Energy-saving at home, in practice

Eric Eisenhandler

Easy steps

- Heating – *properly controlled*
- Low-energy lighting – *no more excuses*
- Items on standby etc. – *bad-design surprises*
- Insulation – *the first thing to do*

  Diversion: thermal imaging

Solar hot water panels

- General considerations
- How they work – *in real life*
- How they perform – *in a climate not famous for sunshine*

  Diversion: don't get ripped off

Solar electricity panels

- General considerations
- How they work – *in real life*
- How they perform – *in a climate not famous for sunshine*

Feed-In Tariff and Renewable Heat Incentive – *big changes*

Main ingredient in the recipe

Fairly modern house (built about 1970)

- Not well insulated when bought in 1982
- One feature not appreciated until 2007 – large-area, unshaded, south-facing roof

For solar, even better if roof slope were 35°–45° instead of 25°

Easy steps I: Heating

Condensing boilers (oil/gas) more efficient – *now mandatory*

- New **boiler scrappage scheme** for old, inefficient models
  - ~4 million eligible boilers but only 125,000 vouchers

Oil heating – *we have no gas, and cooker is electric*

- Oil has been both very cheap (11p/litre) and very dear (51p/litre)
- 1 litre of oil provides about 10 kWh (so a few pence/kWh)
  - Energy from electricity (~12p/kWh) is much dearer than energy from oil (or gas)

Controls

- Thermostat to control overall temperature
- Programmer for heat and hot water – *only on when needed*
- Thermostatic radiator valves – *don't heat unused rooms*
- Turn down the heating! – *20°C → 19°C saves ~10%*

Programmer

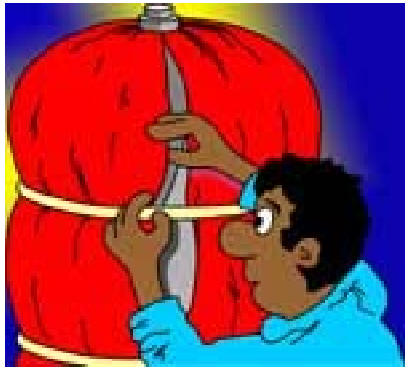
Thermostatic radiator valve

Heating (2)

Hot water

- We have a separate hot water tank (unlike smaller houses or flats) – *controlled by tank thermostat*
- In summer, hot water heated by boiler (cheaper) or electrically (more efficient but dearer)
- Do not overheat hot water – *about 55°C is enough*

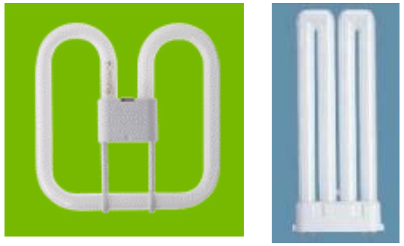
  Over 60°C can burn you
- Insulate tank well – *if not already done, very cheap and easy to do*



Easy steps II: Low-energy lighting

Fluorescent tubes

- Old-style long tubes still save energy
- New-style tubes and shapes even more efficient, and useful in more places



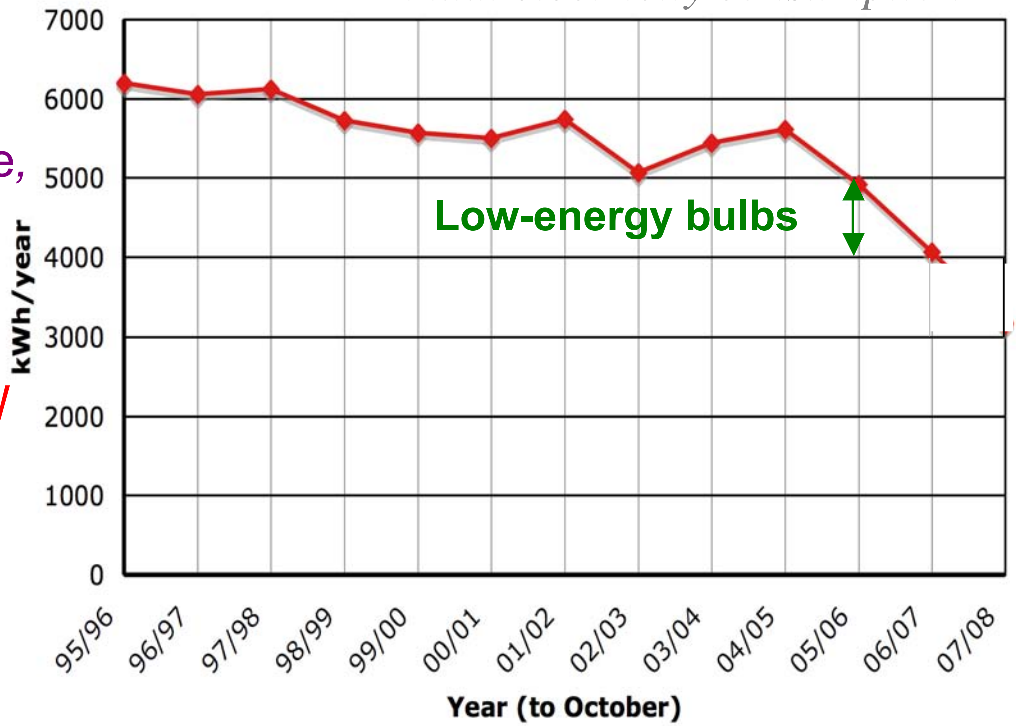
New-style fluorescents

Low-energy bulbs

Low-energy bulbs (CFLs)

- Quick payoff – we're saving at least 1000 kWh per year (about £120)
  - Bulbs last ~10 years; prices vary wildly
- Incandescent bulbs being phased out
  - 150 W, 100 W, 75 W already gone, 60 W this year
- Not bright? Replace with 1/4 the wattage, not 1/5 or less
  - e.g. 60 W by 14 or 15 W, not 11 W
- Dim at first, but improving
- Most can't be dimmed
- Spotlights a problem – try LEDs

Annual electricity consumption



Low-energy lighting *(2)*

Light-emitting diodes *(LEDs)*

- Great potential for the future
  - Very long lifetime
  - Start up at full brightness
  - Many can be dimmed
  - Will soon be much more efficient than low-energy bulbs
  - Design need not be tied to bulb-like shapes
    - Flat arrays and panels coming?
    - Low-voltage operation

- But at present
  - Very directional
    - At present, better for replacing spotlights than for general room lighting
  - Colour balance must be improved
    - White usually still blue-ish, so look for *warm white* (colour temperature 2700K)

Easy steps III: Items on standby (and other bad-design surprises)

Standby facts and myths

- Many TVs and phone chargers are not the problem!

  Some recent TVs and chargers use only 0.2–0.3 W in standby, so the adverts are misleading!

- Other badly designed gadgets use much more in standby

  TV ‘set-top boxes’ typically about 10 W

  Many computer printers 10–20 W (some even when ‘off’!), etc.

- External power supplies (boxes, plugs) are a problem

  Typically a few watts even when item not in use

- Some items are actually on when switched ‘off’

  Unswitched transformers or circuitry inside

  e.g. some halogen lamps, some printers

  Some gadgets don’t have on/off switches!

  e.g. scanner, DVD player

- *Switch things off at the mains socket if you can!*

- Monitoring can identify badly designed culprits

External power supplies

Total consumption monitor

Single-device monitor

Items on standby (2)

Some examples – myself and friends

Set-top box	Sky Plus	11W (standby)	Standby keeps programme guide up to date – now normally switched off
Hard-disk recorder	Humax	9W (standby)	
DAB radio	Pure	4W (off!)	External power supply in plug – now switched off at mains socket
Halogen reading lamp	John Lewis	4W (off!)	Internal transformer not switched – added switch in mains lead
Desktop computer	Apple Mac + LCD screen	5W (sleep)	System uses 32W (sleep) after some items removed (USB hub, printer, …)
Colour inkjet printer	Epson	11W (idle)	Now normally switched off
Scanner	Epson	6W (idle)	No switch! Added one in mains lead
Multifunction printer/scanners	Various	14–20W (idle) 7W (off!)	Switched off at mains socket

Reduced our house's 'background' level by over 50 watts!

