehicle is aggregated here from an ensemble of vehicles (including PHEVs, RE-EVs and BEVs) and **arrival times**.

Annual Distance Driven

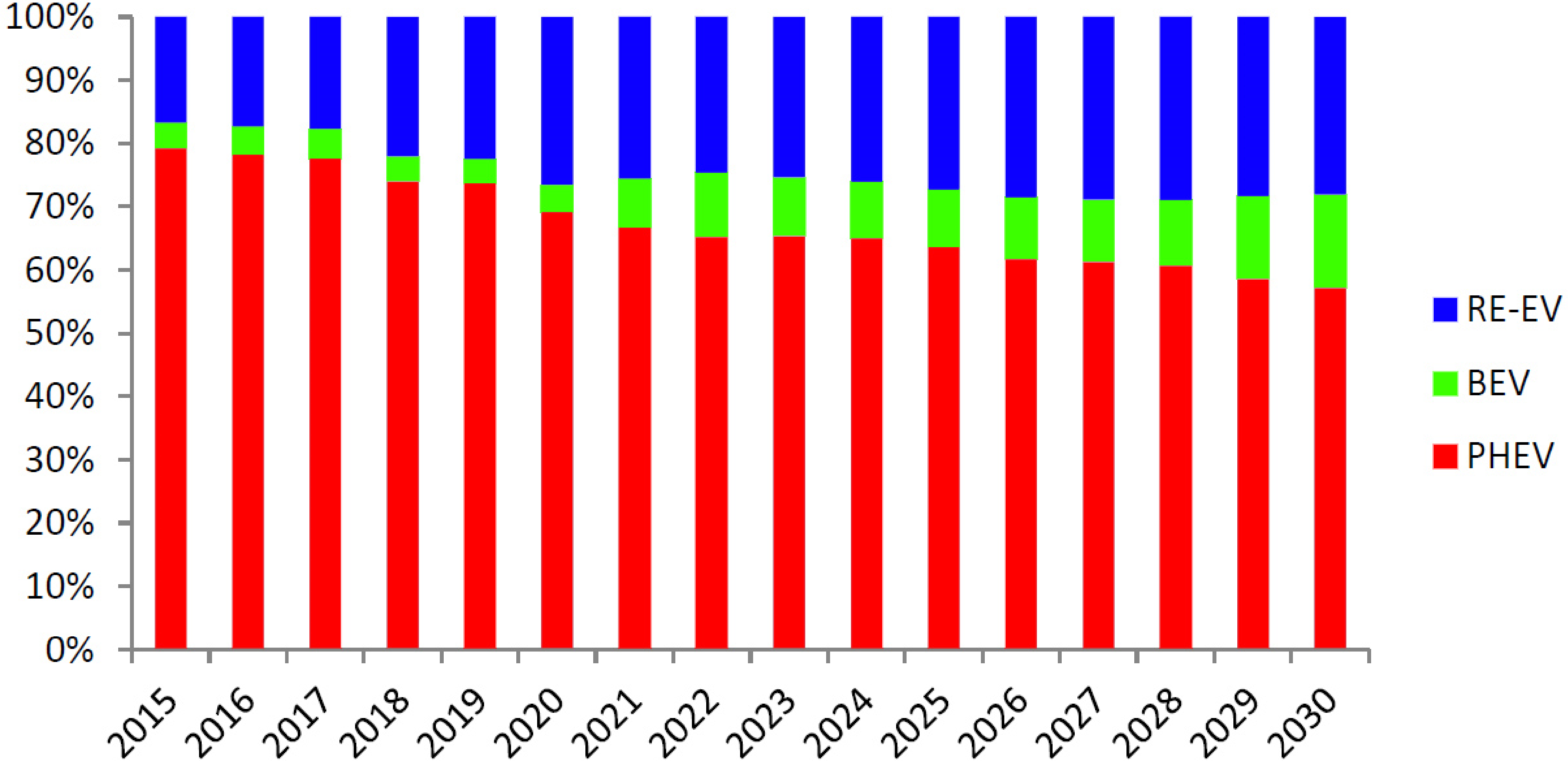
Annual electric vehicle mileage (km) as a function of year



The annual distance driven is informed by Element Energy's work in modelling of the GB vehicle stock.

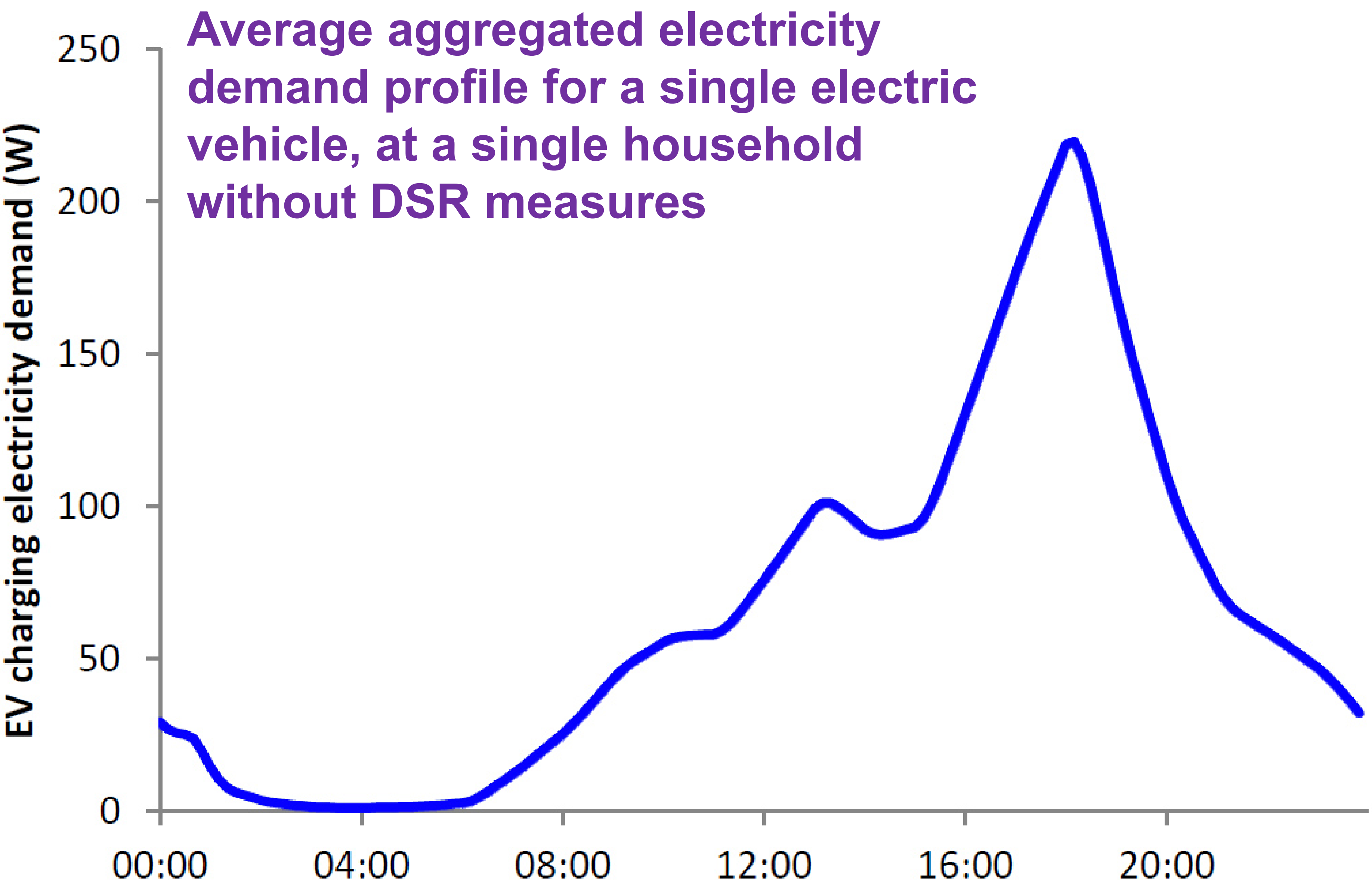
EV Type Evolution

EV type distribution, DECC Low Uptake Scenario



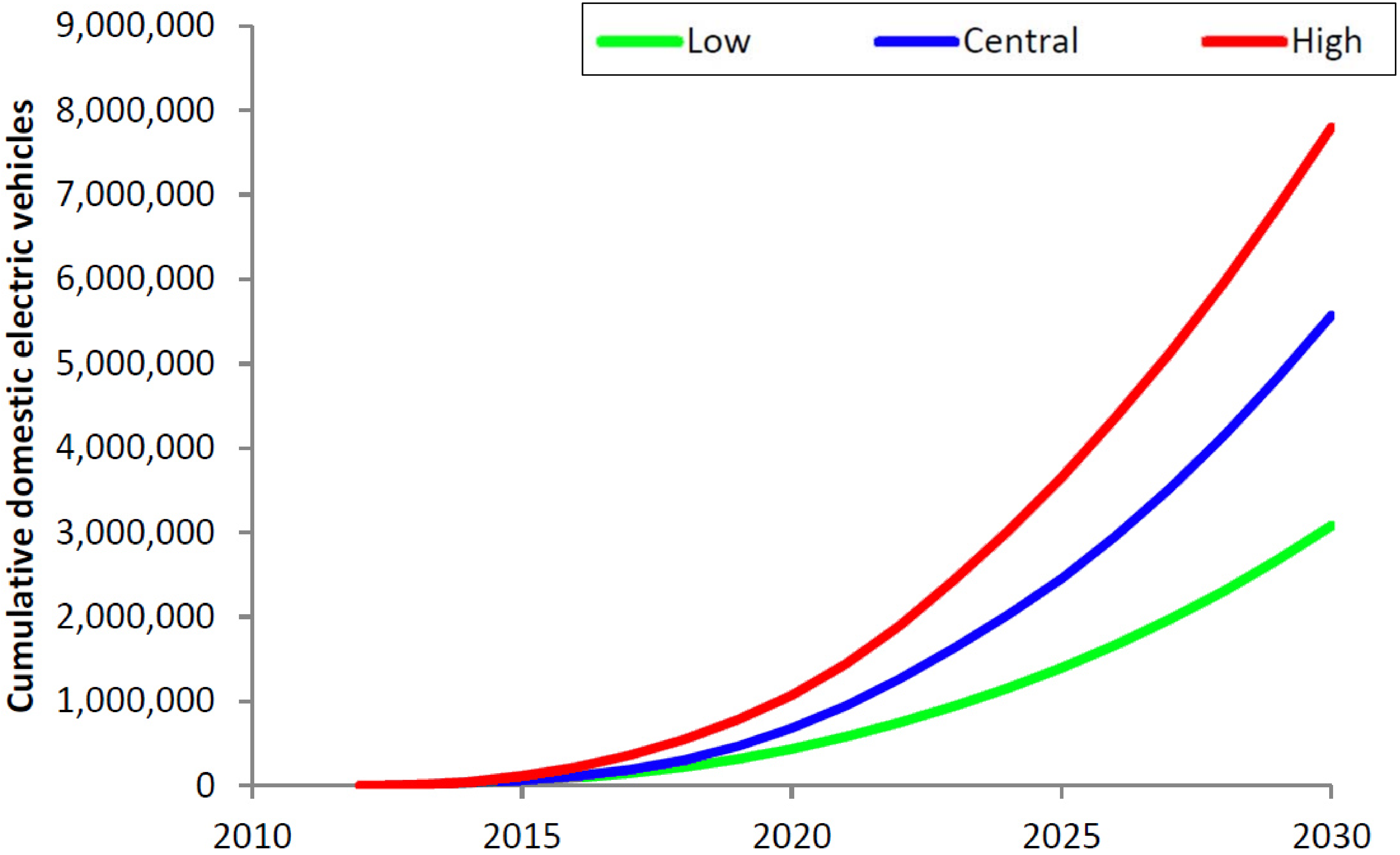
The modelling of electric vehicles assumes battery capacities of **8kWh** for PHEVs, **16kWh** for RE-EVs, and **22kWh** for BEVs

Demand Profile: EV



EV –Prospective 2030

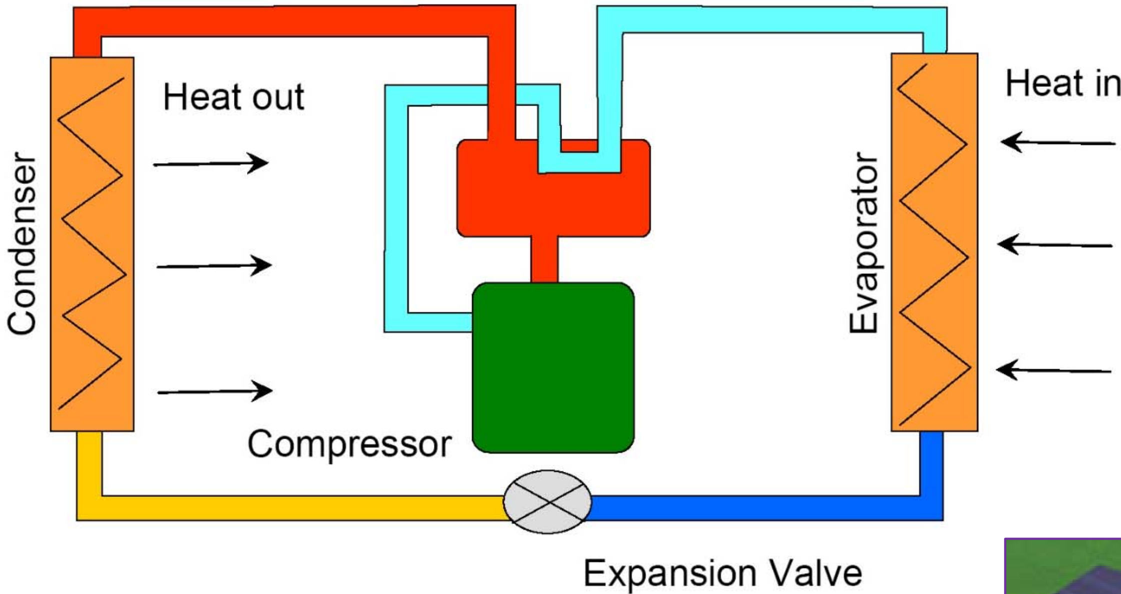
UK domestic electric vehicles uptake for 2012-2030



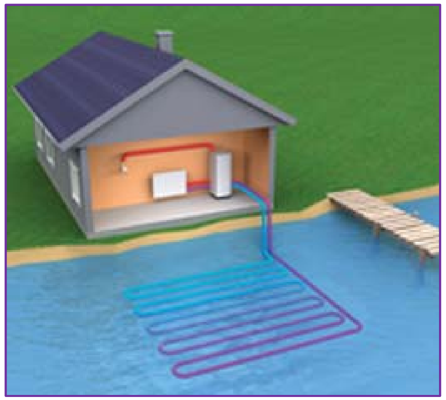
Domestic heat pumps

Heat Pumps: An Introduction

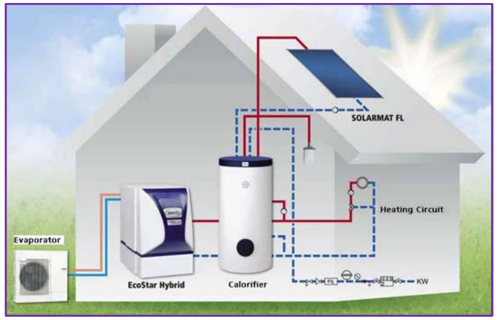
- Heat pumps **move temperature** from a **source** (ground, air or water) to a **destination** (your community building) in order to provide heating or cooling. They work in the same way as your fridge!



