Solar panels and thermal imaging

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Insulation and thermal imaging

- Insulating houses – *the first thing to do*
- Thermal imaging – *diagnosing energy losses*

Solar panels

- Solar basics
- Solar hot-water panels
  - General information
  - How they work – *in a real installation*
  - How they perform – *in a non-ideal climate*
  - Proposed Renewable Heat Incentive – *will renewable heating be rewarded?*
- Solar photovoltaic panels
  - General information
  - How they work – *in a real installation*
  - How they perform – *in a non-ideal climate*
  - Feed-in Tariff – *renewable generation is now an attractive option*

Conclusions

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°

Insulation

The first thing to do! Inexpensive for a modern house, and grants help to pay for it

U=1 means 1 watt per m² per °C temperature difference

** = current standard*

Roof

- Approximate U-values:
  - 25 mm insulation: 1.1 W/m²/°C – *where we started*
  - 100 mm insulation: 0.3 W/m²/°C – *what we had until 2007*
  - 270 mm insulation: 0.16 W/m²/°C* – *what we have now*

Loft insulation

Walls

- Approximate U-values:
  - Solid brick: 2.2 W/m²/°C
  - Cavity wall: 1.0 W/m²/°C – *where we started*
  - Insulated cavity wall: 0.6 W/m²/°C* – *since 1982*
- Old houses don't have cavity walls

Cavity wall insulation

Windows and doors

- Approximate U-values:
  - Single glazed: 5.0 W/m²/°C – *where we started*
  - Double glazed: 2.9 W/m²/°C – *what we have now (new systems 1.7*)*
- Draught-proofing strips can help a lot

Insulation problems

But there are many problems

- Many people *(even those who know better)* somehow ‘don’t get around’ to improving their insulation
- Even in modern buildings, there are often heat losses caused by faults in the insulation or building structure
- Huge number of older houses in the UK (many in poor condition) are difficult and expensive to insulate properly

  - Structure leaks heat – *poor design, and faults due to age*
  - No cavity walls – *so wall insulation is a big, expensive job*
  - Badly fitting, draughty windows and doors