- Saves about 400 kWh per year, or £50 *(1 W is roughly £1 per year)*
- Does not include computer-related items – saved another ~25 W
- For all of UK this would save at least one power station

Easy steps IV: Insulation

The first thing to do! Grants help to pay for it

U=1 means 1 watt per m^2 per °C temperature difference

** = current standard*

Roof

- Approximate U-values:

  25 mm insulation: 1.1 W/m^2/°C – *where we started*

  100 mm insulation: 0.3 W/m^2/°C – *what we had until 2007*

  270 mm insulation: 0.16 W/m^2/°C* – *what we have now*

Loft insulation

Walls

- Approximate U-values:

  Solid brick: 2.2 W/m^2/°C

  Cavity wall: 1.0 W/m^2/°C – *where we started*

  Insulated cavity wall: 0.6 W/m^2/°C* – *since 1982*

- Old houses don't have cavity walls

Cavity wall insulation

Windows and doors

- Approximate U-values:

  Single glazed: 5.0 W/m^2/°C – *where we started*

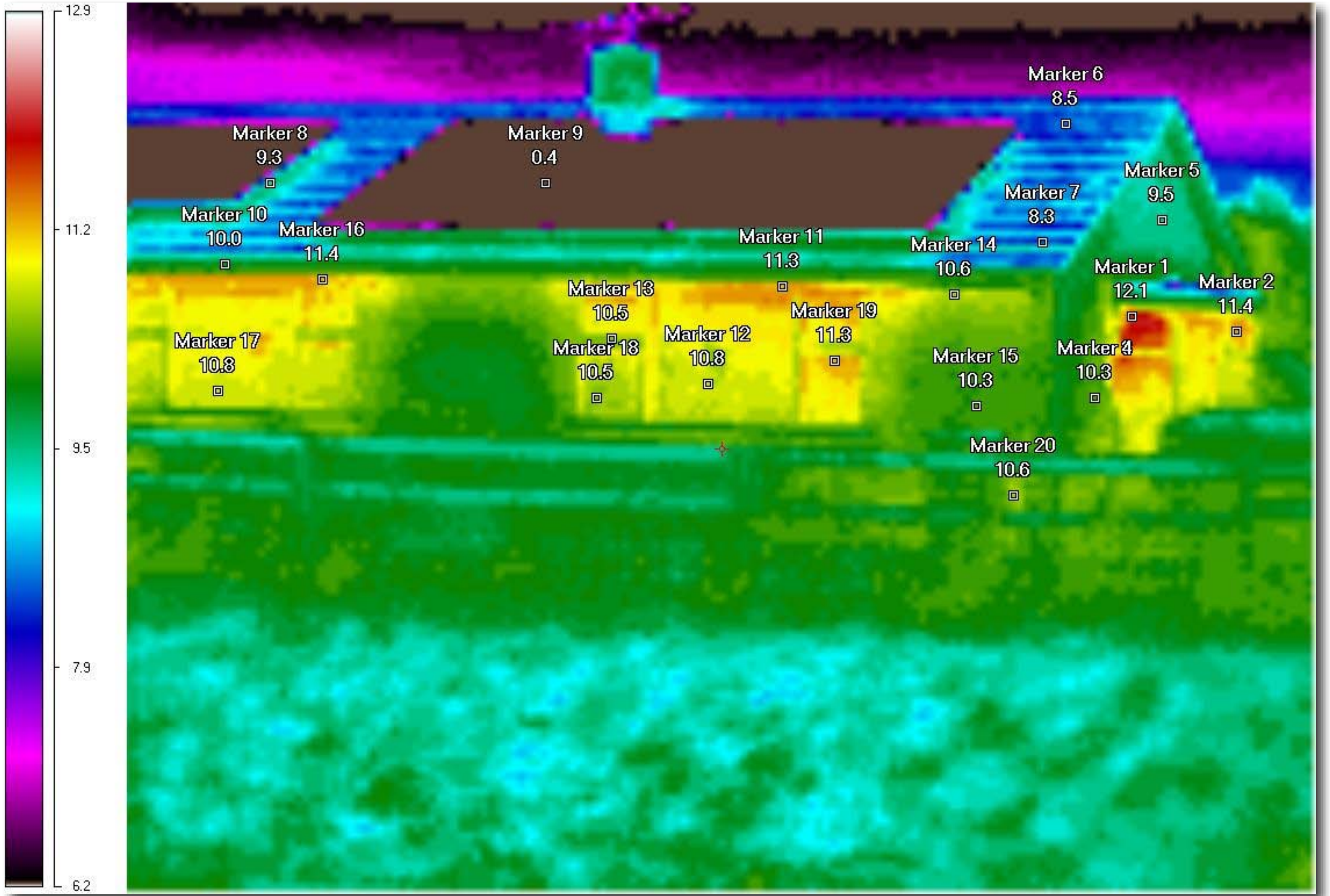
  Double glazed: 2.9 W/m^2/°C – *what we have now (new systems 1.7*)*

- Draught-proofing strips can help a lot
- Problems with old houses – *listed buildings, conservation areas, etc.*

Diversion: Thermal imaging

Useful for checking insulation and finding problems

Markers give temperature in °C; outside temperature for this photo was about 8°C



Thermal imaging *(2)*

Dec. 2008 camera

Lens

- Germanium crystal: transmits λ from 8–12 μm

Raw data

- Sensors: each 'pixel' is effectively a thermometer
- Only about 160×120 or 320×240 pixels – *19k or 77k*
- Recorded image consists of raw temperature readings

  Software can later correct them, alter false-colour scheme, add markers, …

Emissivity

- Net rate of energy radiated from unit area of a surface per second is emission minus absorption: $P = \varepsilon \sigma (T^4 - T_0^4)$

  T is temperature of surface, T_0 is temperature of environment

  σ is Stefan-Boltzmann constant (5.67×10^{-8} Wm^{-2}K^{-4})

  ε is emissivity, 0 to 1 *(1 is black body, absorbing all incident radiation)*

  Default value of emissivity used in images was ~0.9

  Brick 0.85–0.95, glass at least 0.9, wood 0.8–0.9

  - Metals 0.05–0.5, but hardly any in images
  - So 0.9 not bad – and we want differences, not absolute values!
- Must assume convection *(e.g. from wind)* is negligible