Ground source



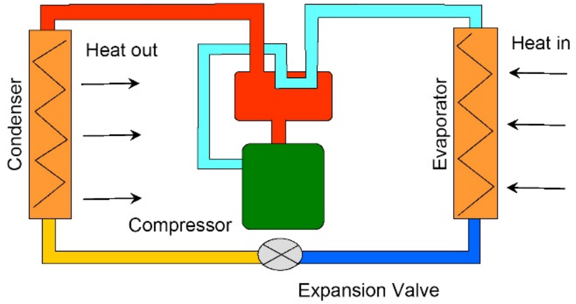
Water source

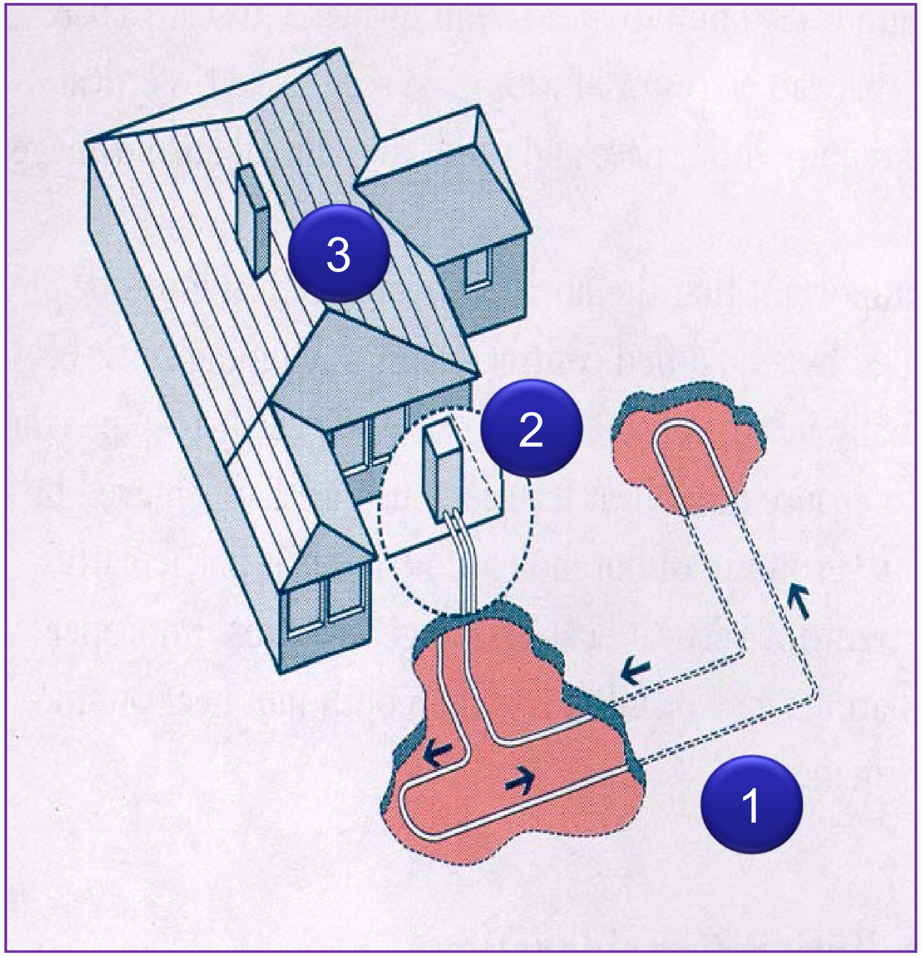


Air source

Components of GSHP Systems

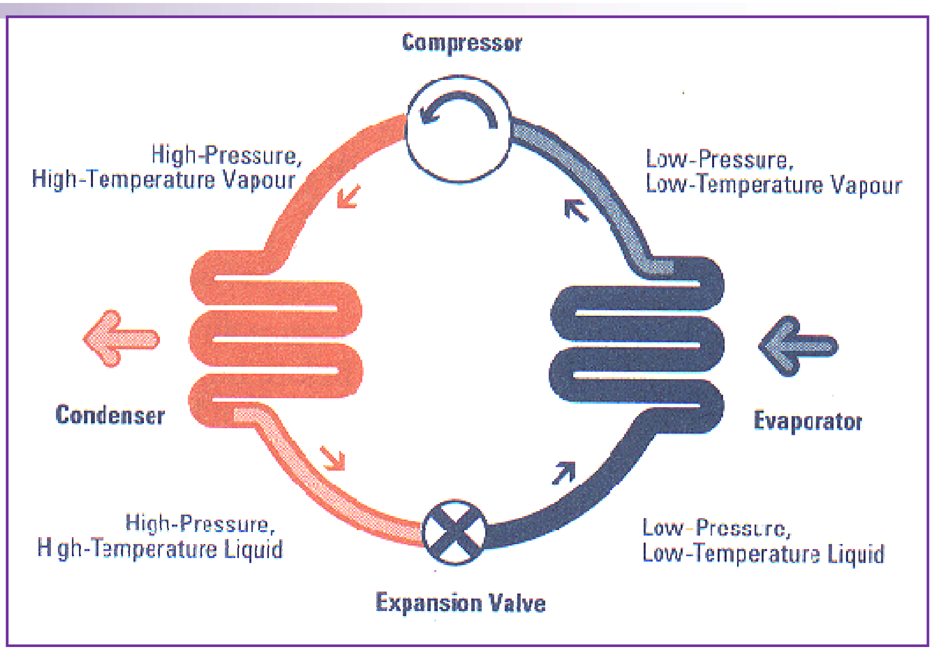
1. **Earth connection**
   - Ground-coupled
   - Groundwater
   - Surface water
2. **Liquid-source heat pump**
3. **Interior heating/ cooling distribution subsystem**
   - Conventional ductwork

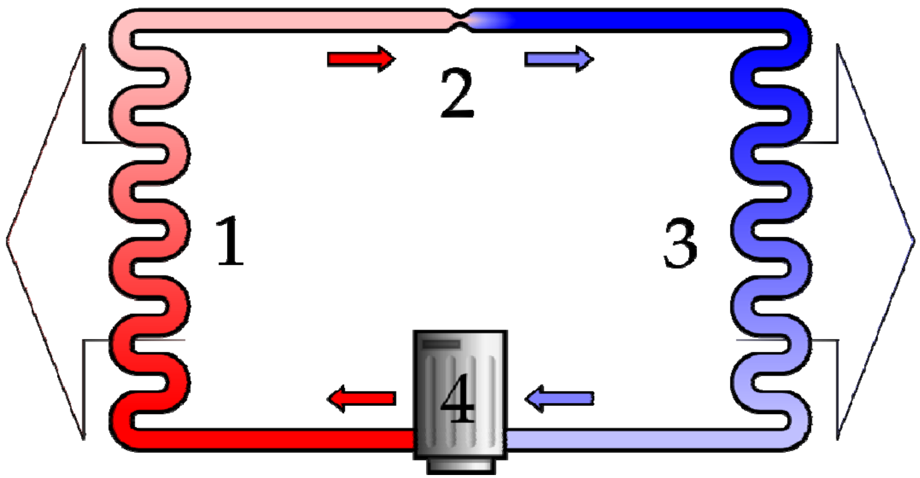




Liquid-Source Heat Pump

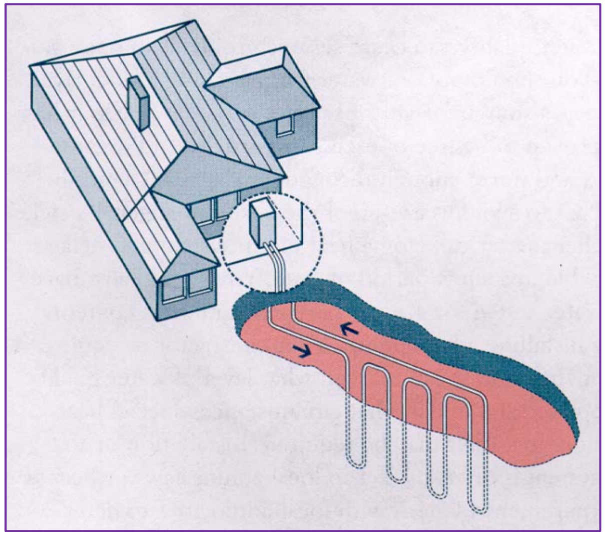
- Water-to-air heat pump
- Reverses direction
- 3.5 to 35 kW of cooling per unit
- Multiple units for big buildings
- Excess heat following compression provides hot water via de-superheater

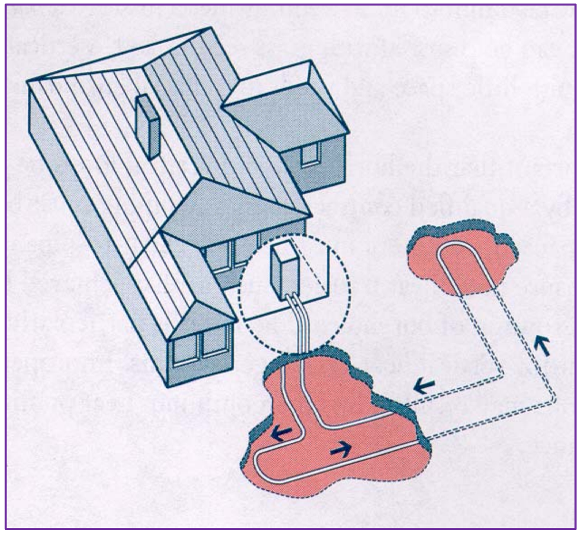


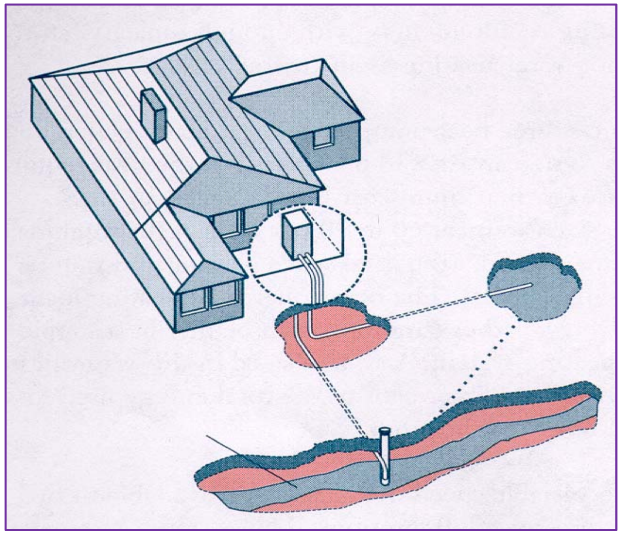


Ground-Source Heat Pumps

Vertical (GCHP)	Horizontal (GCHP)	Groundwater (GWHP)
• Rocky ground	• Most land used	• Aquifer+Injection
• More expensive	• Less expensive	• Least expensive
• Little land used	• Small buildings	• Regulations
• High efficiency	• Temp. varies	• Fouling



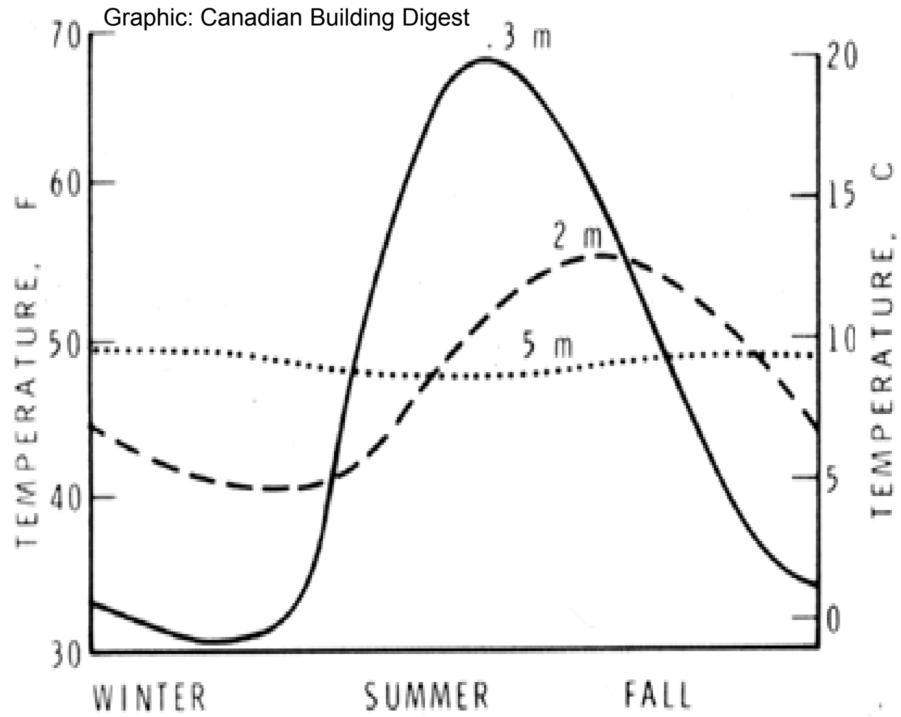


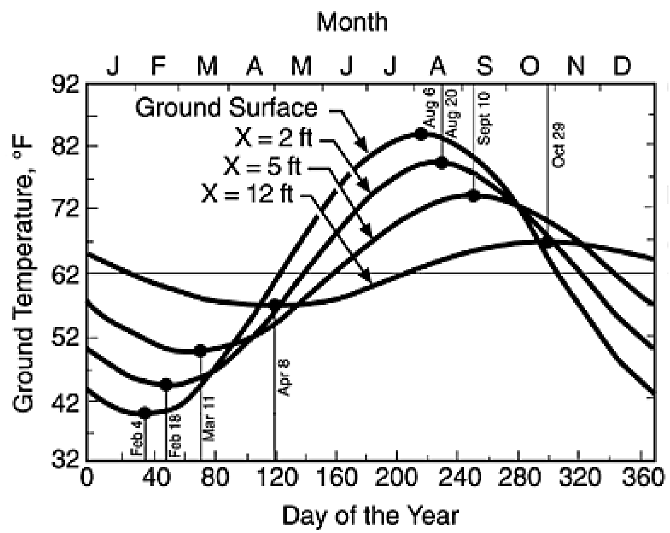


Also surface water and standing column heat exchangers

GSHP Resource: Ground Temperatures

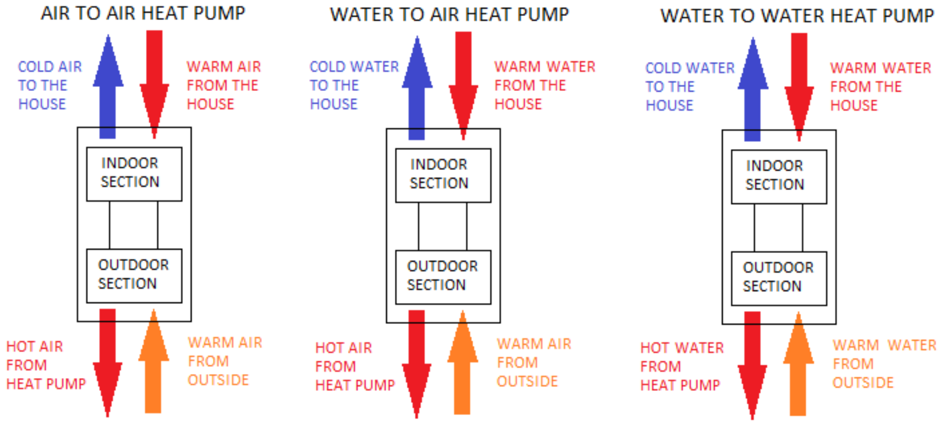
- Ground absorbs about half of sun's incident energy
- Ground dampens temperature variation
  - GSHP more efficient
- Temperature variation decreases with depth
  - Negligible below 15 m
- Local ground temperatures depend on climate, ground & snow cover, slope, soil properties, etc.