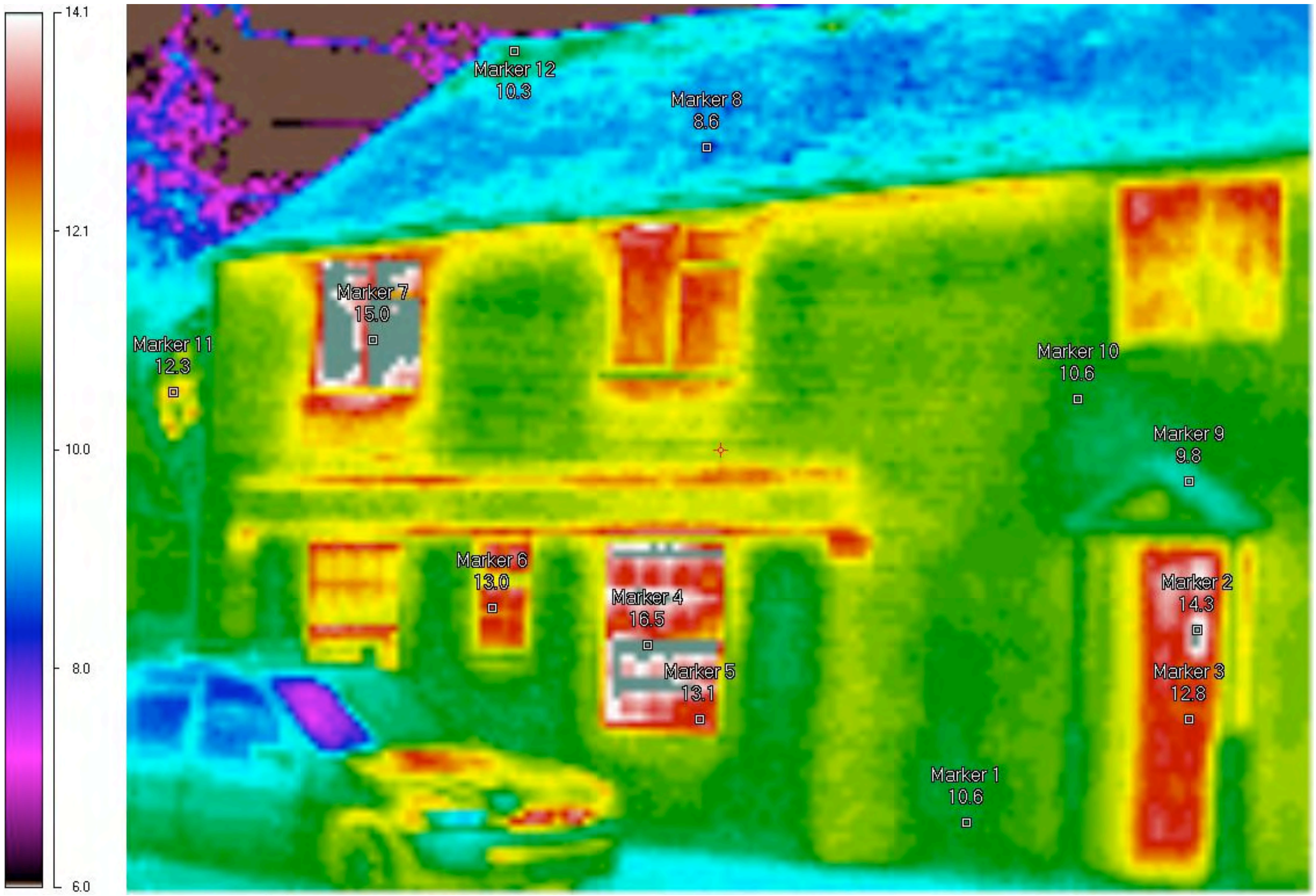
  - Owners often can’t afford to do it – *so they must pay huge energy bills*
  - Landlords don’t do it – *they don’t pay the energy bills*
  - Conservation areas and listed buildings – *good in principle, but make it difficult to replace things like old windows*

We need a way to diagnose insulation problems!

Thermal imaging

For checking insulation and finding problems

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



Thermal imaging basics

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, …
- Outside temperature should be at least 10–20°C lower than inside

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 ($5.67 \times 10^{-8}\ \mathrm{W m^{-2} K^{-4}}$)
  - 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 our images
    - So 0.9 not bad approximation – and we want differences, not absolute values!