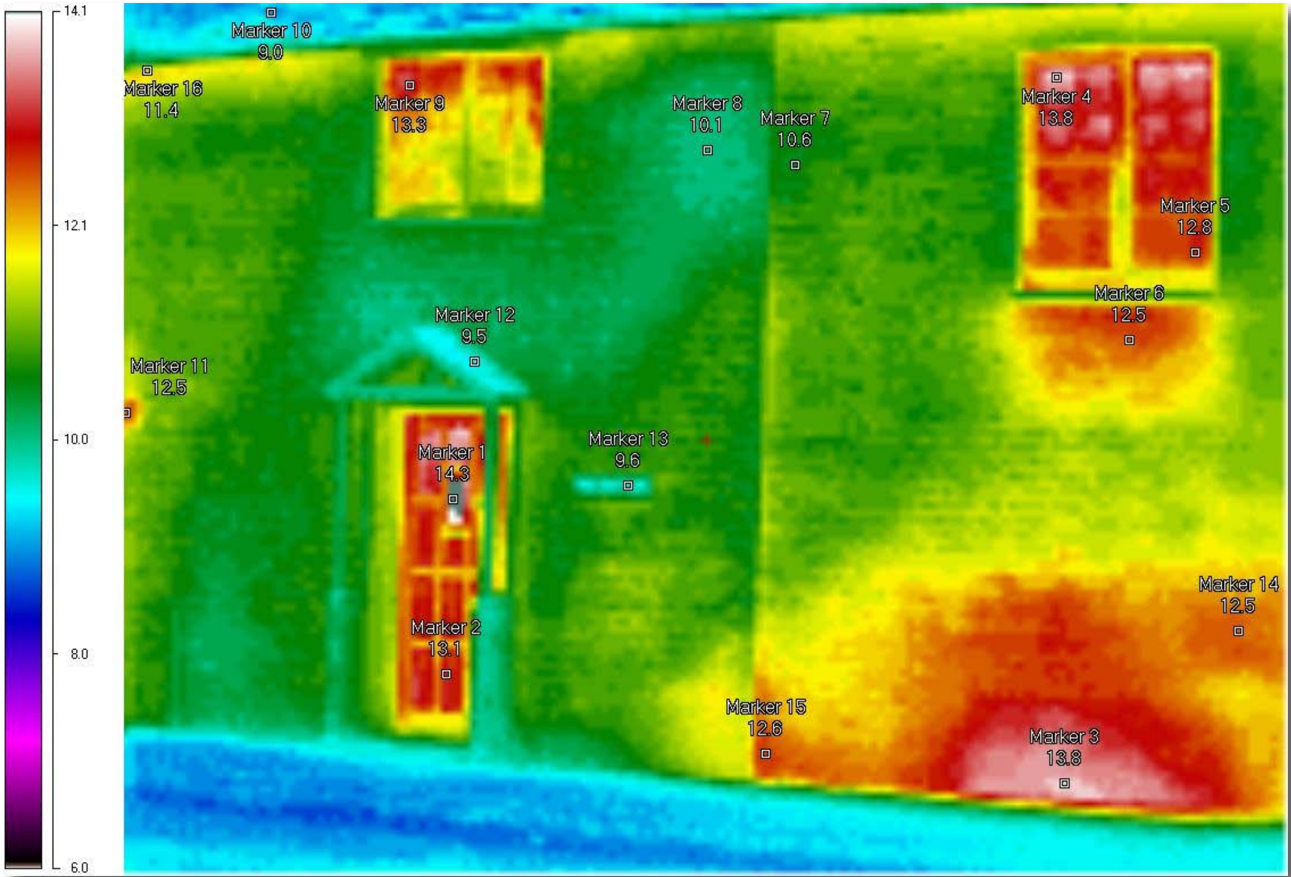
Thermal imaging (3)

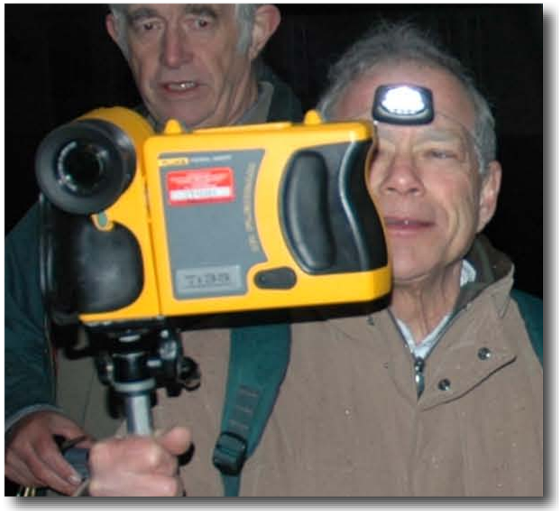
Took images of 19 houses in Dec. 2008

- Outside temperature was 4°C for some, but then 8°C

More photos taken in Jan. 2010

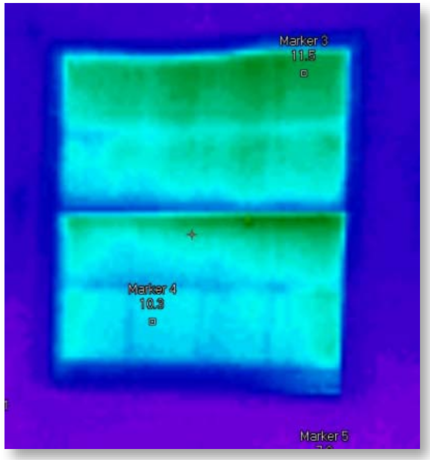
- Outside temperature was below 0°C



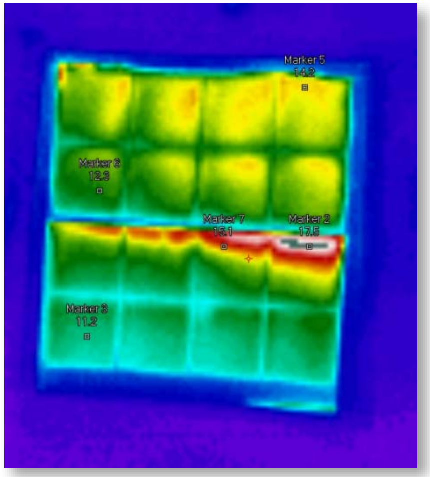


Thermal imaging *(4)*

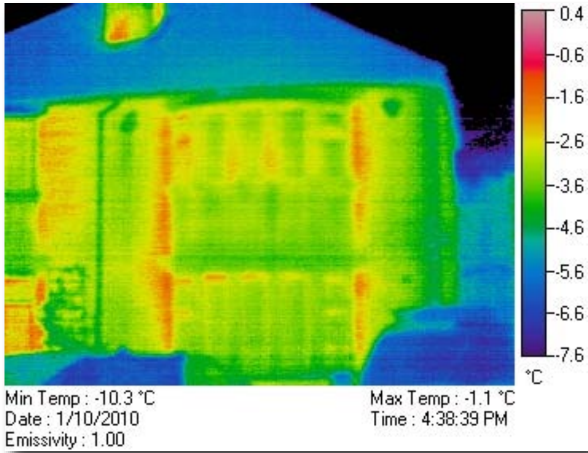
Secondary double-glazing on an old house