Domestic heat pumps

- The model for the operation of a typical heat pump is based on the performance of a *real device* with a **water heating loop** and a design flow temperature of 50°C and return temperature of 45°C.

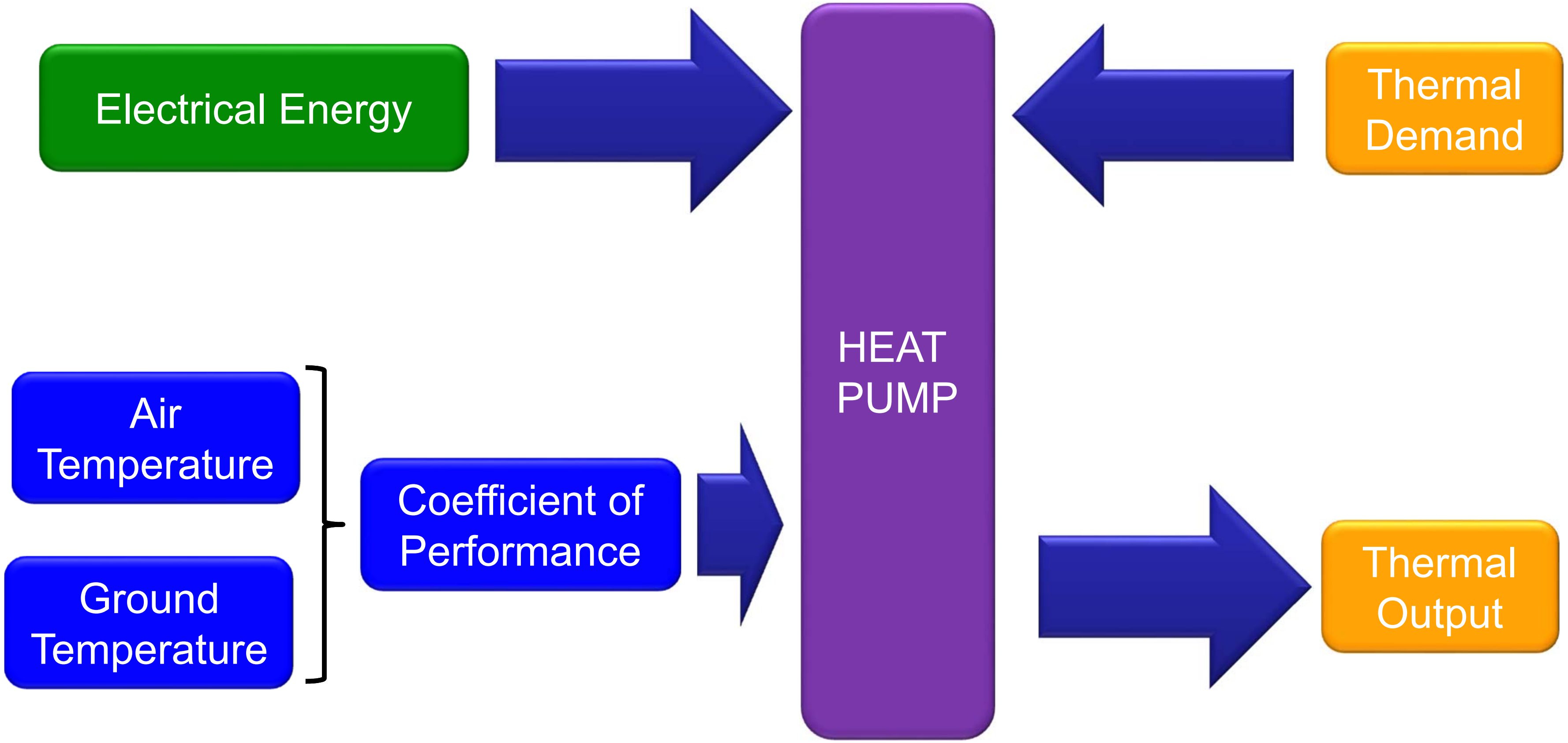


- It is assumed **no thermal loss** in pipes leading from the heat exchanger to radiators, and 20 litres of water in the heating system per kW of electric heating power, with a target indoor temperature of 20°C, based on figures from a publication for the **Energy Saving Trust** where heat pumps underwent field trial

EA Technology (2011), "The effect of thermostatic radiator valves on heat pump performance".
Kiwa GASTEC at CRE (2013), "Investigation of the interaction between hot water cylinders, buffer tanks and heat pumps".

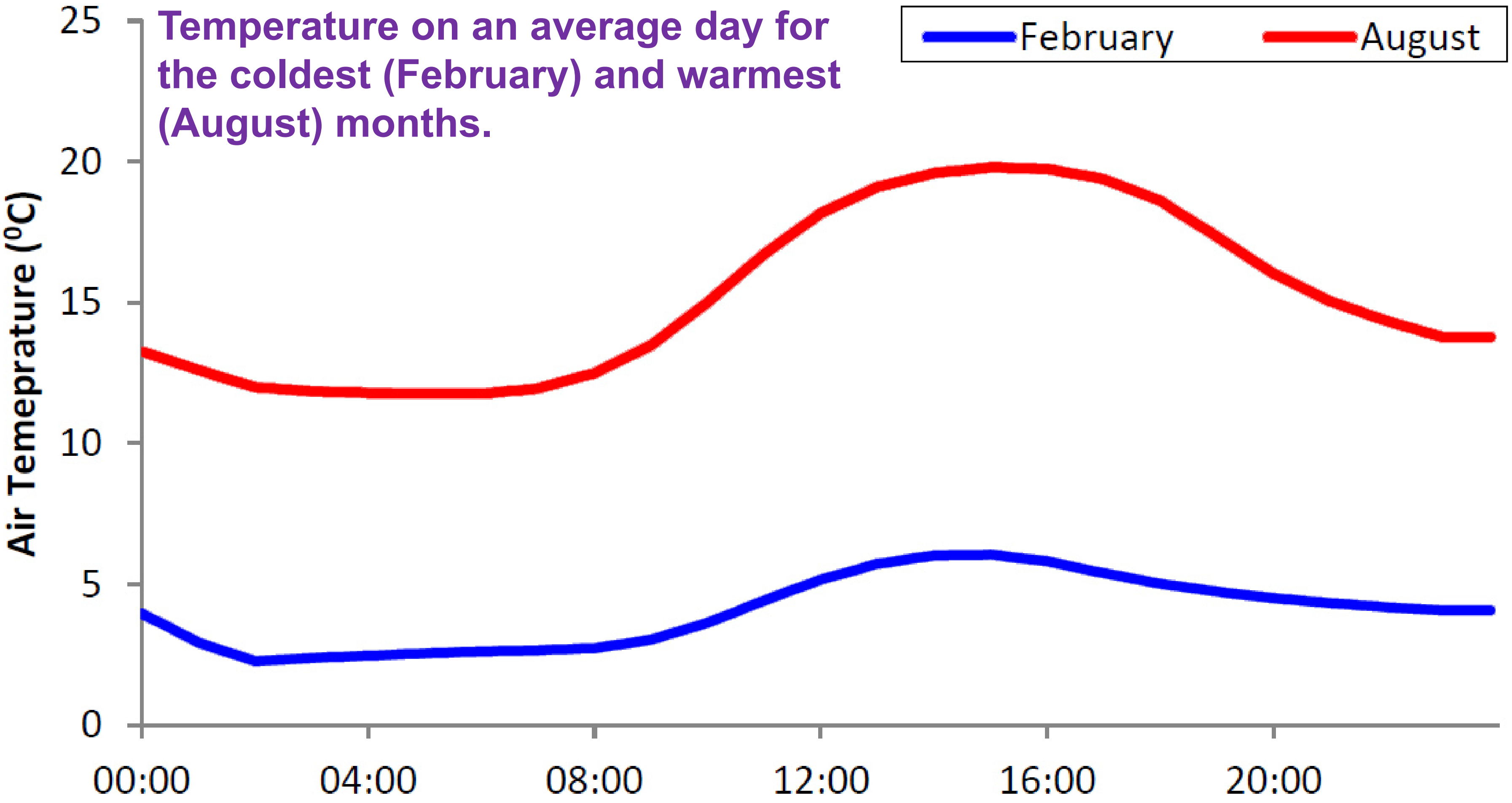
Heat Pump Model

Schematic of the heat pump model and its inputs and outputs



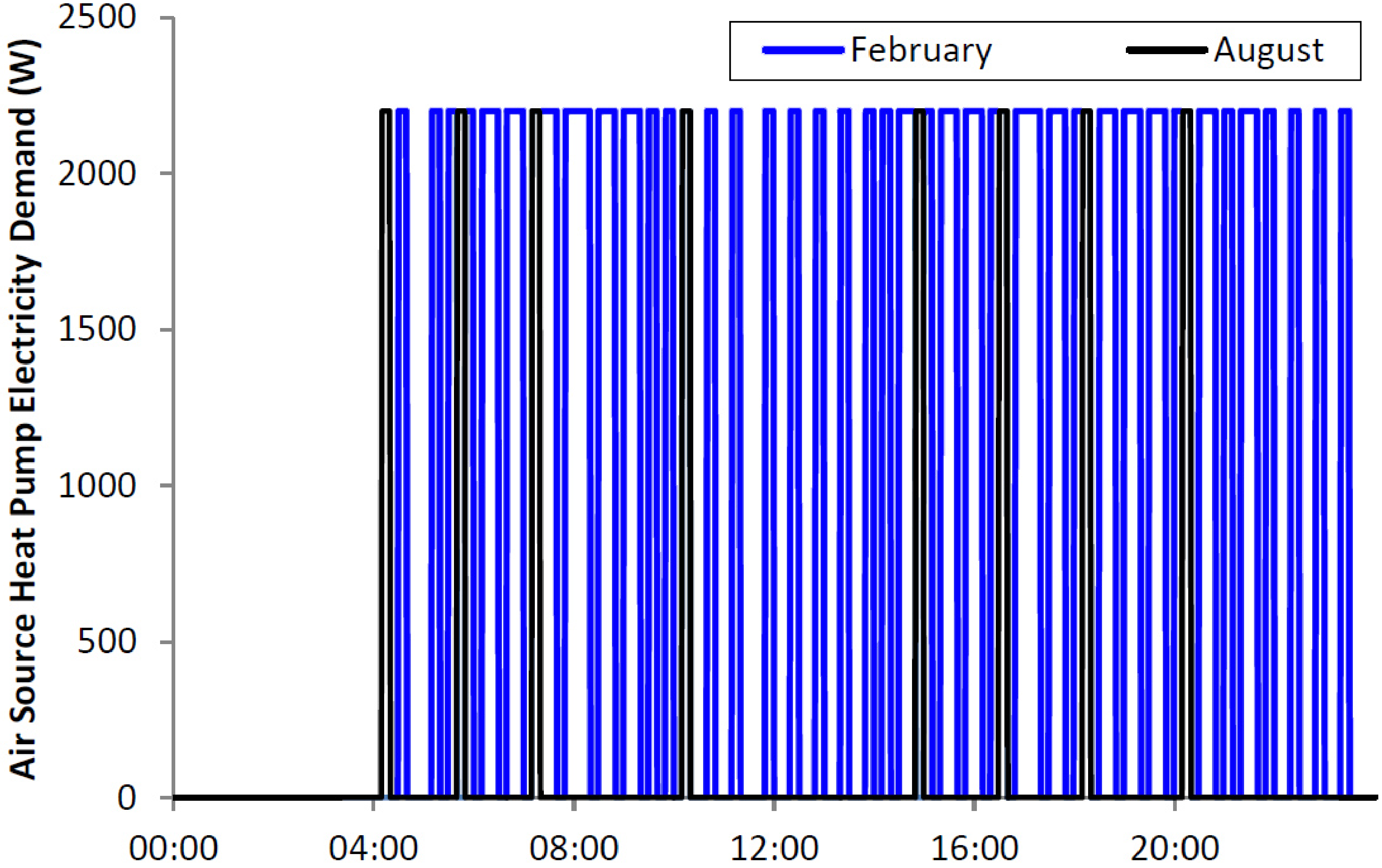
Domestic heat pumps

For each day in a given month, the mean temperature for each 10-minute interval has been calculated for a representative central England site



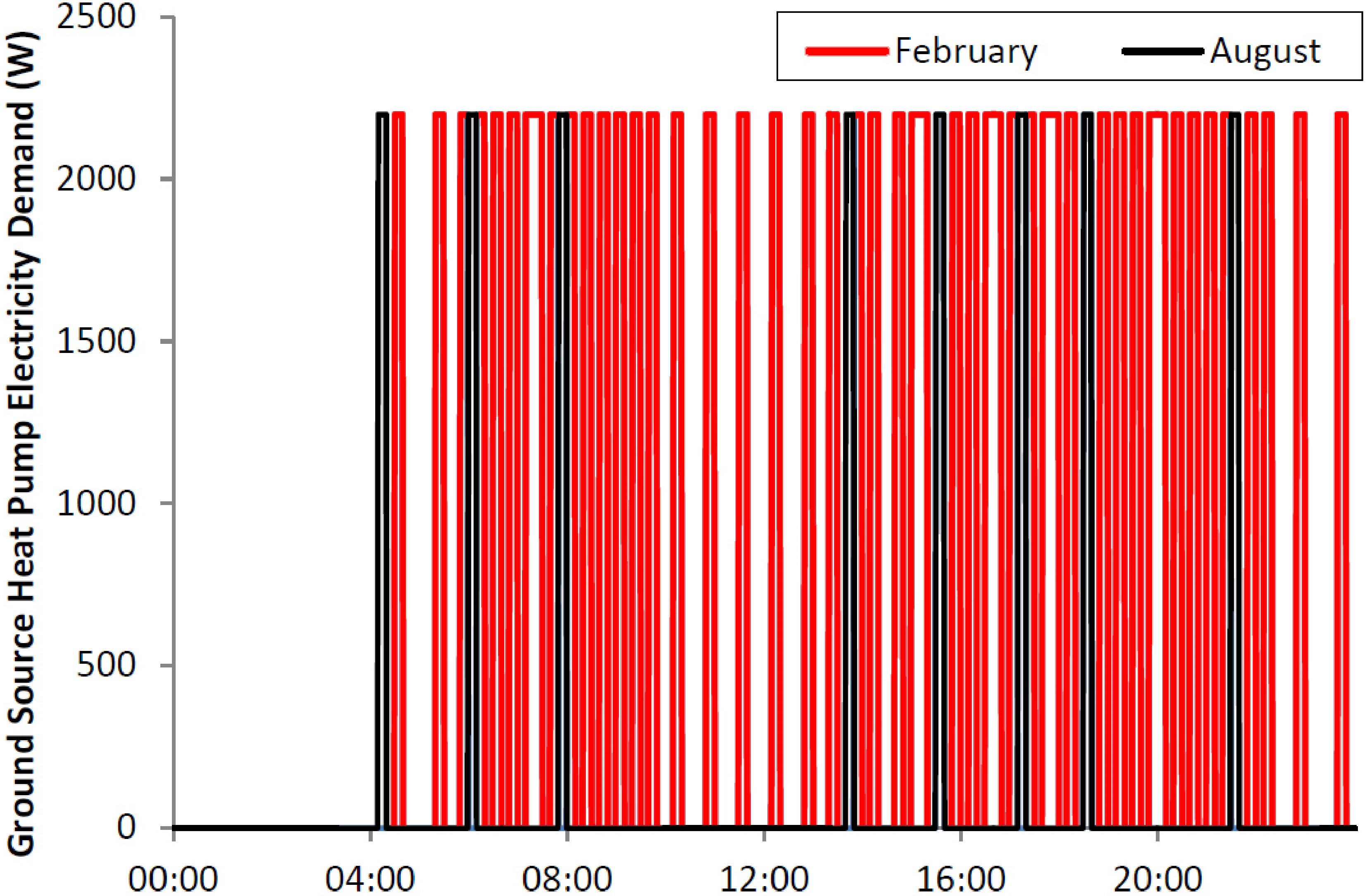
Electricity demand from an air source

Electricity demand from an air source heat pump during representative days in February and August