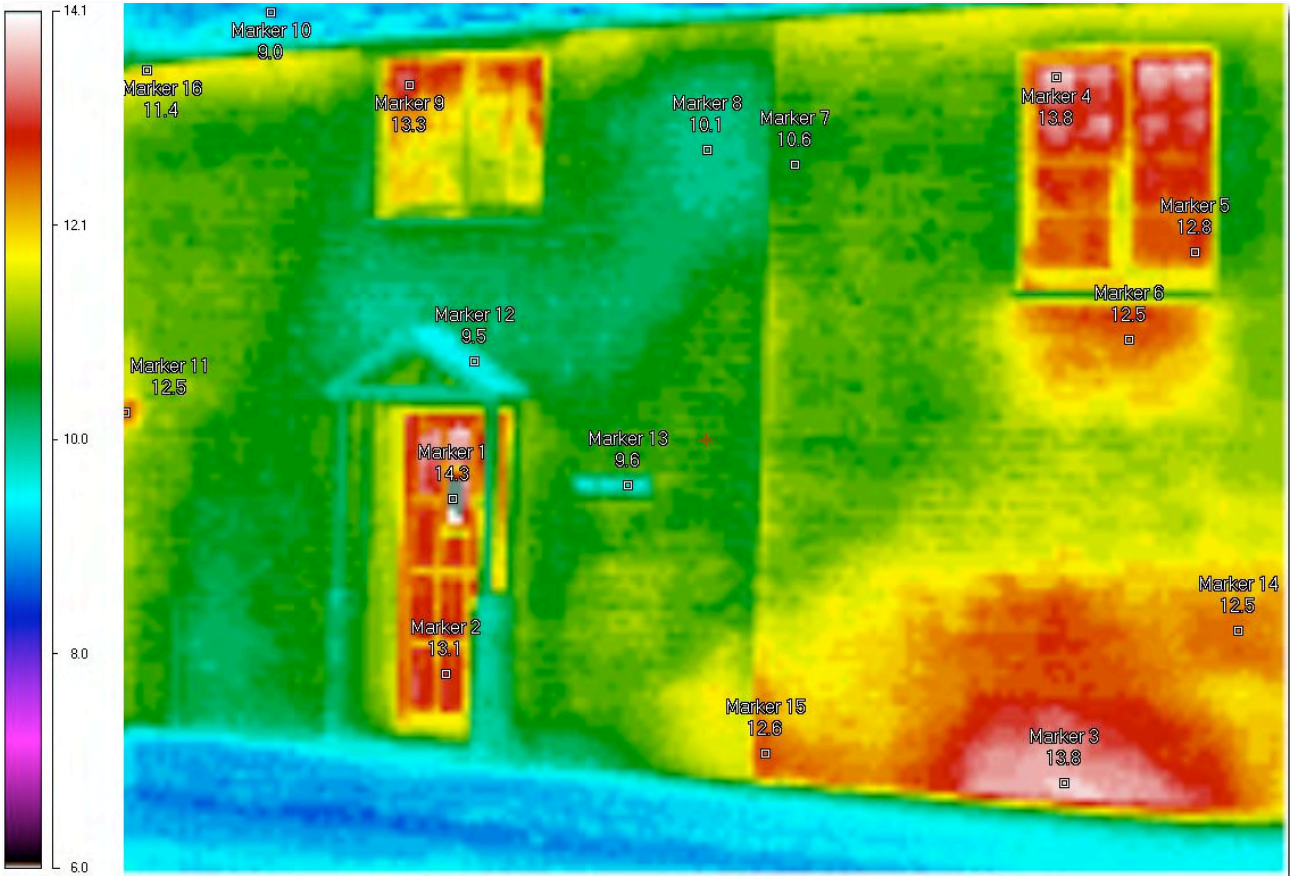
Thermal images

Took images of 19 houses in Dec. 2008

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

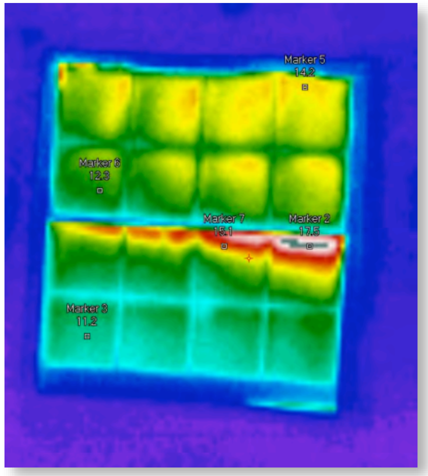
More photos taken in Jan. 2010 and 2011

- Outside temperature was below 0°C

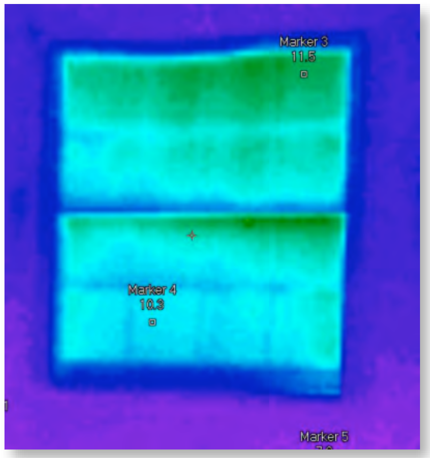