In place

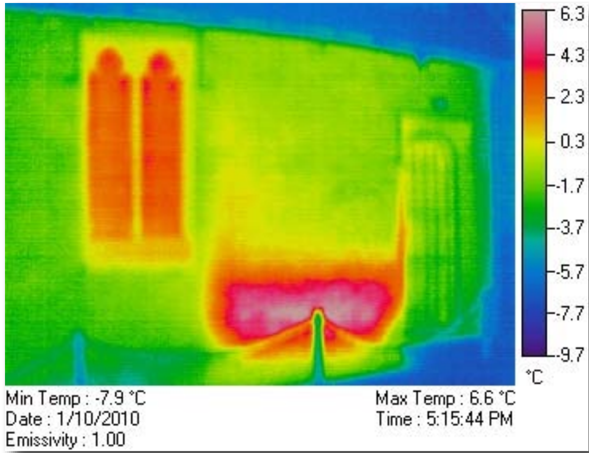


30 minutes after removal

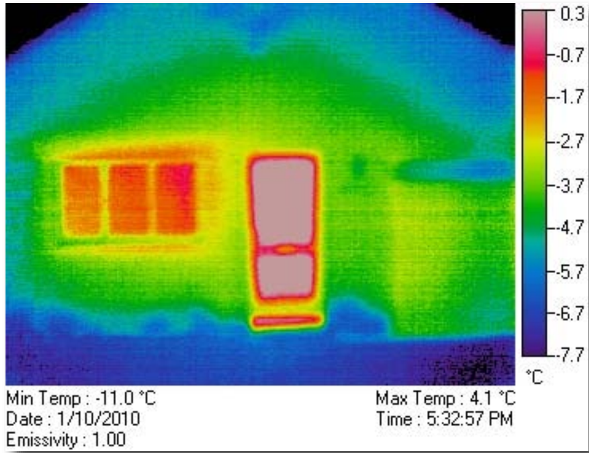


Bay-window joins

Radiator and thin outer wall

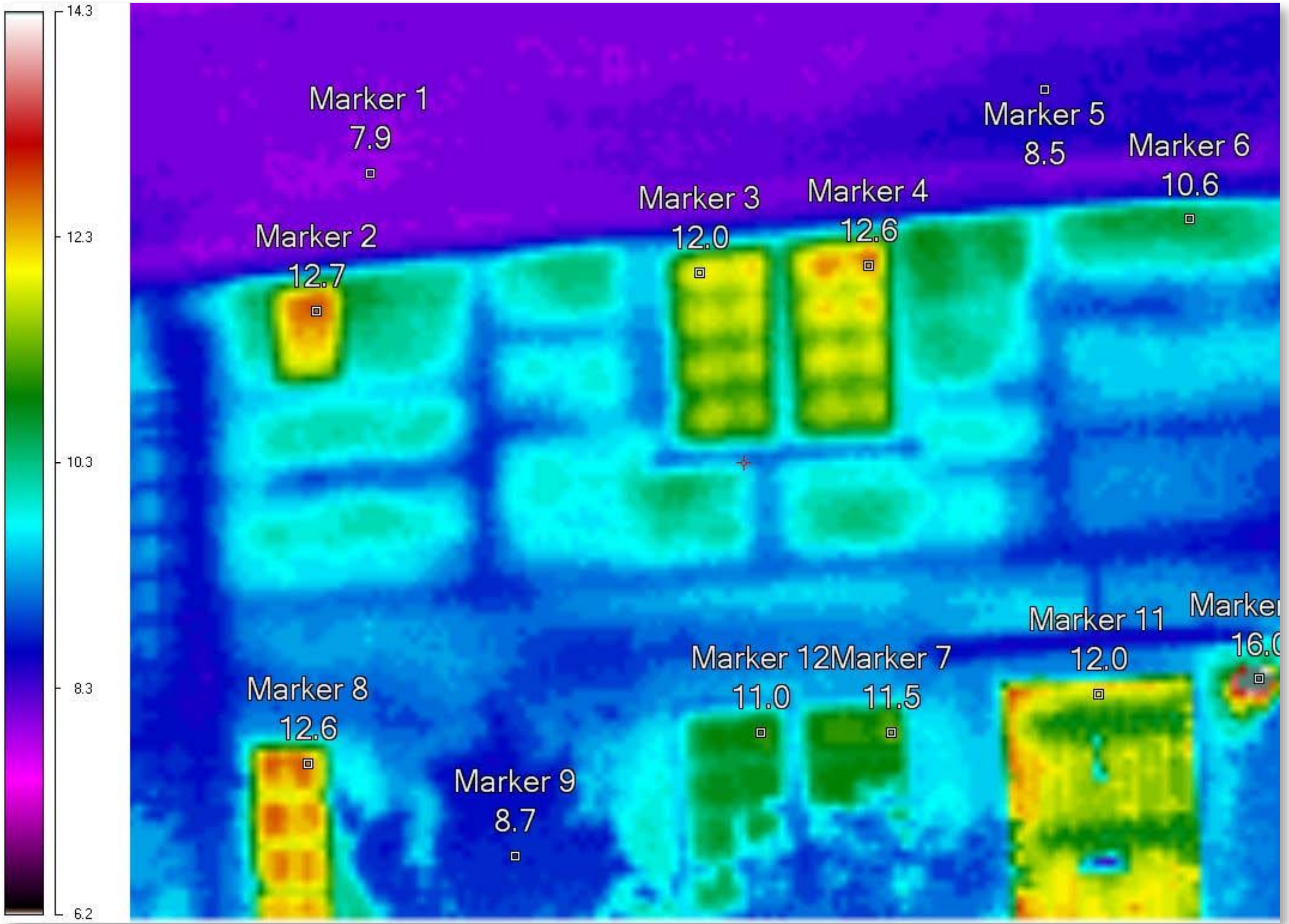


Jan. 2010 camera



Poor-quality door

Thermal imaging (5)



Timber beams inside walls, normally invisible, show up in this old cottage

Interesting to experts on old timber-framed buildings!

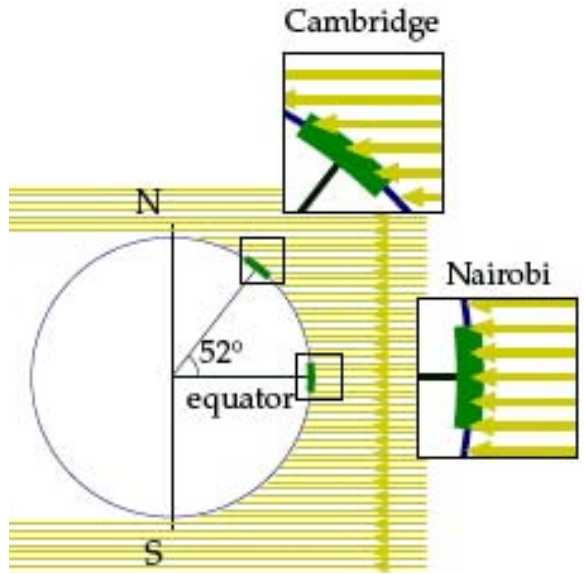
Solar basics

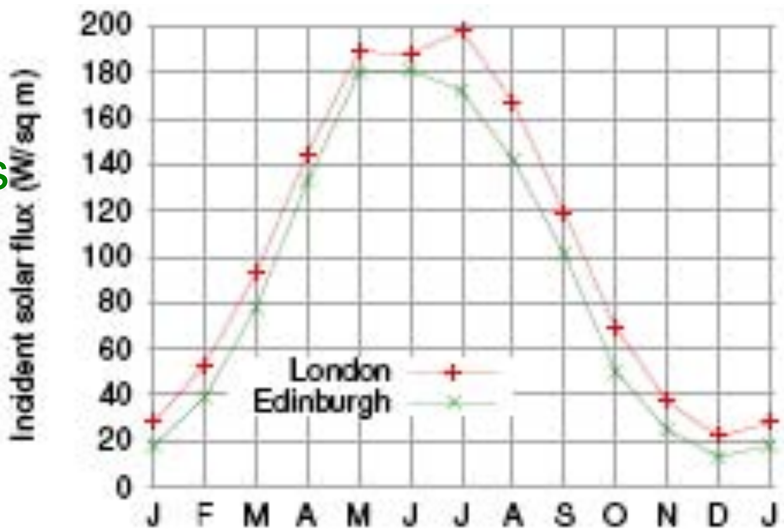
Potential of solar energy in the UK

- At midday, and if no cloud, a surface tilted towards to the sun gets about **1000 W/m²**

  If not tilted, the angle of sun reduces this to about **600 W/m²**

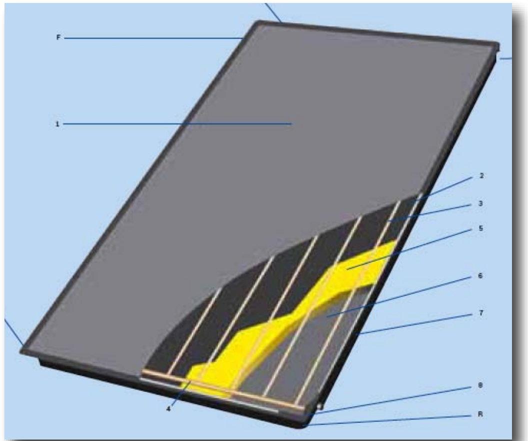
- It's not always midday! For a cloudless day in March or September the 24-hour average is about **320 W/m²**
- Very often it's cloudy! In a typical UK location, sun shines 34% of daylight hours
- Must take account of the seasons
- Overall average for a *tilted*, south-facing UK roof is about **110 W/m²**, or about **960 kWh/m² per year** (more in the south)





Solar thermal panels for hot water

- **In UK, usually claimed to yield ~60% of annual hot water**
  - Even better in sunnier places; e.g. widely used in China, Israel, …
  - Hot water only, not central heating – *not much sun in winter*



- **Two main types**
  - Flat plates: simpler and cheaper
    - Claim: 4 $m^2 \Rightarrow$ 1400 kWh per year – *about 36% efficiency*
  - Evacuated tubes: more efficient but dearer
    - Claim: 4 $m^2 \Rightarrow$ 1800 kWh per year – *about 47% efficiency*
  - Backing painted black to absorb incoming energy
  - Glass plate or tubes trap energy,
    avoiding convection and re-radiation

- **Energy storage**
  - Can use hot water overnight
    or the next day – *good*
  - But on a bright day some incident energy
    is ‘wasted’ once there’s a full tank of hot water