Electricity demand from a ground source

Electricity demand from a ground source heat pump during representative days in February and August



Heat Pumps – Renewable Heat Incentive

Government incentive to encourage the generation of renewable heat

- Owners of ground or water source heat pumps can **make money from heat generated by the system**
- Guaranteed for **20 years**
- **Retail price index linked**
- **Does not include air source heat pumps** (presently)
- **New incentive** – visit the Government website for further information and updates

http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/policy/incentive/incentive.aspx

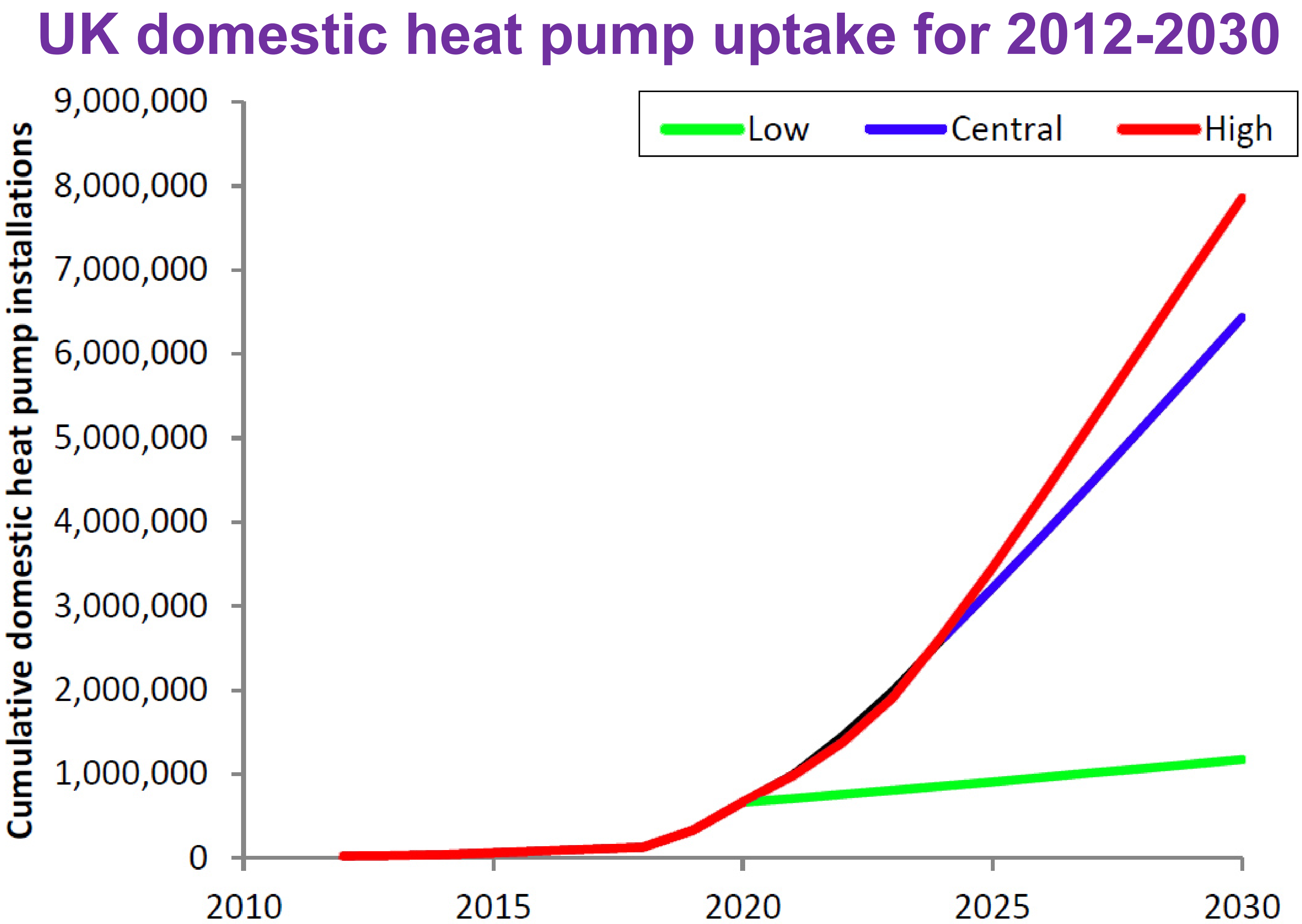
Heat Pumps – Case studies

North West Case Study – Barley village hall heat pump and PV

UK Case Study – A heat pump for a community building in Woolfardisworthy

Use the case study 'Barley village hall heat pump and PV' from the CLASP website (North West)
Use the case study: 'Heat pump for a community building in Woolfardisworthy' (UK) from
http://www.planlocal.org.uk/downloads/group/case-studies/page:2#listTop

Domestic heat pumps – Protective 2030



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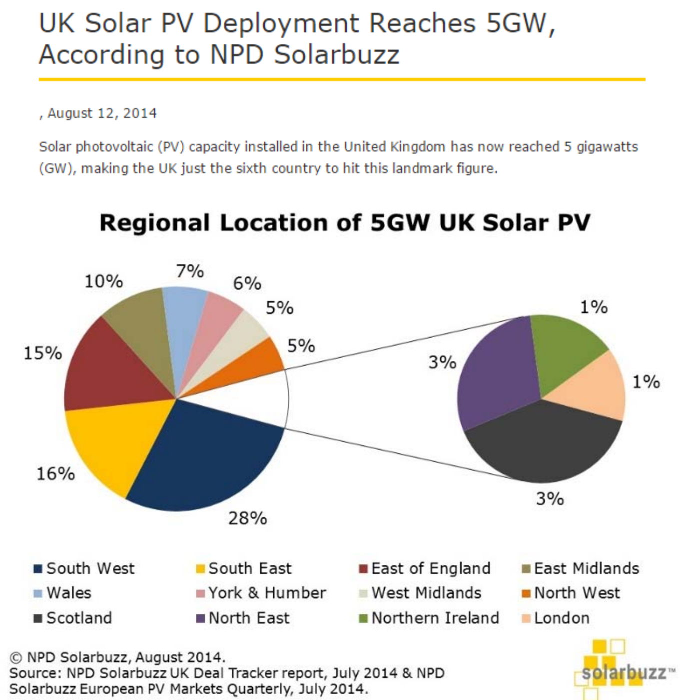
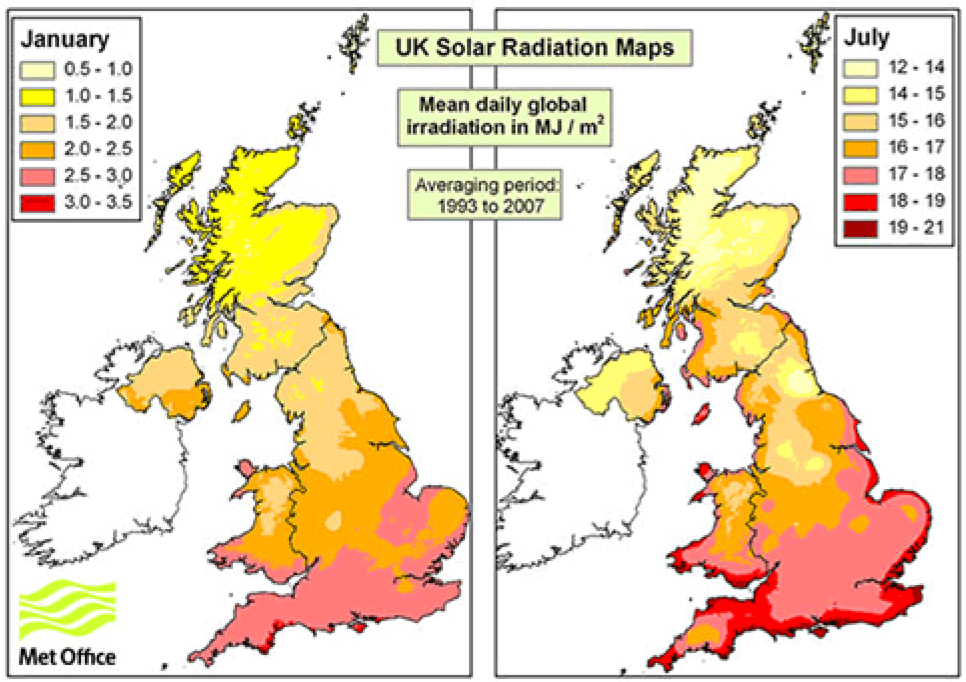
GOVERNMENT OF INDIA
Ministry of Science and Technology
Department of Science and Technology
Technology Bhavan, New Mehrauli Road
New Delhi - 110016

Domestic solar photovoltaic systems

- The number of domestic solar photovoltaic (PV) installations has increased rapidly in recent years, with over **480,000 systems of between 0 and 4kW$_P$ installed by November 2013**.
- On average, these systems are rated at 3kW$_P$ – the size assumed in this study for a *typical household installation*

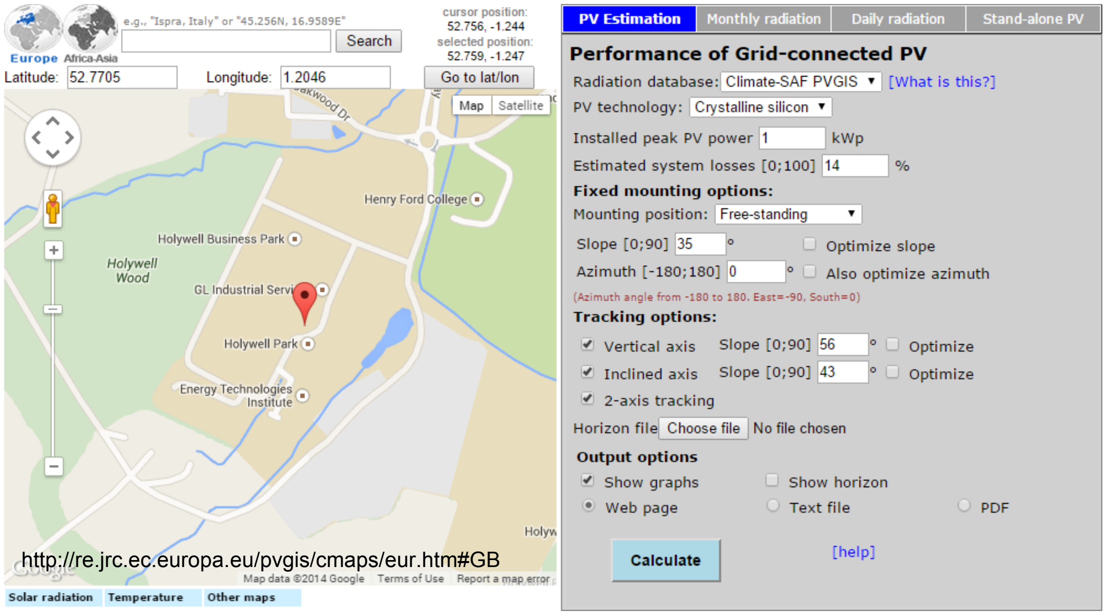




Department of Energy and Climate Change (2013), "Statistical data set: Weekly solar PV installation & capacity based on registration date".

Domestic solar photovoltaic systems

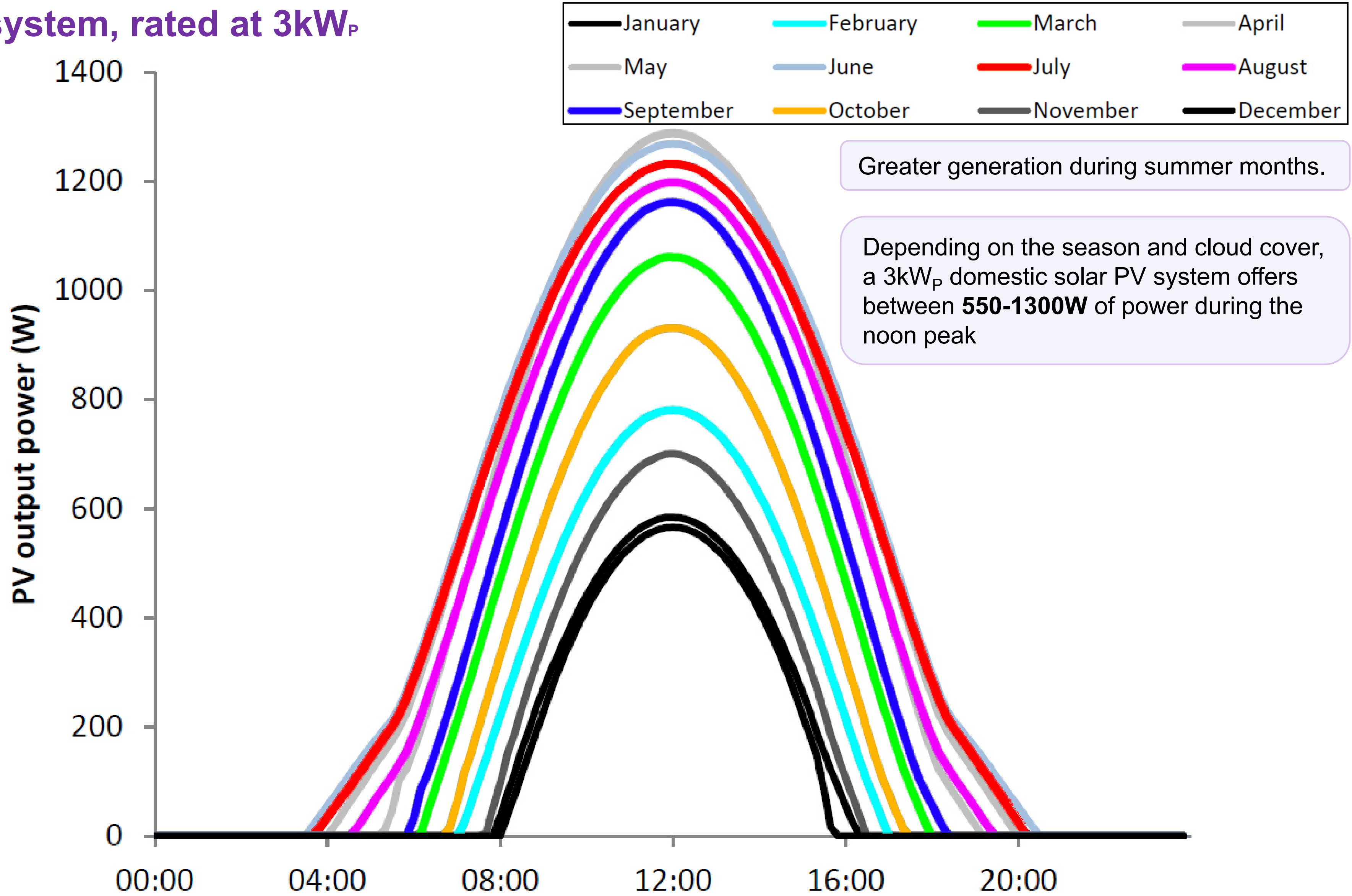
- The hourly PV generation profile shapes for each month are determined using the **PVGIS solar output estimation tool**, for a tilted plane on a southfacing, 40° tilt roof in Market Harborough, Leicestershire.
- This has been scaled to give electricity production of 937kWh/kW$_P$, as given by the MCS PV Installation Guide



Department of Energy and Climate Change (2013), "Statistical data set: Weekly solar PV installation & capacity based on registration date".
European Commission, Joint Research Centre (2013), "Photovoltaic Geographical Information System (PVGIS)".
The Microgeneration Certification Scheme (2013), "Solar Irradiance Datasets, MIS 3002". Note this source does not include inverter and charge controller losses, or any de-rating for soiling or shading.