Diagnosing problems

Secondary double-glazing on an old house

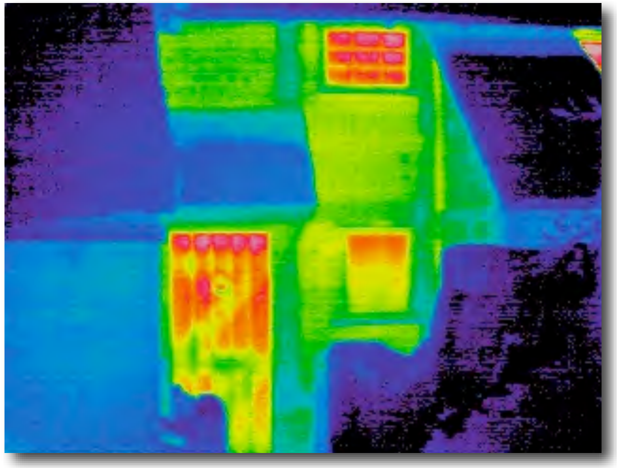


Before

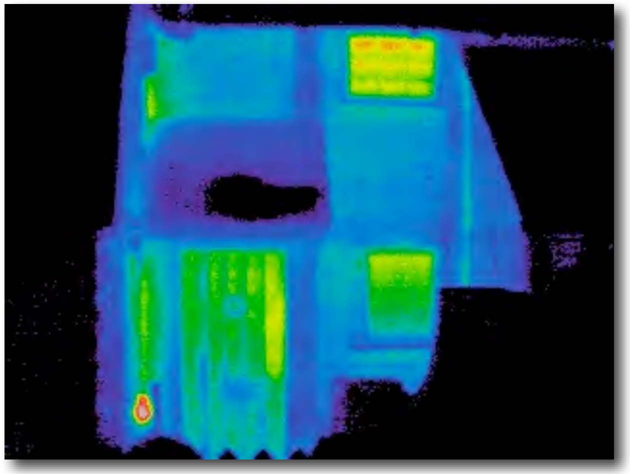


After

Leaky door fixed by insulation

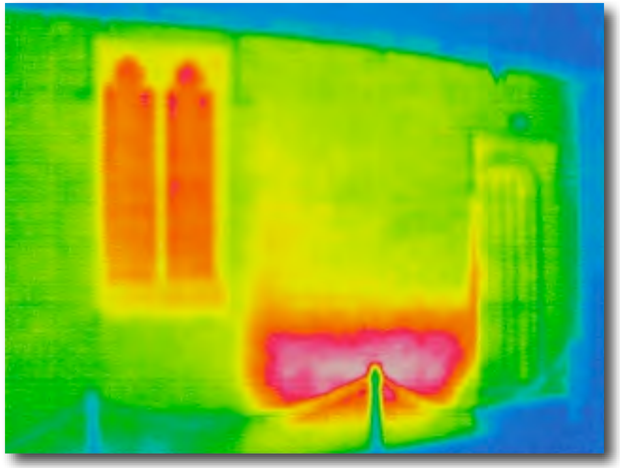


Before



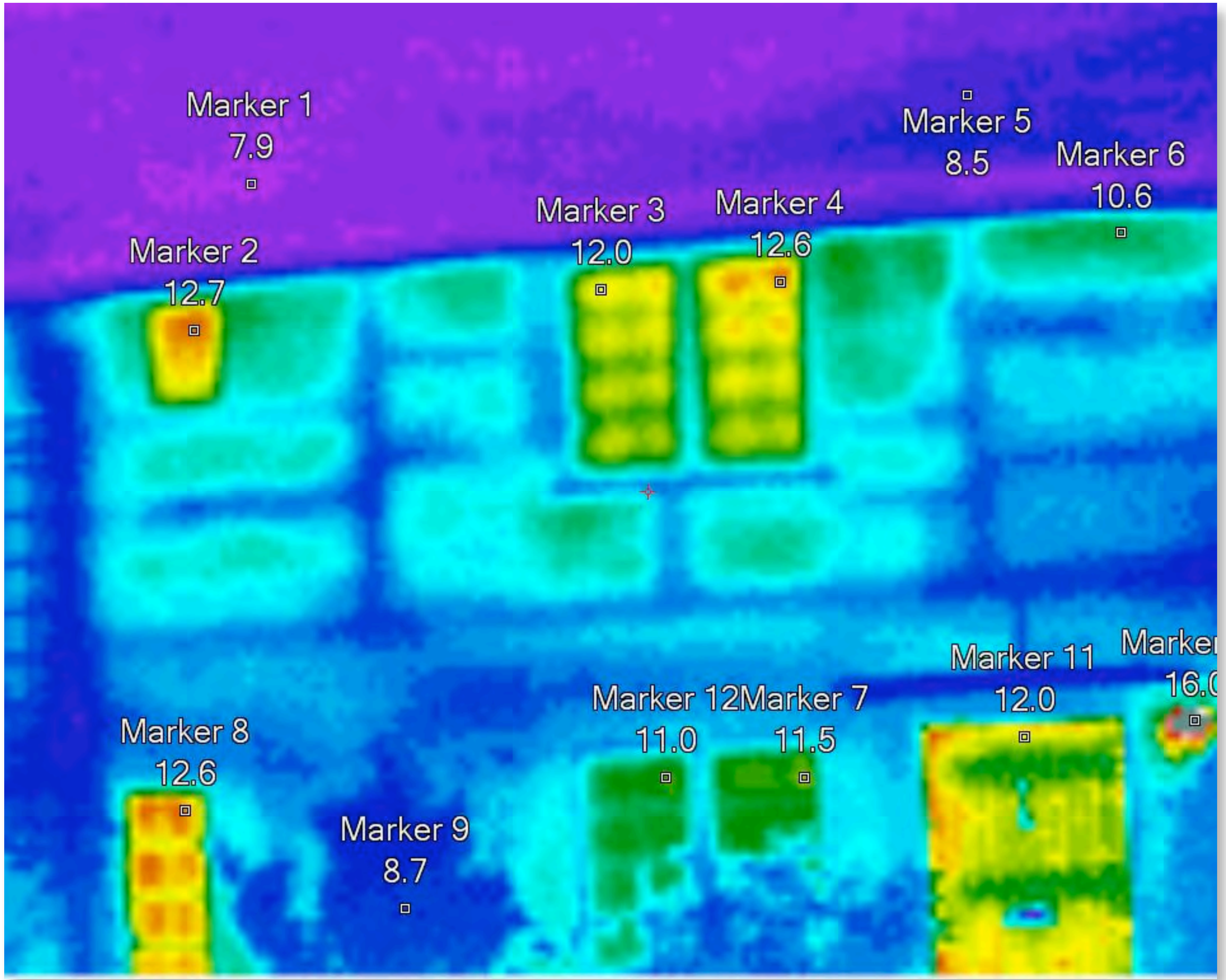
After