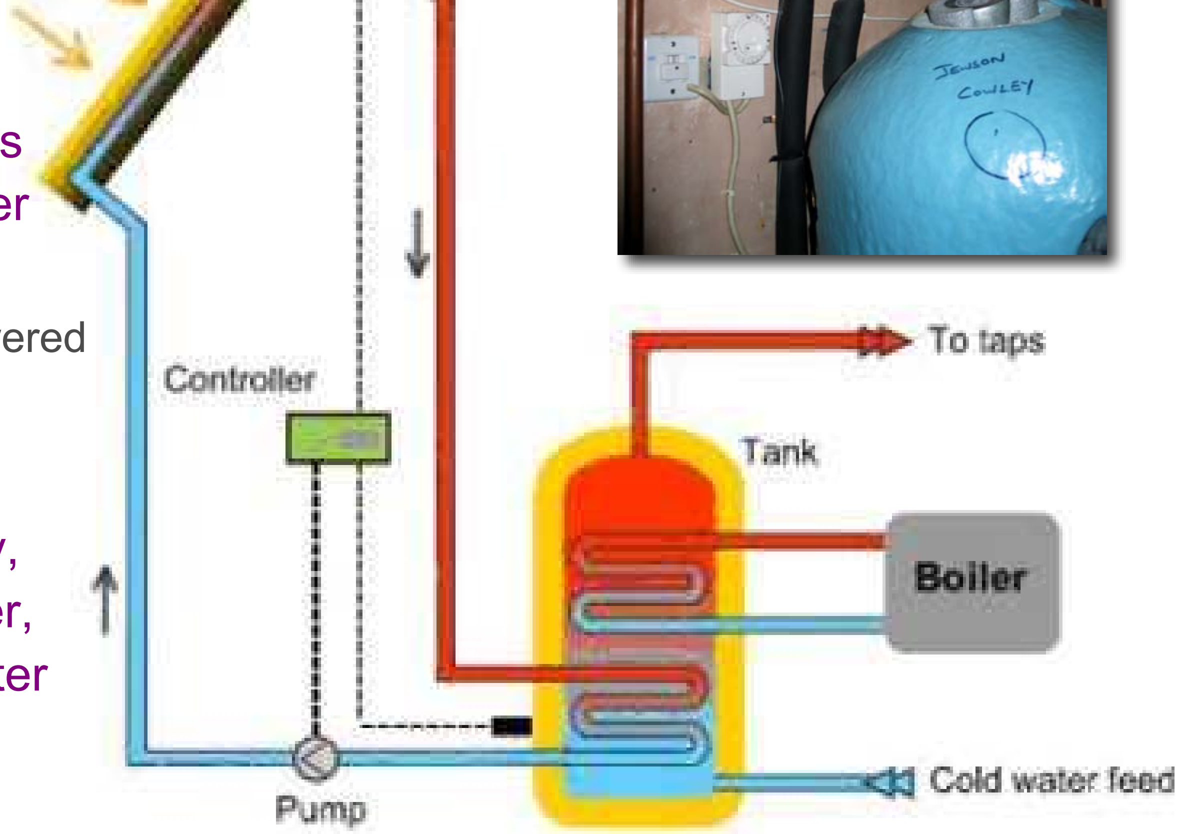
***Solar thermal** (2)*

Large roof area, so we chose the best value rather than highest efficiency

4 m^2 flat-plate system – installed September 2007

- New, bigger hot-water tank:
  - 190 litres
  - *(enough for over 24 hours)*
- Pump uses 30 W; on as long as panels more than 4°C warmer than water at bottom of tank
  - Sometimes pump is solar-powered
- Controller displays status, and panel and tank temperatures
- When not enough solar energy, water can be heated by boiler, or by electric immersion heater
- Harder to install if a 'combi' boiler heats the water

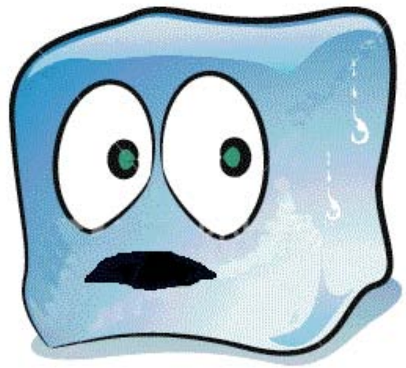
Controller, pump and hot-water tank

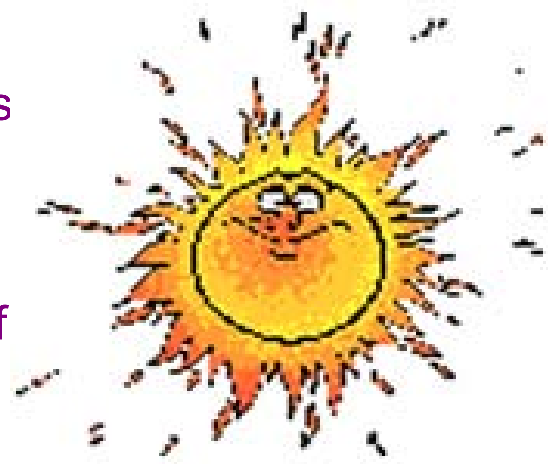


Solar thermal *(3)*

What if it gets very cold or very hot?

- Fluid for panels is in a closed loop – does not mix with the hot water
- Use ethylene glycol *(antifreeze)* so it won't *freeze* in *cold* weather *(some systems use water but drain the tubes when system is not active)*
- On a *hot* sunny day the fluid can *vapourise* – pump turns off at 140°C and there is an expansion tank for the vapour
- Hot water is *never* heated beyond 60°C – pump turns off



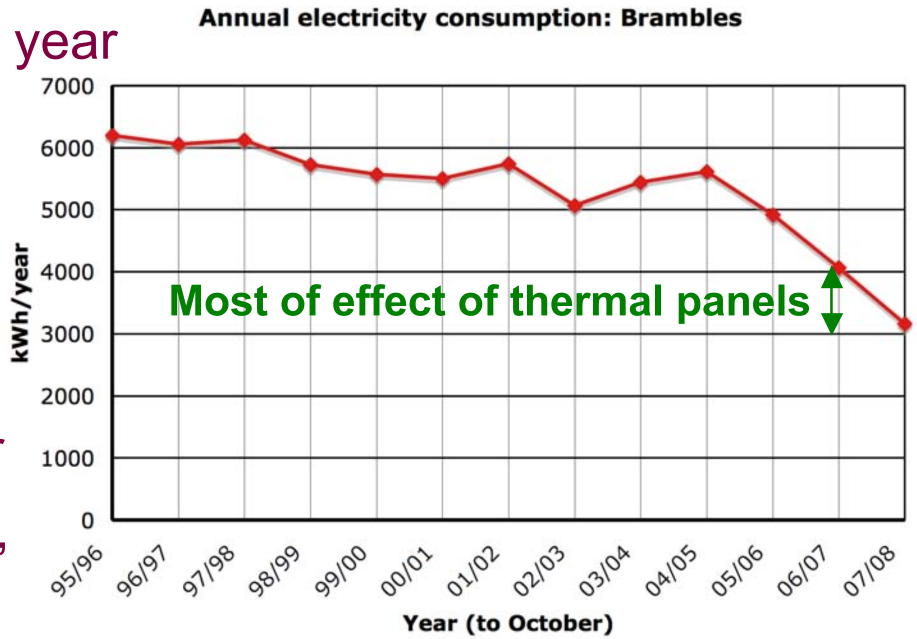


Solar thermal (4)

Performance

- In summer water is fully heated by midday except when it's *very* grey
- In spring and autumn get full heating on sunny days, and some heating (to 30–40°C) on most others
- In winter over 45°C is possible even on a cold, very sunny day, but little on most
- Electricity saving over 1000 kWh per year

  Also saves oil, but harder to measure



Cost

- Simple flat-plate systems cost about £3500–£4000

  Evacuated tubes roughly £1000 more

  Government grant of £400 – *see later*
- Pay-back time perhaps 15–20 years, *but see later*

Solar thermal (5)

Don't get ripped off!!