Domestic solar photovoltaic systems

Modelled electricity generation from a typical domestic solar photovoltaic system, rated at 3kW$_P$

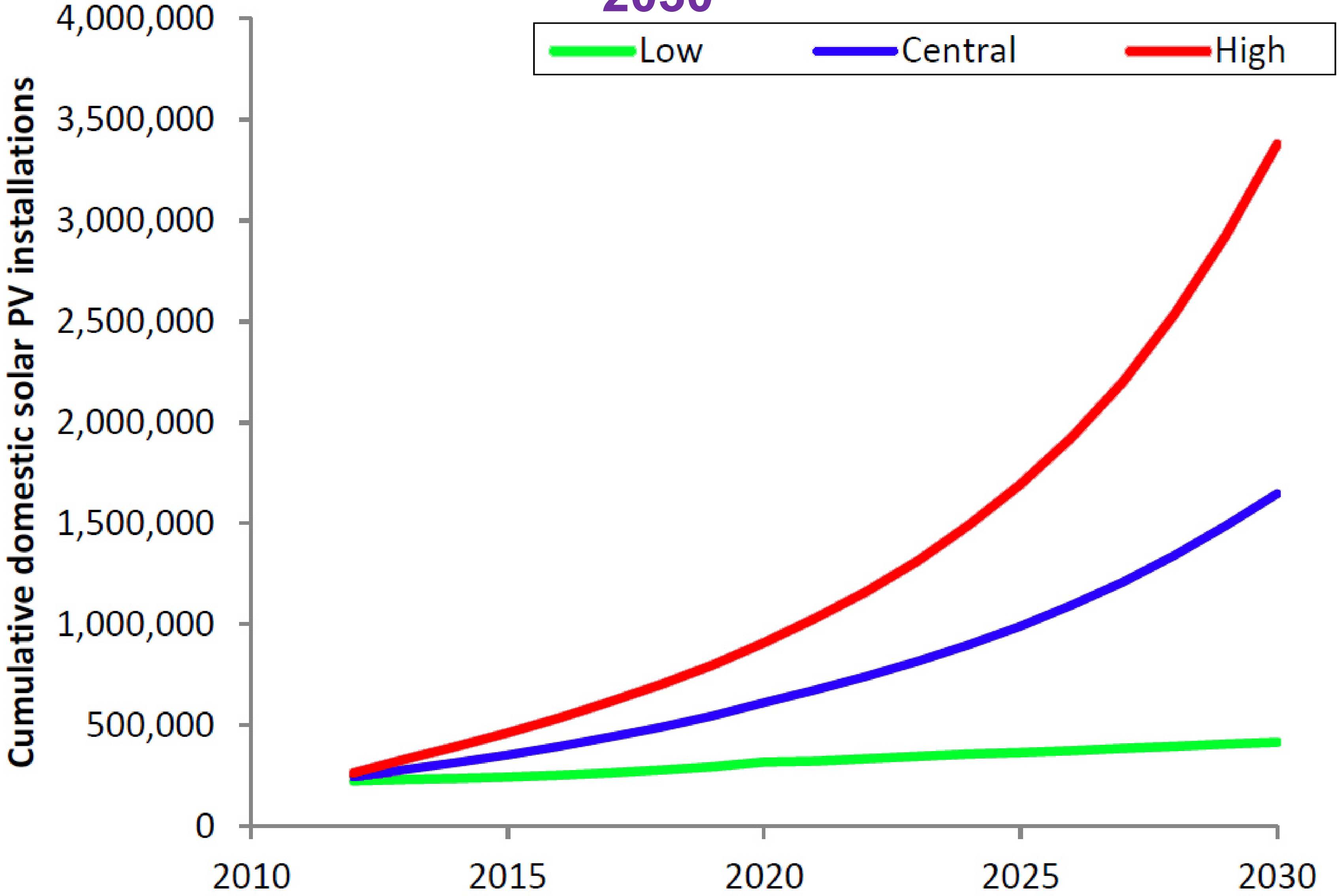


Greater generation during summer months.

Depending on the season and cloud cover, a 3kW$_P$ domestic solar PV system offers between **550-1300W** of power during the noon peak

Domestic solar photovoltaic systems

UK domestic solar photovoltaic systems uptake for 2012-2030



Small-scale wind turbines

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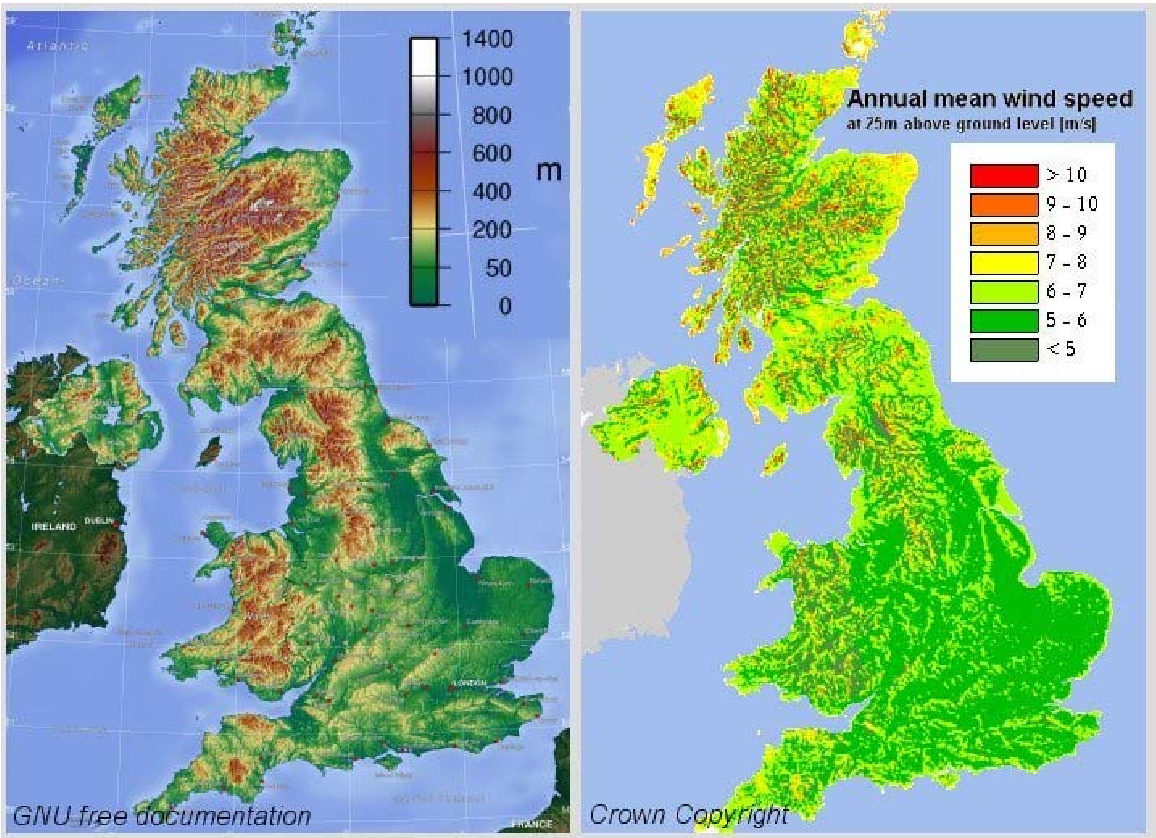
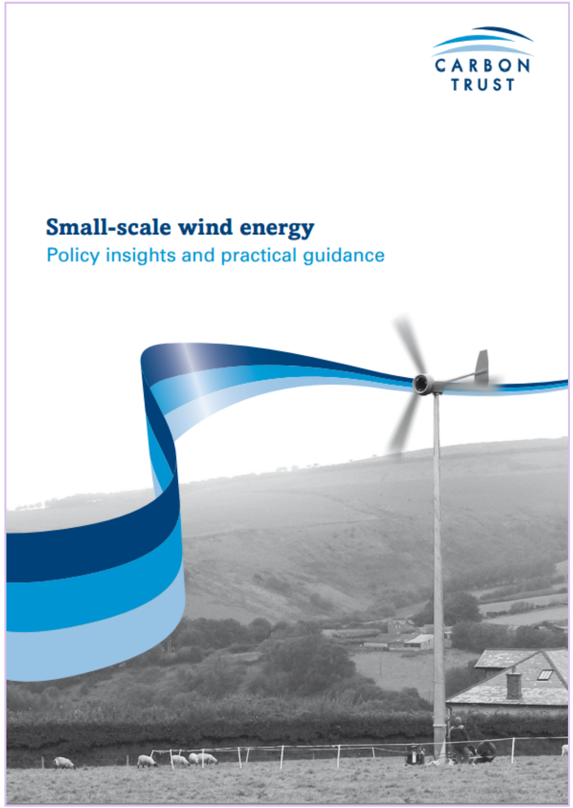
Small-scale wind turbines

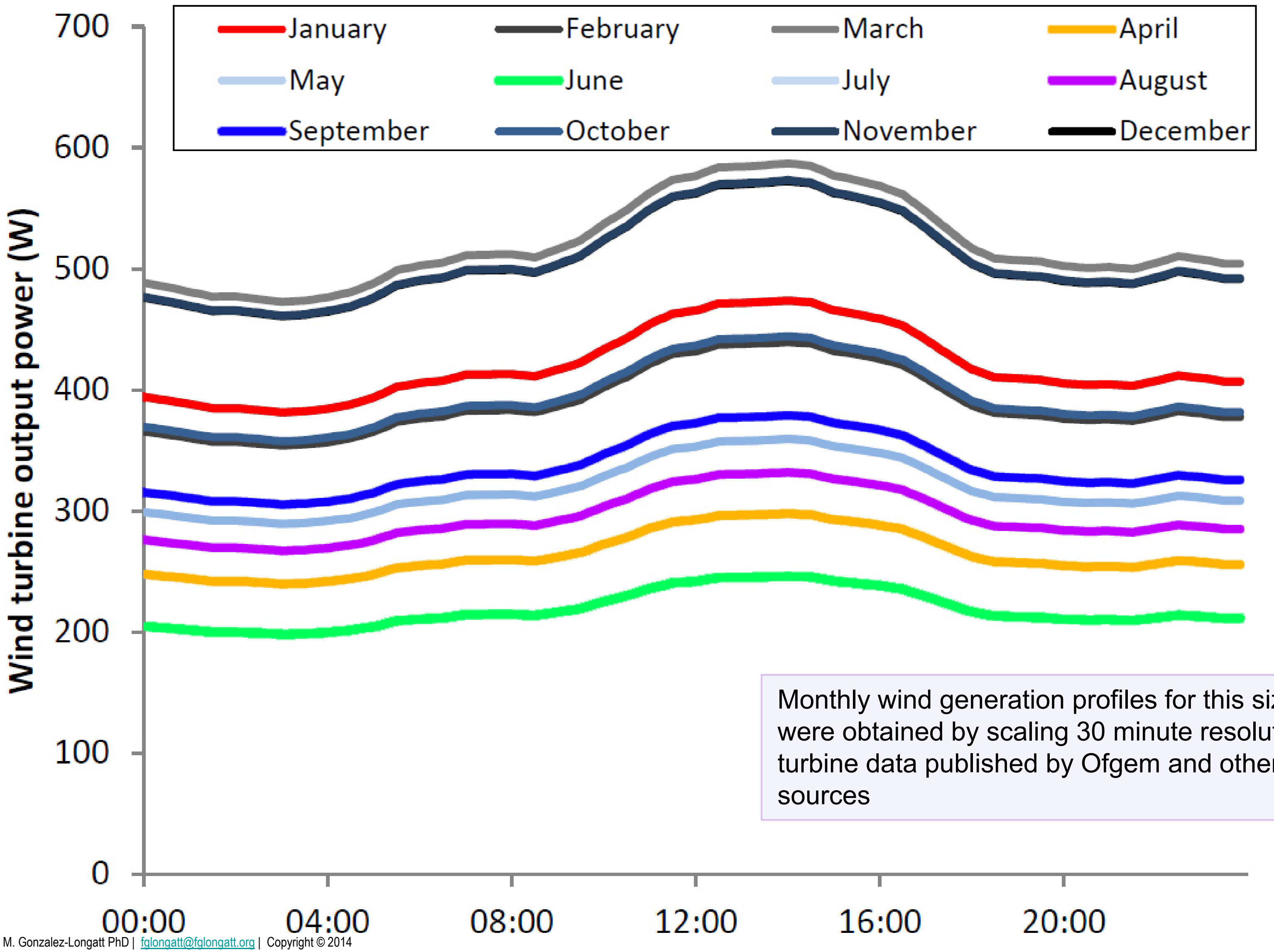
- In this report, we assume a typical small-scale wind turbine installation with a rated power of 2.5kW$_P$ and 15% load factor, based on typical installations in a report by the **Carbon Trust** and feed-in tariff generation statistics.





Small-scale wind turbines

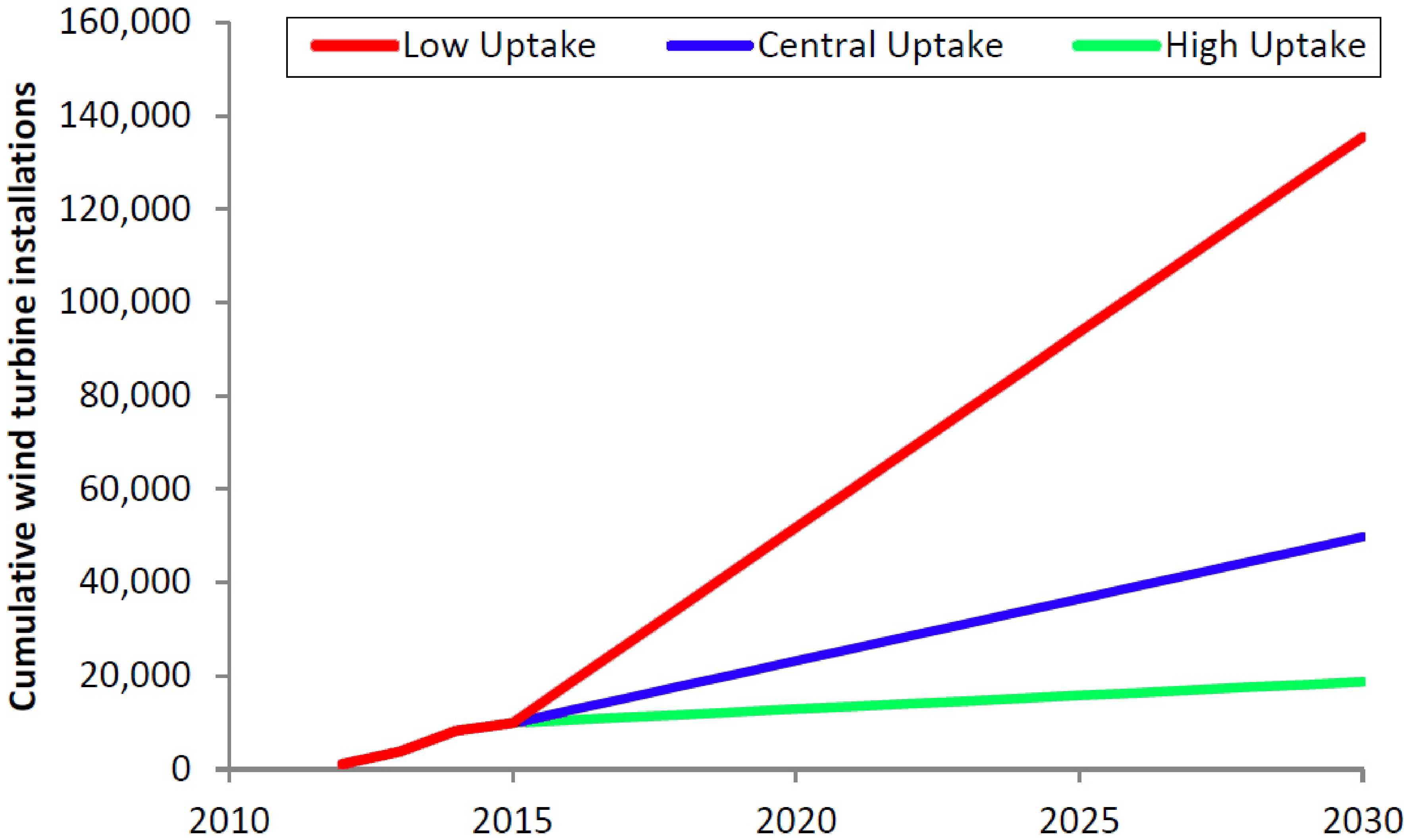
Modelled electricity generation from a typical small-scale wind turbine, rated at 2.5kW$_P$ with capacity factor of 15%.