Radiator and thin outer wall



Jan. 2010/2011 camera

Digression



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

Interesting to experts on old timber-framed buildings!

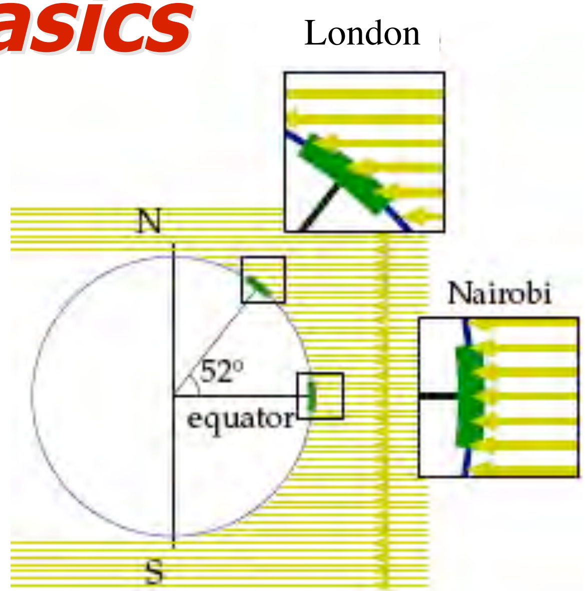
Thermal imaging 2011

Took more images in Jan. 2011

Pub (heating off next door)