Like the bad old days of double-glazing sales

- Companies cold-call by phone, post, or on doorstep
- Offer a 'solar energy' system – *at several times the right price*
  - Are not very clear on what it does – *often imply central heating too*
- Much cheaper 'special offer' if you sign before they leave – *but price is still far too high*
- Do not tell you about government support, because that requires:
  - Government-approved solar panels and controls ***and***
  - Government-approved installation company
- System may or may not be competently installed, and may or may not work reliably and well

Solar photovoltaic (PV) panels

See lectures for how solar cells work

PV panels are expensive

- They produce electricity best when the sun is shining – not when you *need* it
- Whatever you *can* use saves you the cost of 'importing' electricity from the grid
- Usually no battery storage – surplus energy is 'exported' to the grid
  - A domestic system might export *roughly half*
- So the price of importing, and what you get paid for exporting, is important
  - UK did not yet have a 'feed-in' export tariff – used in many countries to encourage microgeneration – *but see later*
  - Our electricity supplier was charging ~12p per kWh for electricity we imported, but paying only 5p per kWh for export
  - In summer 2008 they started offering 20p per kWh for export – more 'interesting'
  - And in April 2009 export went up to 28p per kWh!
    - The supplier is required to install more renewables, but saves because their customers pay the capital costs by installing their own systems

Solar photovoltaic (2)

Choosing a system

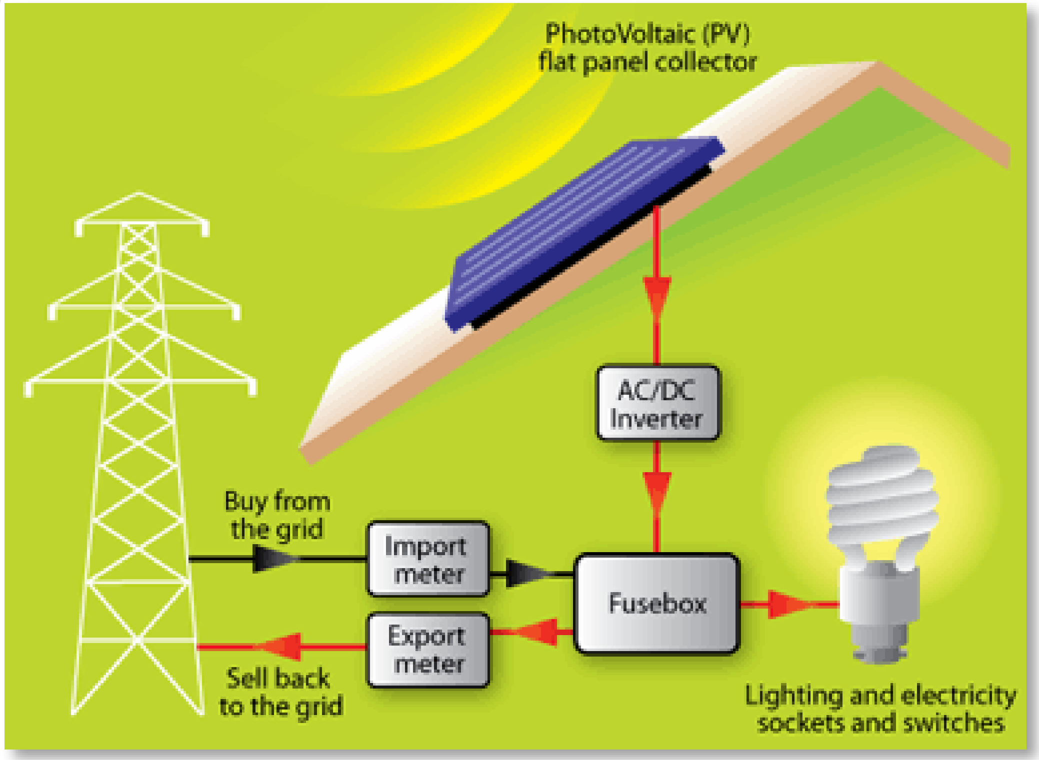
- Got quotes from 3 companies on 8 systems using 5 brands of panels
  - Wide range: 1.3–2.5 kWp, 10.5 to 17.6 m^2, 12.4% to 17.2% efficiency
  - Estimated yields from 1040 to 2100 kWh/year
  - Not like solar thermal, where you just want enough capacity for your needs, and it's relatively low-tech

- How to choose?
  - For us, capacity was limited by cost not roof area, so we looked for best value rather than highest efficiency
  - Cost *per kWp* was similar for most systems
    - Highest efficiencies using latest panels were most expensive
    - One brand of panels was roughly 20% cheaper: made in UK, bought direct
- What we chose
  - Monocrystalline panels, 10×1.3 m^2 = 13 m^2, **1.8 kWp** at 20°C, 13.7% efficient
  - Cost £9500 (panels are now cheaper – current price would be about £8000)
    - Got government grant of £2500 minus £400 already received for solar thermal (*but see later*)

Solar photovoltaic (3)

How the system works

- Panels generate DC, with variable voltage
- Inverter converts to 240 V, 50 Hz AC, in phase with mains
- Switches to disconnect from grid
  - Automatically if grid goes off, for safety
- Meters for total generation, grid import, grid export, and instantaneous power



Inverter

Import/export meter (green) Total generation meter (white) Disconnect (red)

Solar photovoltaic *(4)*

Performance

- Installed October 2008

  Estimated annual output:

  Official (SAP): 1440 kWh per year

  Installer's prediction: 1710 kWh per year

  Actually got: 1770±25 kWh(!)

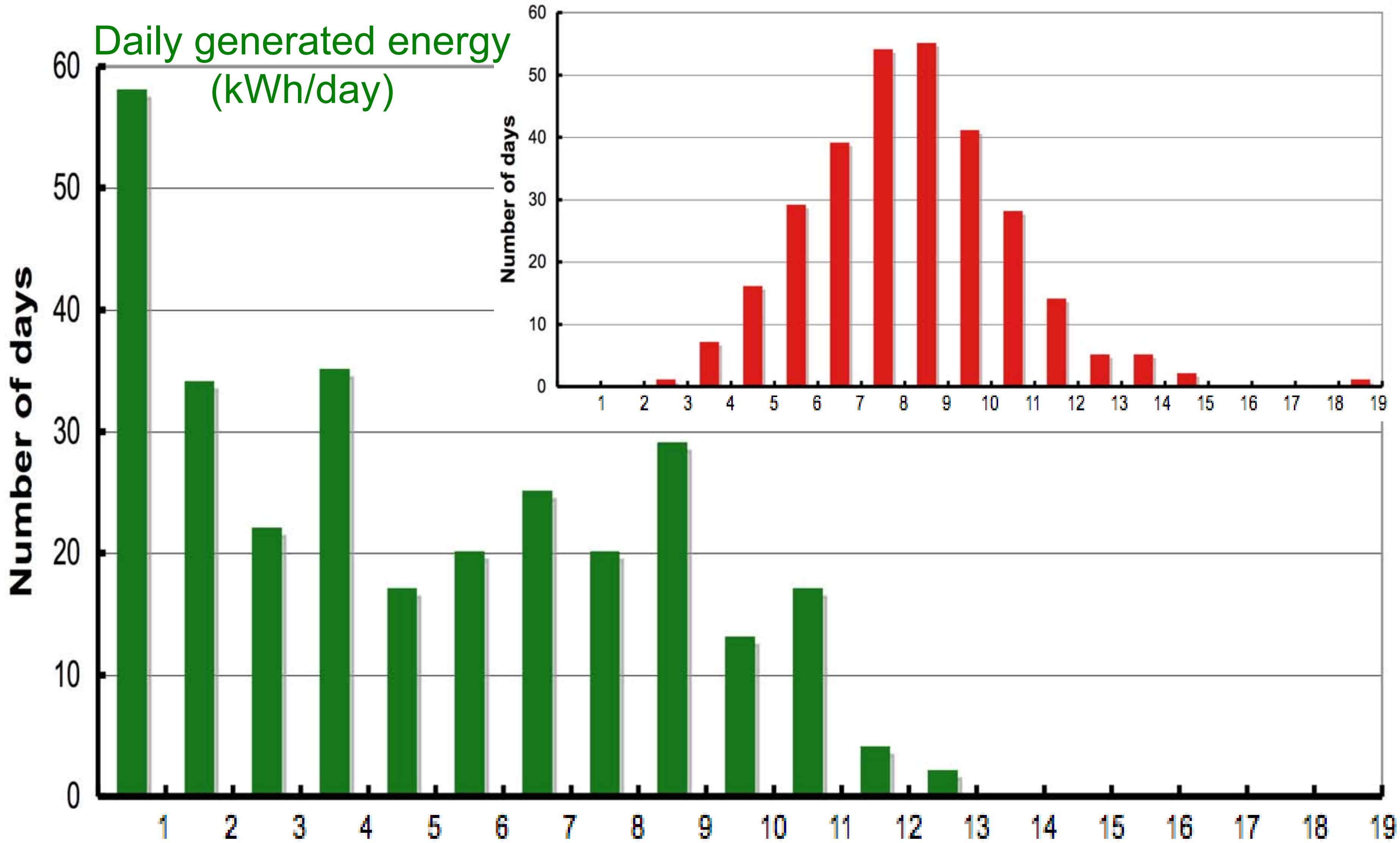
- In summer the best sunny days generate > 12 kWh
- In winter get over 3 kWh if very sunny day, but only tenths of a kWh if grey