Monthly wind generation profiles for this size system were obtained by scaling 30 minute resolution wind-turbine data published by Ofgem and other literature sources

Small-scale wind turbines -Prospective

UK domestic small-scale wind turbine uptake in the UK for 2012- 2030



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Define and Scenarios to reflect different rural and urban representative areas in UK

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Forecasting Horizons

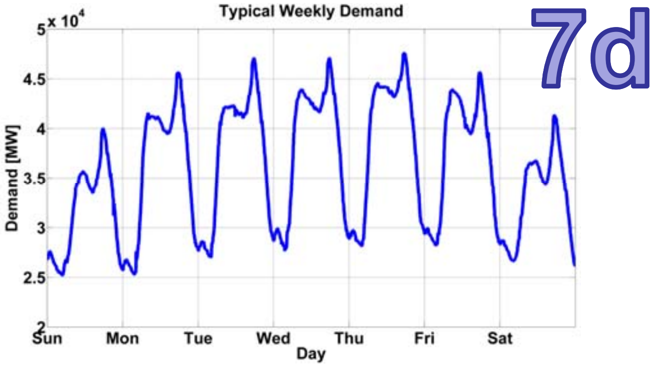
- **Long Term**
  - 5+ years into the future
  - R&D, plant location, product planning
  - Principally judgement-based
- **Medium Term**
  - 1 season to 2 years
  - Aggregate planning, capacity planning, sales forecasts
  - Mixture of quantitative methods and judgement
- **Short Term**
  - 1 day to 1 year, less than 1 season
  - Demand forecasting, staffing levels, purchasing, inventory levels
  - Quantitative methods

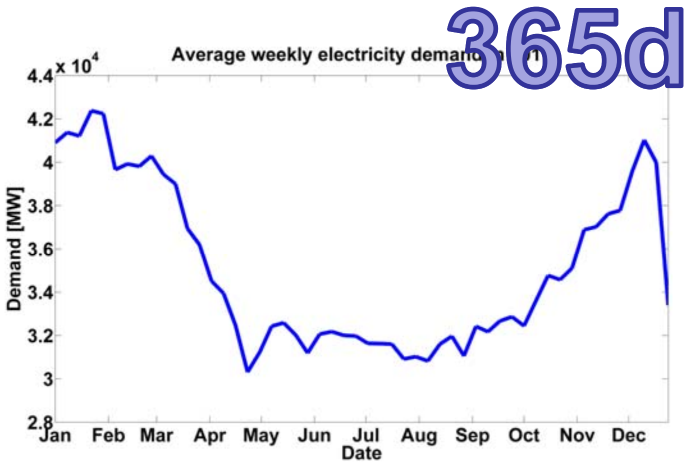
Dilemma: Time Resolution

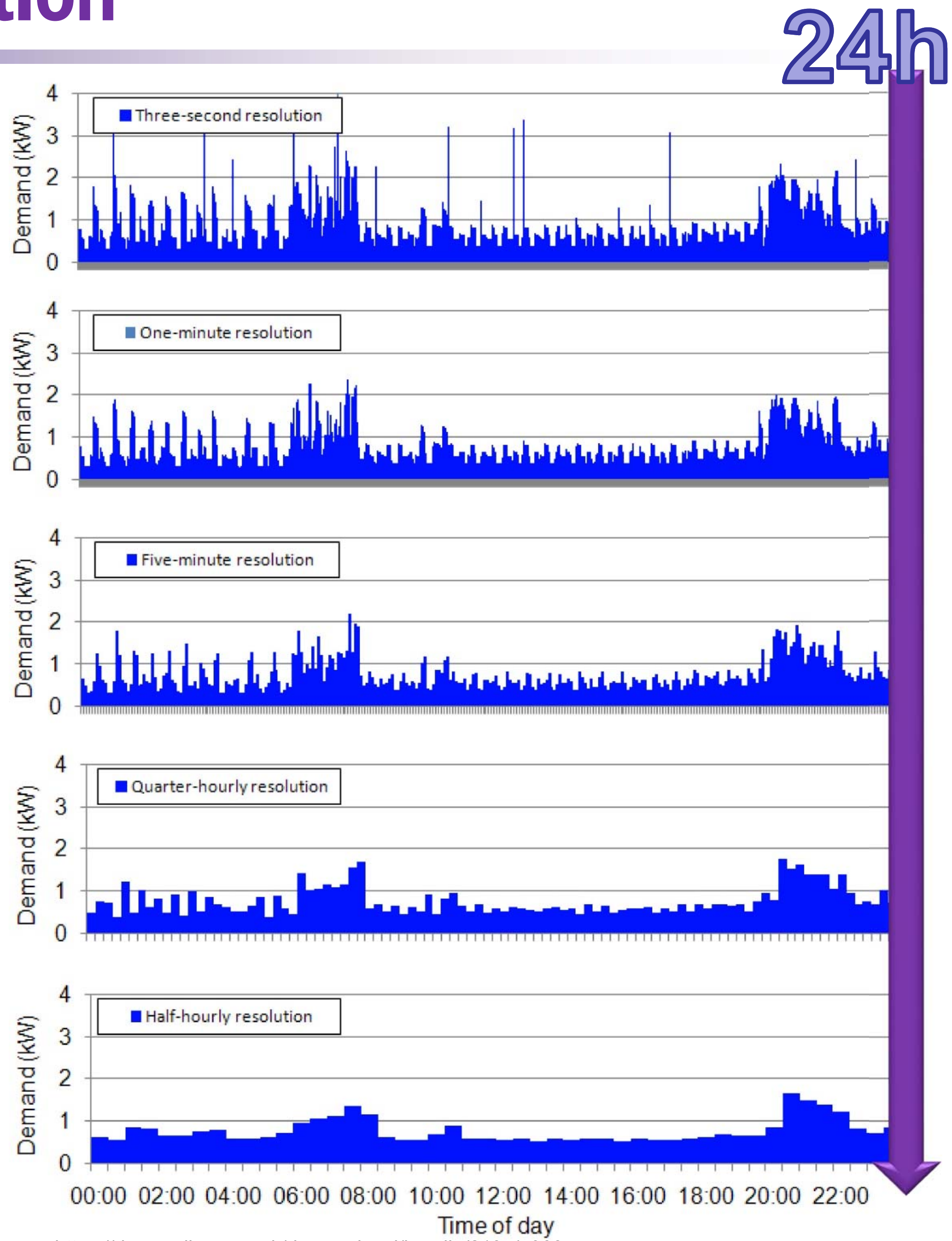
Time Resolution:

An issue with two faces:

- **Short Term Balancing**
- **Long Term Balancing**





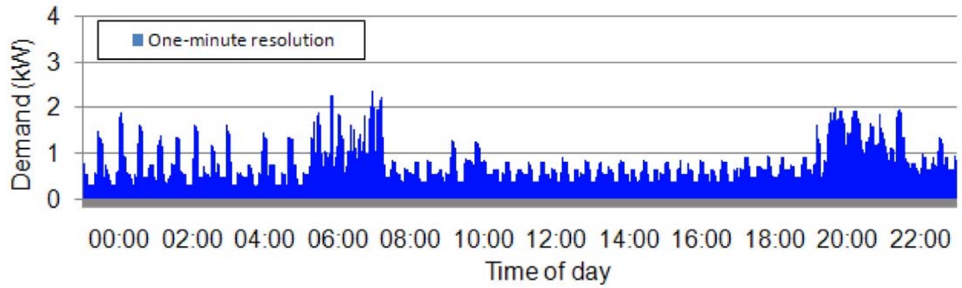


http://www.physics.gla.ac.uk/~shild/grid2025challenge/introduction.html

https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/7968

Dilemma: Time Resolution

- A **one-minute time resolution** was chosen.

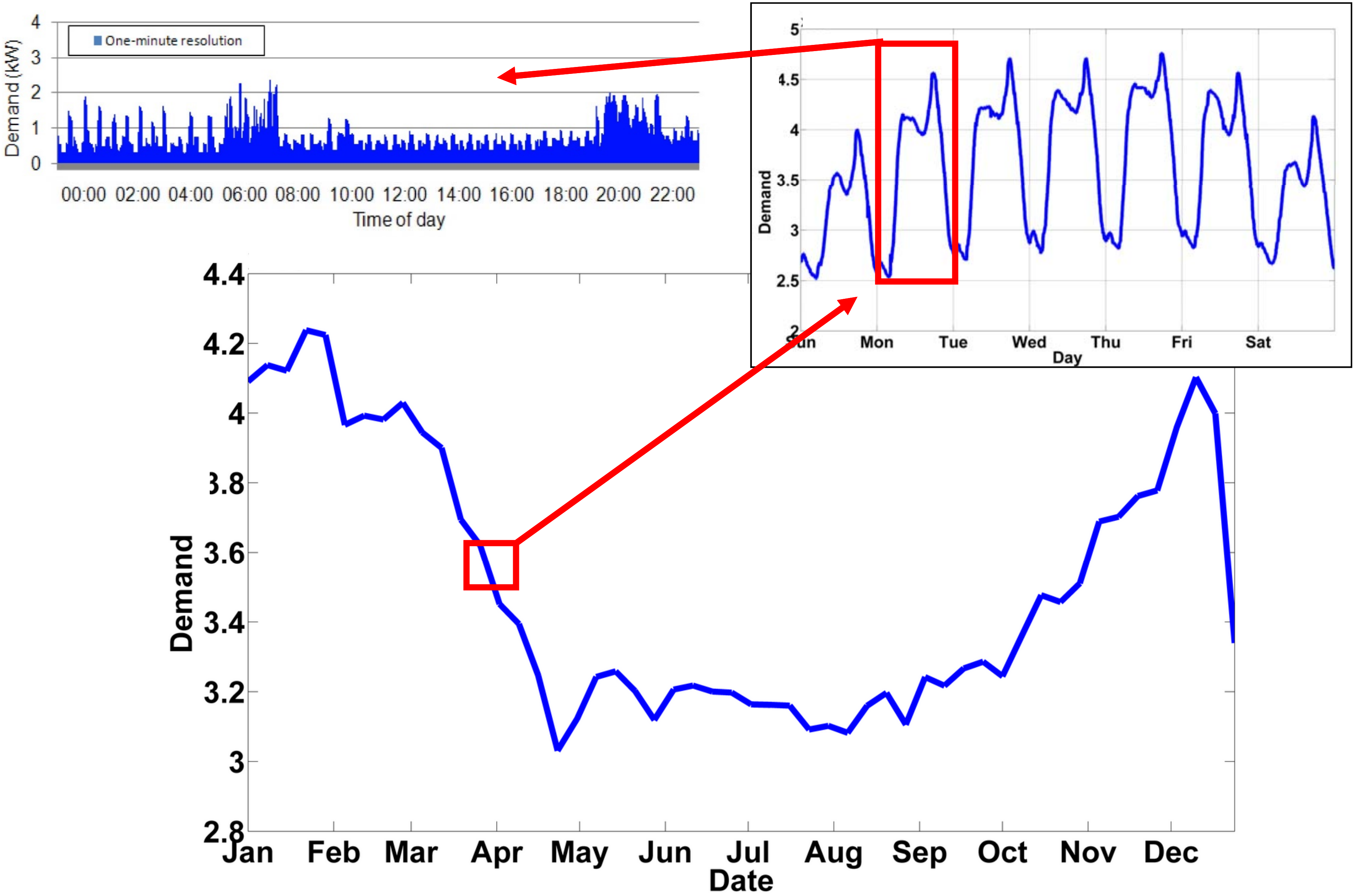


- At this resolution, a 365 day simulation yields **525,600 data points** per dwelling.

- Wright and Firth (2007) discuss how "**…averaging data over periods longer than a minute is shown to under-estimate the proportions of both [electricity] export and import.**"

A. Wright, S. Firth, *The nature of domestic electricity-loads and effects of time averaging on statistics and on-site generation calculations*, Applied Energy 84 (4) (2007) 389-403

Complexity Related to Forecast



Appliances Model

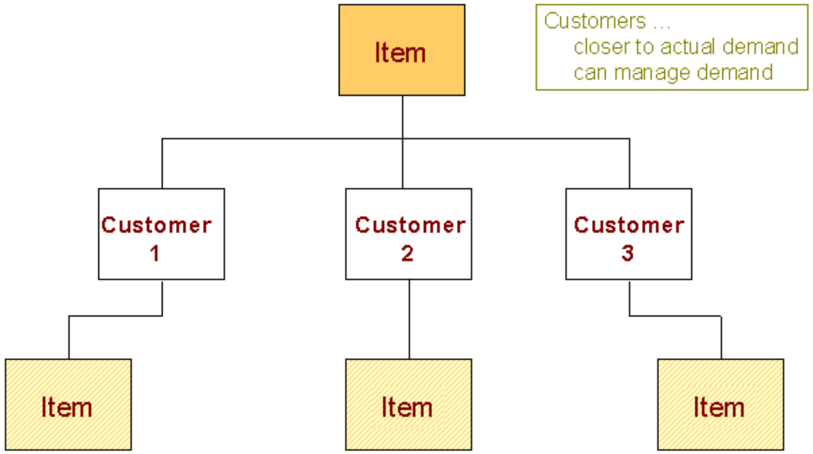
- The most common and simple model uses the appliance as the basic building block, where "**appliance**" refers to any individual domestic electricity load, such as a television, washing machine or vacuum cleaner.

Methods

- Load forecasting techniques are classified into ten categories:
  - Multiple regression;
  - Exponential smoothing;
  - Iterative reweighted least-squares;
  - Adaptive load forecasting;
  - Stochastic time series;
  - ARMAX models based on genetic algorithms;
  - Fuzzy logic;
  - Neural networks;
  - Knowledge-based expert systems and,
  - Support vector machine.