  Temperature coefficient of –0.5% per °C helps in winter, hurts in summer

  Big difference between direct sunlight and even a fluffy little cloud over the sun

Solar photovoltaic (5)

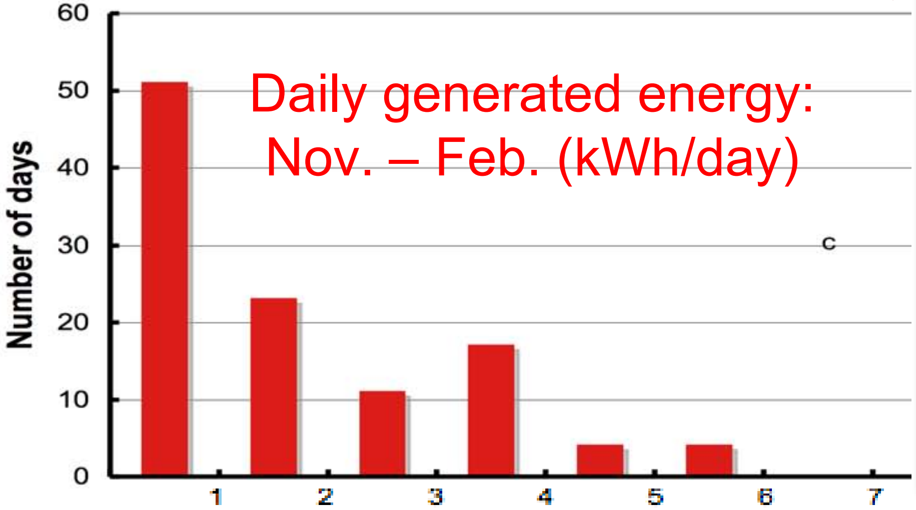
Day-to-day generation varies a lot!

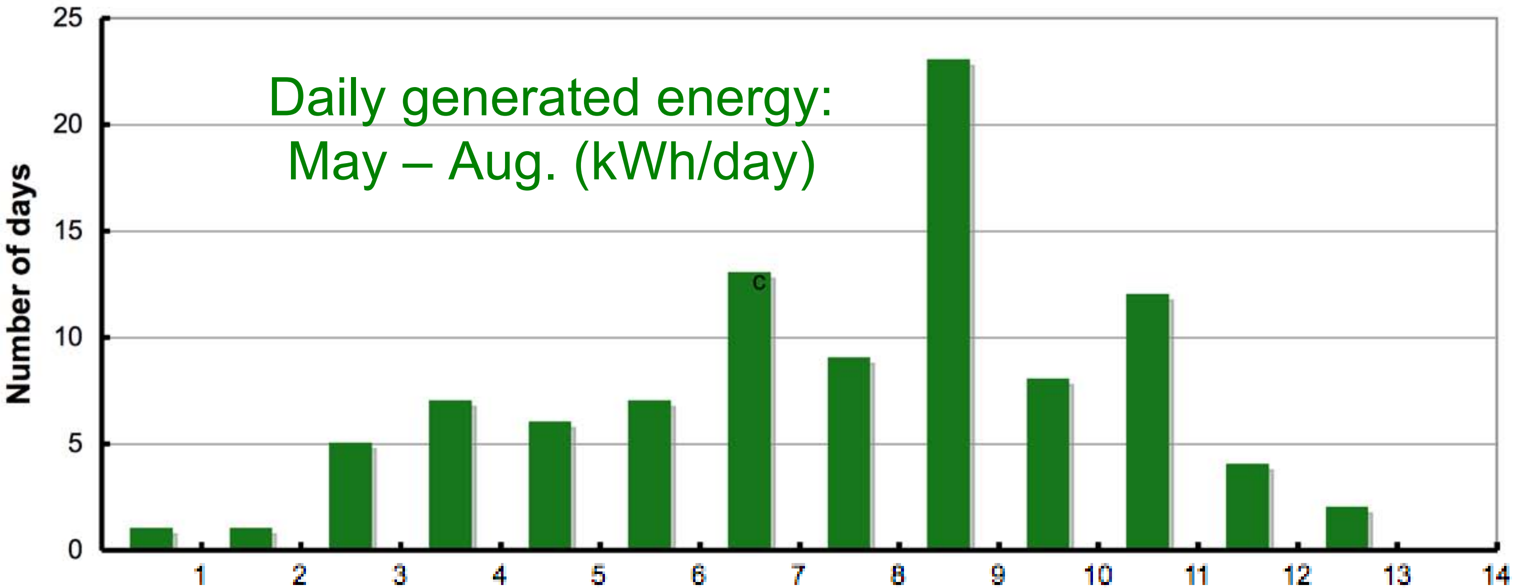


Solar photovoltaic *(6)*

Huge seasonal variation!

Even more if Dec–Jan compared to June–July

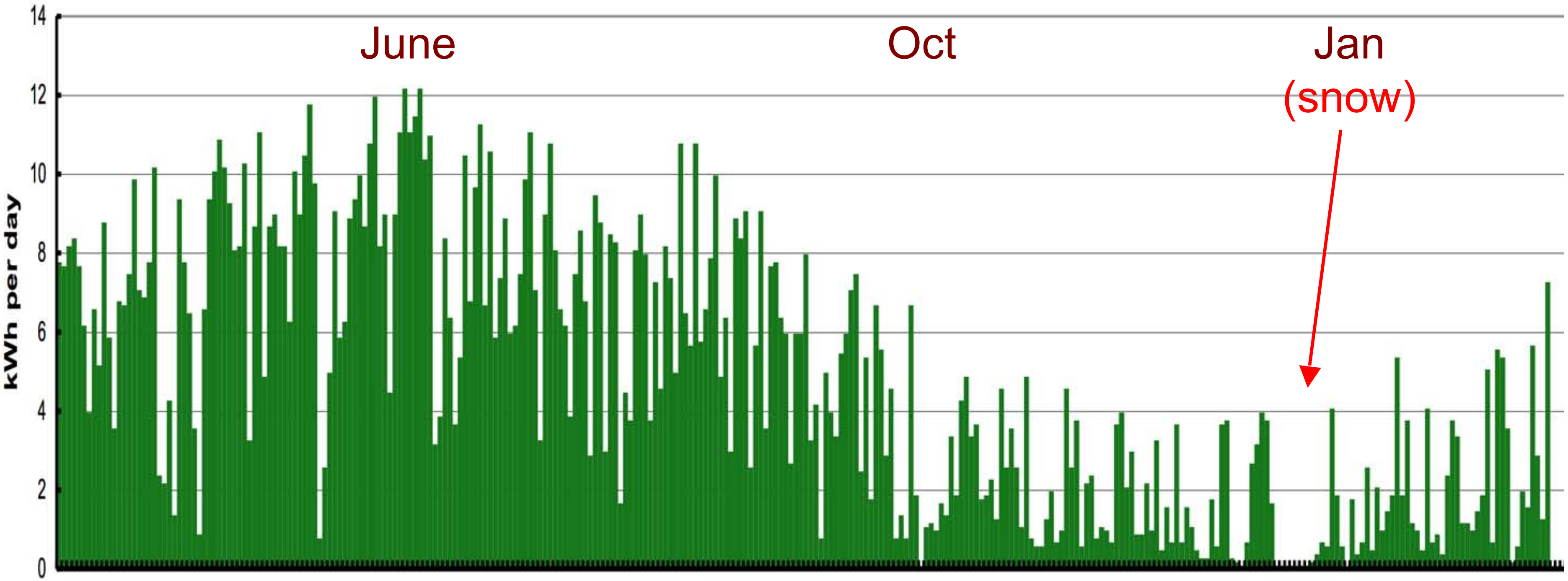




Solar photovoltaic *(7)*

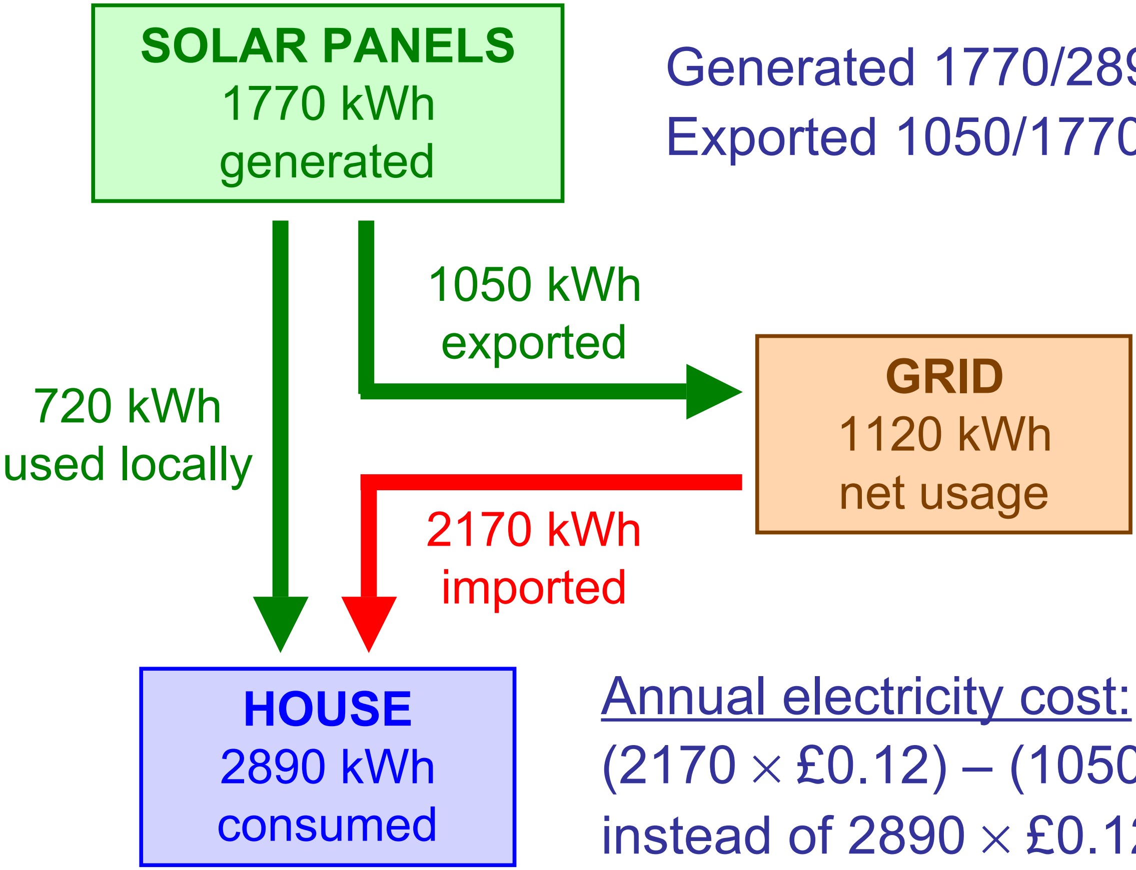
Daily generation (kWh/day):

March 2009 – February 2010



Solar photovoltaic *(8)*

Results from the first year of operation



Generated 1770/2890 = 61% of usage
Exported 1050/1770 = 59% of generated

<u>Annual electricity cost:</u>

(2170 × £0.12) – (1050 × £0.28) = **– £33!**

instead of 2890 × £0.12 = **+ £347** without PV

(Ignores standing charges of about £50. Negative means payment to us.)

Feed-In Tariff

General points

- Aims to increase small-scale renewable electricity, and expand market so systems get cheaper

  Make small systems a reasonable investment – covers up to 5 MW

  Aim to 'incentivise', not reward, so systems installed < July 2009 get *much less*
- Starts 1 April 2010, planned to last 20 years (25 for solar PV)
- Pays for total generation (+ a bit for export), *not* just export as elsewhere

  Local use reduces transmission losses; makes people more aware of their usage
- Technologies covered:
  - solar photovoltaic panels
  - wind turbines
  - small-scale hydro
  - anaerobic digestion
  - 'micro' combined heat and power

  Tariffs differ by technology, and for different-size systems – higher for small ones
- Existing up-front grants will be ended
- Installer and system must be government approved

Feed-In Tariff (2)

Feed-In Tariffs for solar photovoltaics

- Rate for a given system will be fixed (though indexed for inflation), but for new systems the rates will decline with time as prices get cheaper
- For systems of less than 4 kW the tariff starts at:

  41.3 p/kWh + 3 p/kWh for export for existing houses

  36.5 p/kWh + 3 p/kWh for export for new houses

  9.0 p/kWh + 3 p/kWh for export for older systems
- Other technologies get lower rates – very detailed list
- Example: annual electricity 'bill' of a system like ours:

  If new system: (2170 × £0.12) – (1770 × £0.413) – (1050 × £0.03) = **– £502**

  If old system: (2170 × £0.12) – (1770 × £0.090) – (1050 × £0.03) = **+ £70**

  Compare with +£347 if no solar PV and –£33 at present

Renewable Heat Incentive

General points

- Aims to increase renewable heating at all scales, and expand market so systems get cheaper
  - Target is 15% of *total* UK energy from renewables by 2020
  - Claims to be a world first, so no models to base it on (unlike Feed-In Tariff)
  - Make renewable systems a reasonable investment
  - Aim to 'incentivise', not reward, so systems installed < July 2009 get *nothing at all*
- Currently in public consultation (closes 26 April), aim to start 1 April 2011
  - Proposals will probably change a bit
- Technologies covered:
  - solar thermal
  - heat pumps (ground, air or water source), and geothermal
  - biomass boilers (e.g. wood pellet boilers, but not wood-burning stoves)
  - renewable combined heat and power
  - biogas (from anaerobic digestion) and bioliquids for replacing heating oil
  - biomethane for gas grid
  - district heating schemes

  Tariffs differ by technology, and for different-size systems – higher for small ones

Renewable Heat Incentive (2)

- Existing up-front grants will be ended
- Installer and system must be government approved

Air-source heat pump

Tariffs for renewable heating

- Major problem is that, unlike electricity, heat is hard to measure accurately
- Therefore, payments will be based on what the installer estimates the annual output of the system will be – nominal ('deemed') value
- Rate for a given system will be fixed (possibly indexed for inflation), but for new systems the rates will decline with time as prices get cheaper

Common domestic examples:

- Ground-source heat pumps (and geothermal): 7.0 p/kWh for 23 years.
- Air-source heat pumps: 7.5 p/kWh for 18 years
- Solar thermal: 18 p/kWh for 20 years

A system like mine (if new) might get £250–£350 per year

Conclusions and observations

There is a lot that can be done in homes to save energy

- Some of it is easy, and offers very quick payback
- Microgeneration much more attractive with Feed-In Tariff and Renewable Heat Incentive – *solar photovoltaics, solar thermal, heat pumps, …*

The bigger picture

- UK is good for wind and tidal, but less good for solar, hydro, etc. How do we get enough renewable energy?
- Solar energy fluctuates, by the minute, time of day, weather and season. Much of this is unpredictable.
- Once past 20–30% renewables overall, an energy supply that matches demand becomes a problem.

*Further (provocative!) reading: **Sustainable Energy – without the hot air**, by David MacKay. Entire book available free at:* **`www.withouthotair.com`**

Acknowledgement: Much of this was done in the context of the Blewbury Energy Initiative: **`www.blewbury.co.uk/energy`**