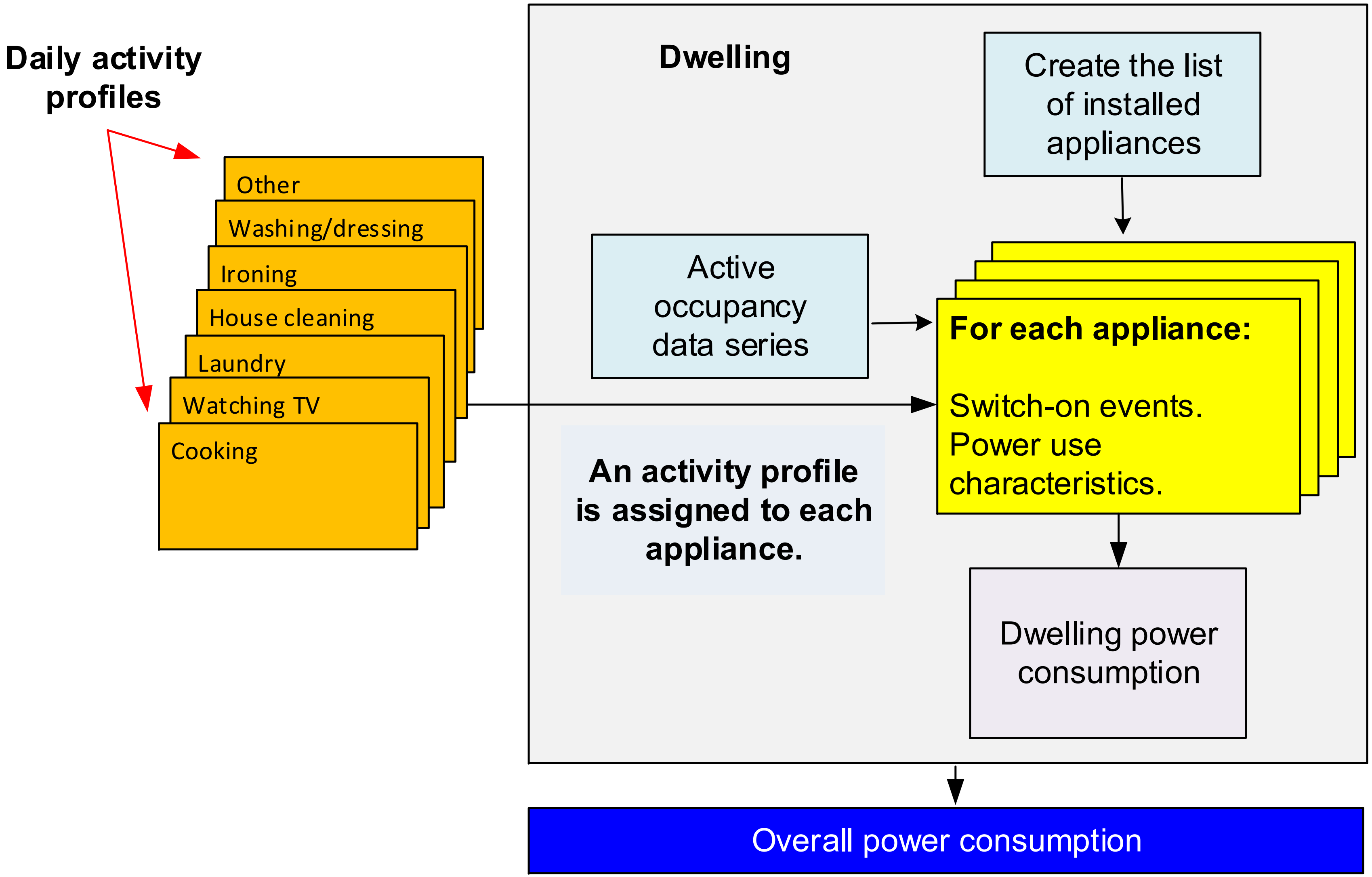
Methods

- It is therefore a **“bottom-up” model**, in common with those developed by Paatero and Lund [1], Capasso et al. [2], Yao and Steemers [3], Stokes [4] and Armstrong et al. [5].
- An important feature of the new model is in its approach to representing **time-correlated appliance use**.



[1] J. Paatero, P. Lund, A model for generating household electricity load profiles, International Journal of Energy Research 30 (5) (2006) 273–290.
[2] A. Capasso, W. Grattieri, R. Lamedica, A. Prudenzi, A bottom-up approach to residential load modeling, IEEE Transactions on Power Systems 9 (2) (1994) 957–964.
[3] R. Yao, K. Steemers, A method of formulating energy load profile for domestic buildings in the UK, Energy and Buildings 37 (6) (2005) 663–671.
[4] M. Stokes, Domestic Model Layer 3, Removing barriers to embedded generation: a finegrained load model to support low voltage network performance analysis (PhD Thesis), Institute of Energy and Sustainable Development, De Montfort University, Leicester, 2005.
[5] M. Armstrong, M. Swinton, H. Ribberink, I. Beausoleil-Morrison, J. Millette, Synthetically derived profiles for representing occupant-driven electric loads in Canadian housing, Journal of Building Performance Simulation 2 (1) (2009) 15-30.

Electricity demand model architecture



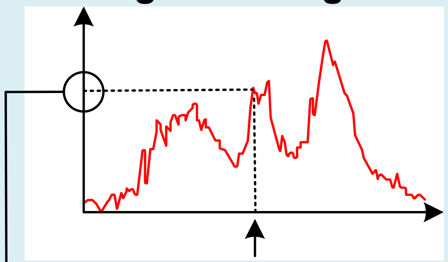
Switch-on events

Step 1. Pick the relevant activity profile

- Appliance activity
- Number of active occupants at the current time step
- Weekday or weekend

Step 2. Determine the activity probability from the profile

Activity profile (One active occupant) e.g. "Cooking"



Time of day

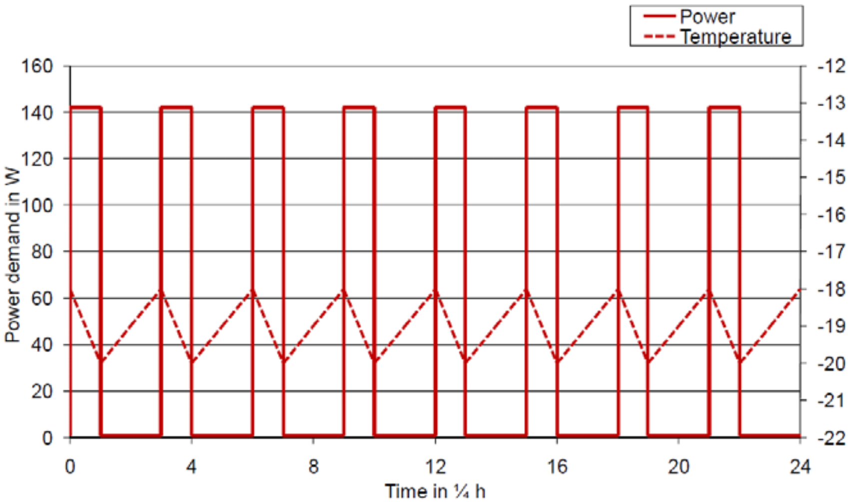
Step 3. Calculate switch-on probability

Calibration scalar × Activity probability = Probability of appliance switch-on at each time step

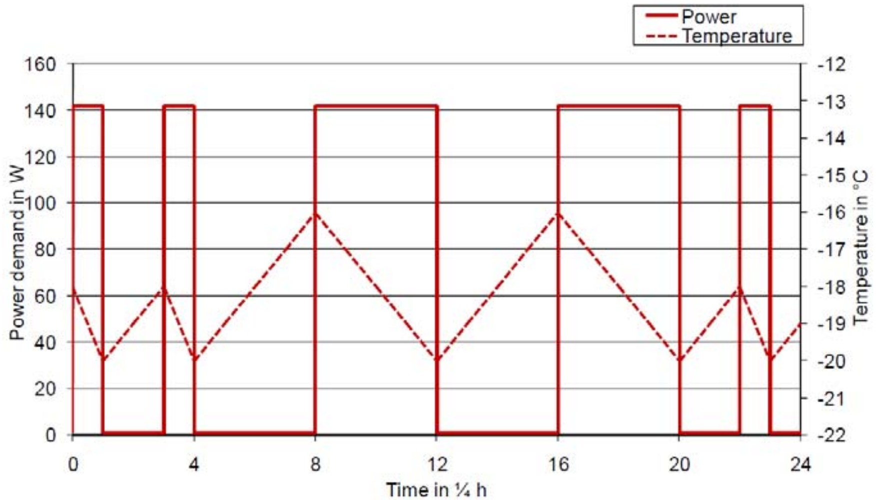
Step 4. Determine if switch-on occurs

Compare against a random number

Power Demand Pattern



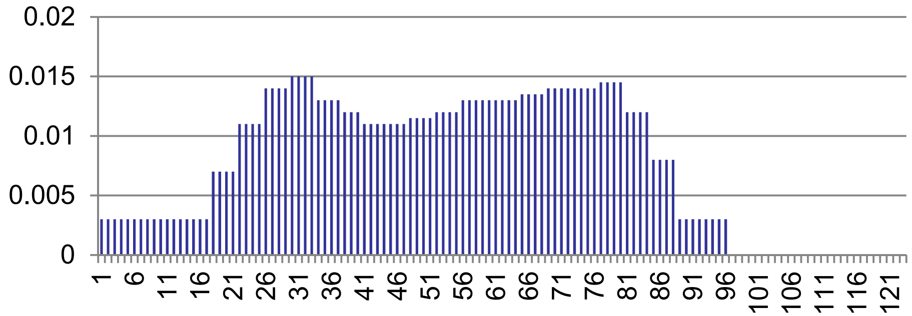
General pattern of a power demand curve of a freezer in ¼ hour steps



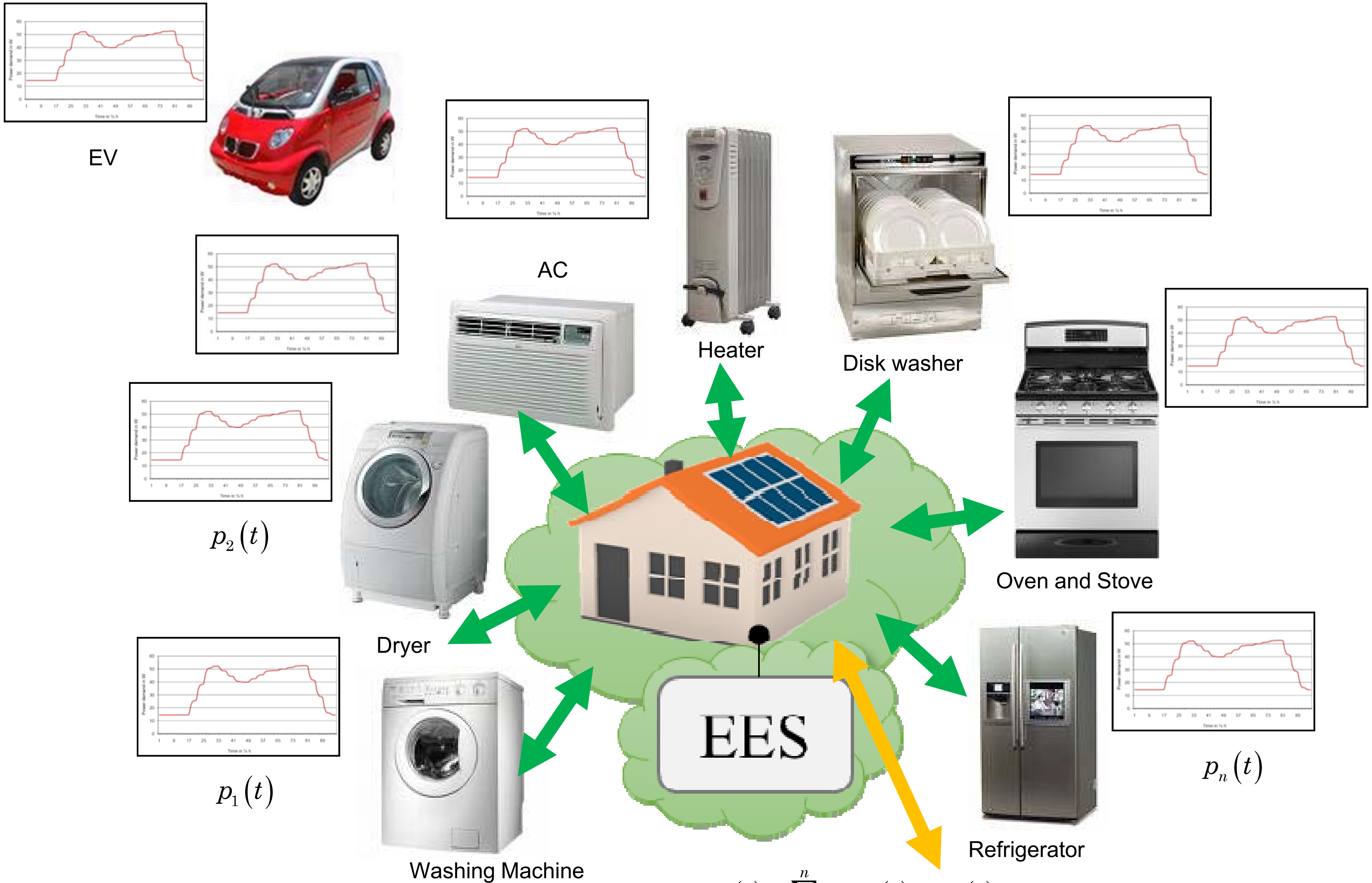
*General pattern of a power demand curve of a freezer with **postponed start of compressor** and rising temperature in ¼ hour steps*

	One cicle profile without micro-CHP	One cicle profile with micro-CHP
Total energy in Wh	887.5	212.5
Time Step in 1/4h		
1	100	100
2	2000	100
3	900	100
4	100	100
5	100	100
6	300	300
7	50	50
8	0	0

Probability of Operation per 1/4 hour



Average power demand during the day



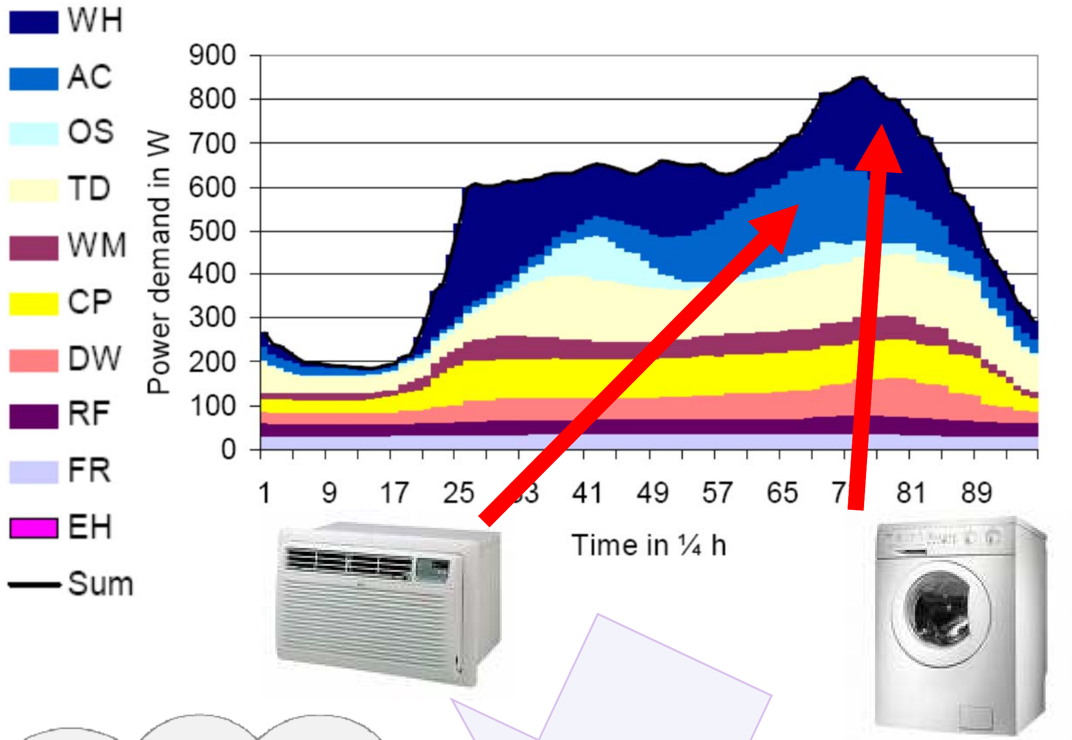
$$P_k(t) = \sum_{i=1}^{n} \beta_{ik} p_i(t) + p_0(t)$$

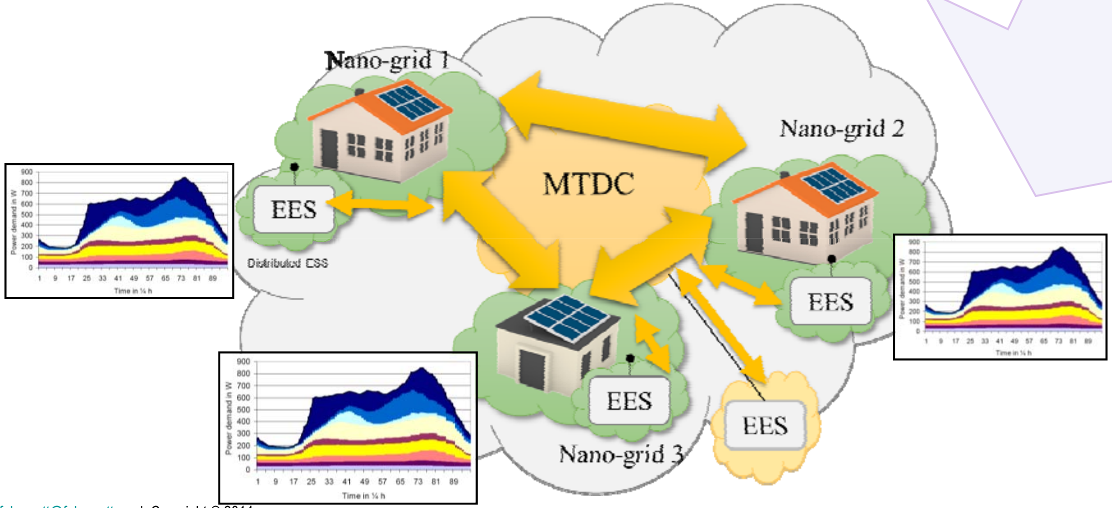
To eliminate the absolute size of the region, consider only the specific penetration rates βik of each appliance type in this region *k*.

all other electricity consumption in the household

Average power demand during the day

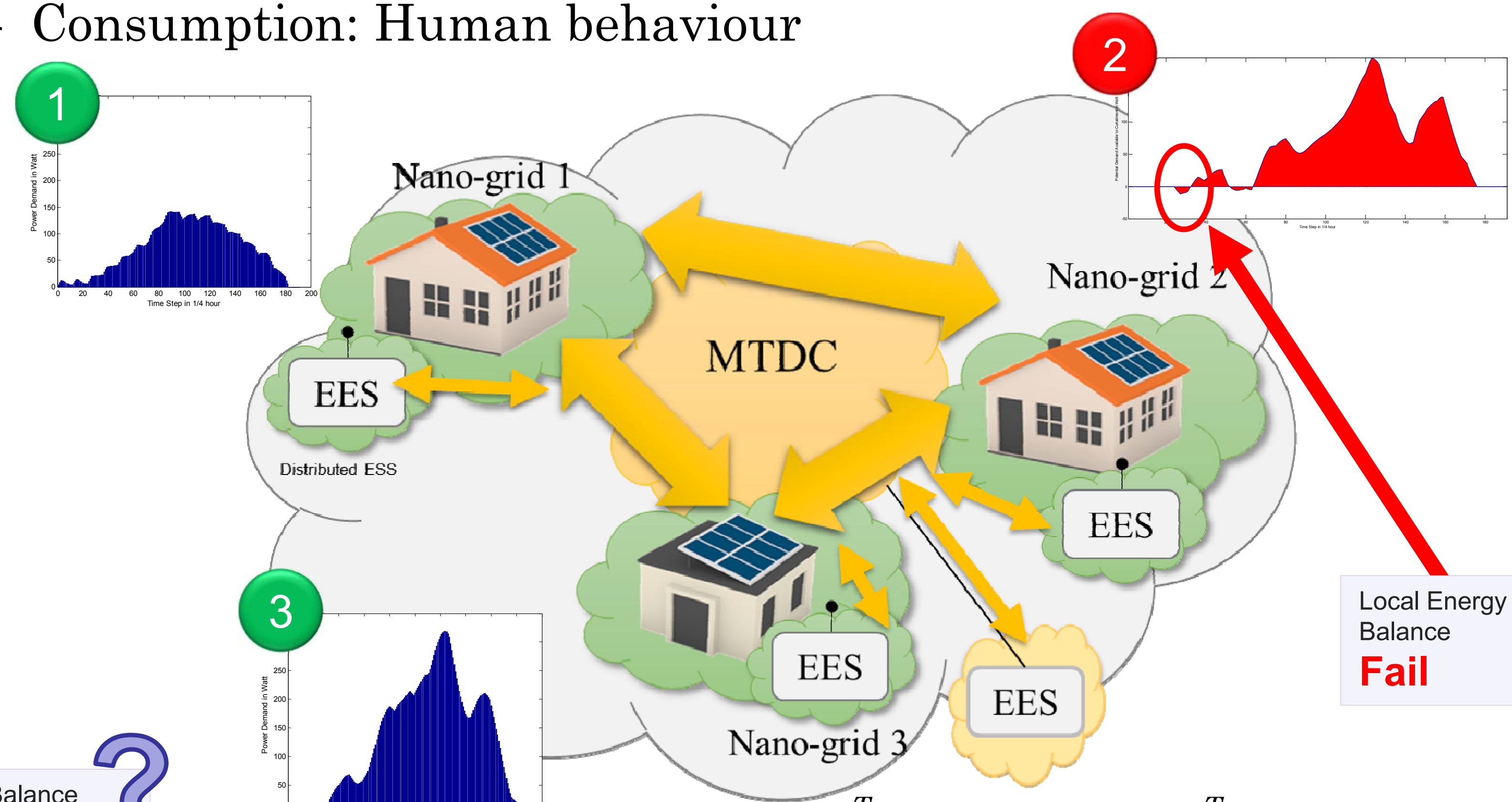
$$P_k\left(t\right) = \sum_{i=1}^{n} \beta_{ik} p_i\left(t\right) + p_0\left(t\right)$$





Complexity

- Increased Uncertainties in:
  - Primary Energy
  - Consumption: Human behaviour



Local Energy Balance
Fail

$$\sum_{i=1}^{T} E_{production}^{nano,j}(t_i) - \sum_{k=1}^{T} E_{consumption}^{nano,j}(t_k) < \xi$$

Energy Balance
Success

$$\sum_{i=1}^{T} E_{production}^{MTDC}(t_i) - \sum_{k=1}^{T} E_{consumption}^{MTDC}(t_k) = 0$$

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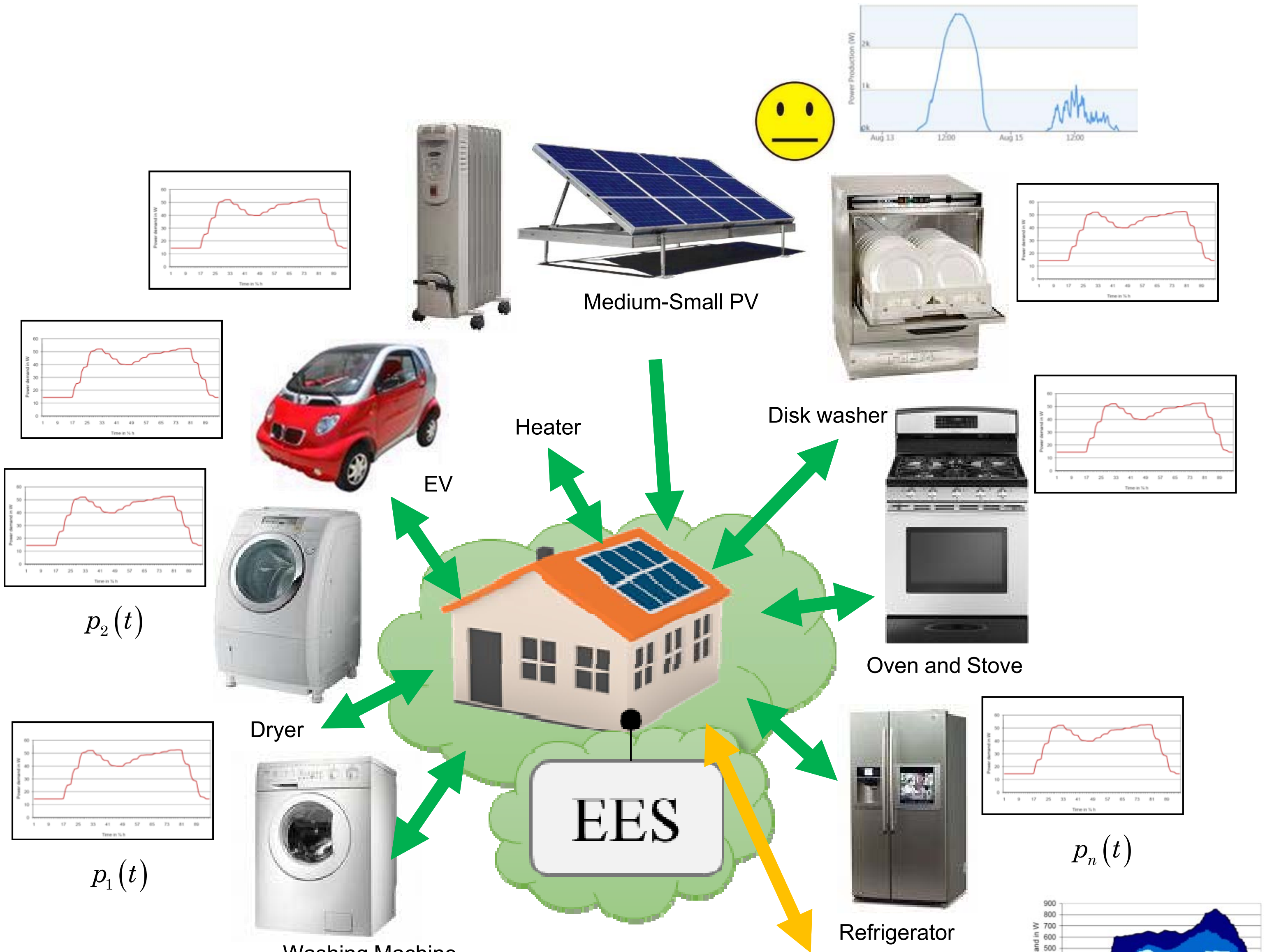
Scenario 1: UK Urban



$$P_k(t) = \sum_{i=1}^{n} \beta_{ik} p_i(t) + p_0(t)$$

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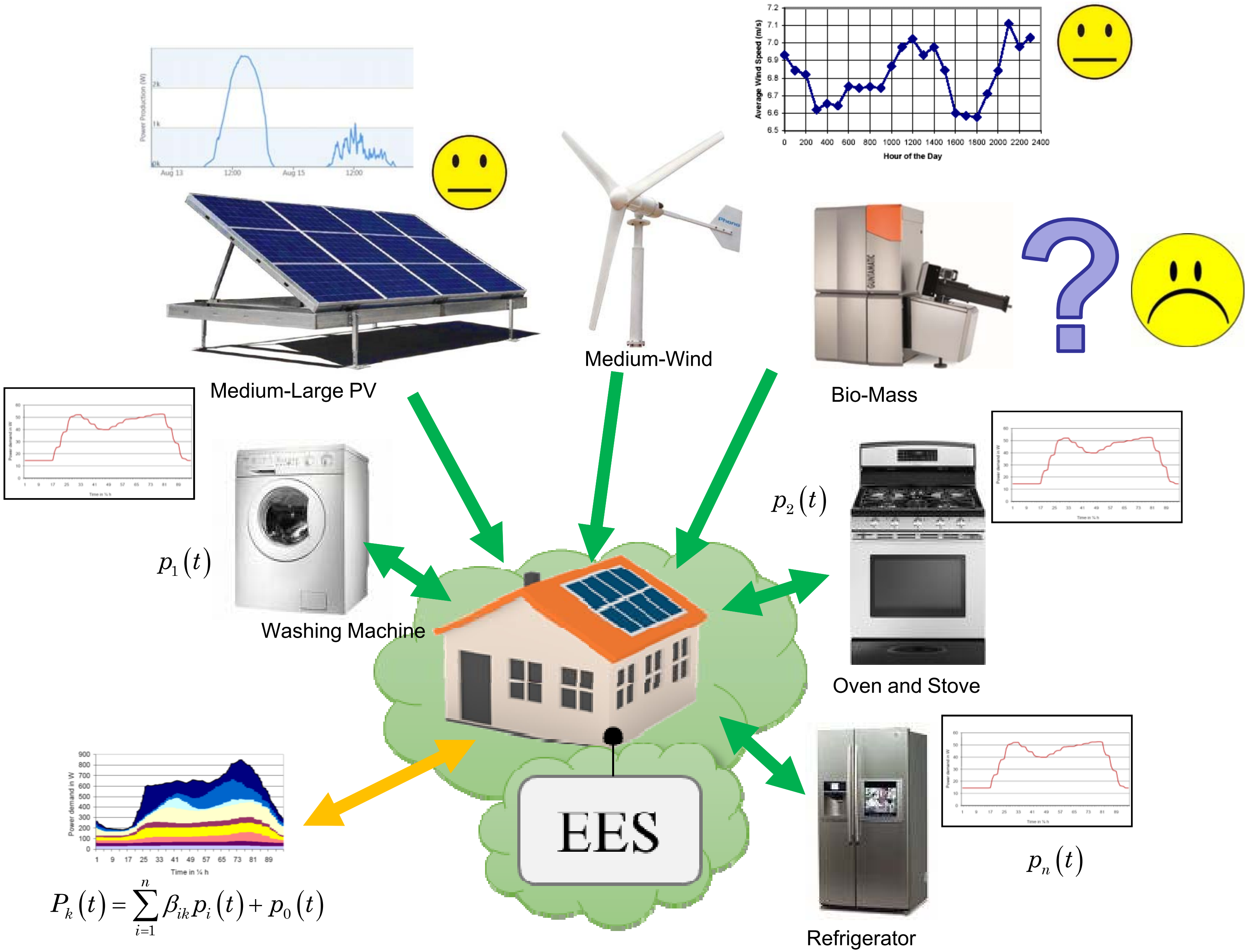
Scenario 2: UK Rural



$p_1(t)$

$p_2(t)$

$p_n(t)$

$$P_k(t) = \sum_{i=1}^{n} \beta_{ik} p_i(t) + p_0(t)$$

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Thanks
Any Question?

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