Recent development: small, easy-to-use, less expensive cameras now available

Solar energy basics

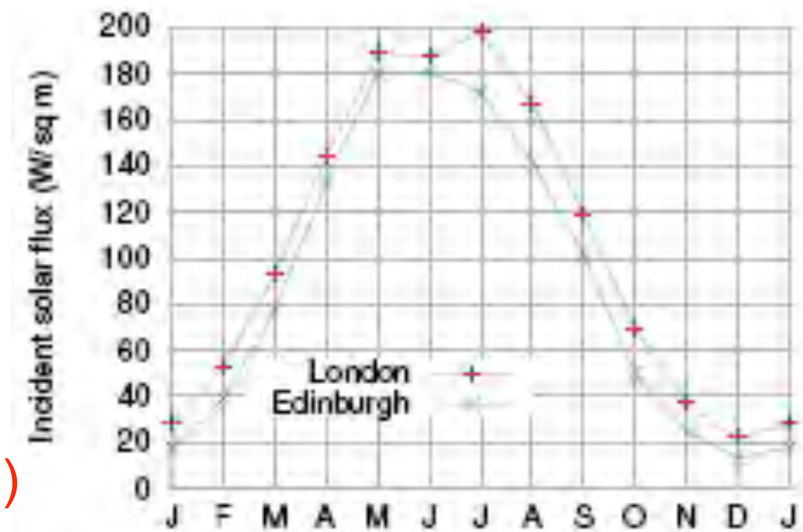


Potential of solar energy in the UK

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

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

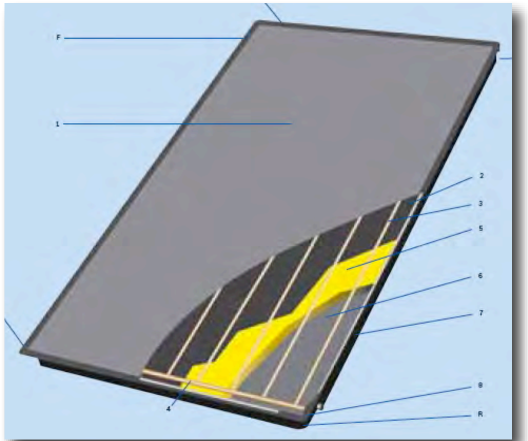
- For a cloudless day in March or September the 24-hour average is about **320 W/m²**
- But in a typical UK location, it is sunny for only 34% of daylight hours
- Must take account of the seasons
- Overall average for a *tilted*, south-facing UK roof is about **110 W/m²**, or about **960 kWh/m² per year** (more in the south)



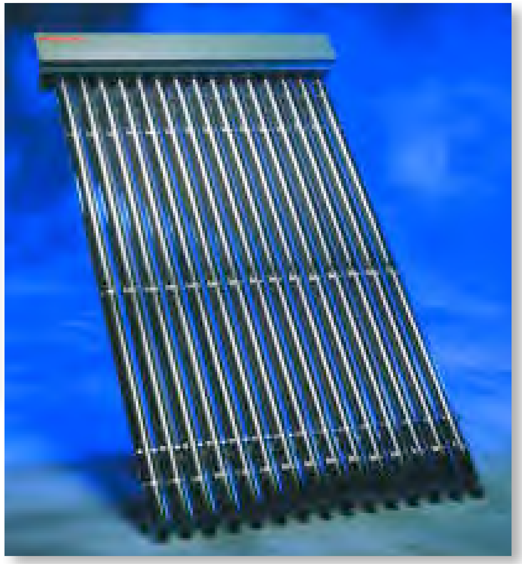
Two ways to use it: solar electricity and solar hot water

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 glass tubes trap energy, avoiding convection and re-radiation
  - Fluid circulating in thin metal pipes gets hot, for heating the hot water tank



- **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

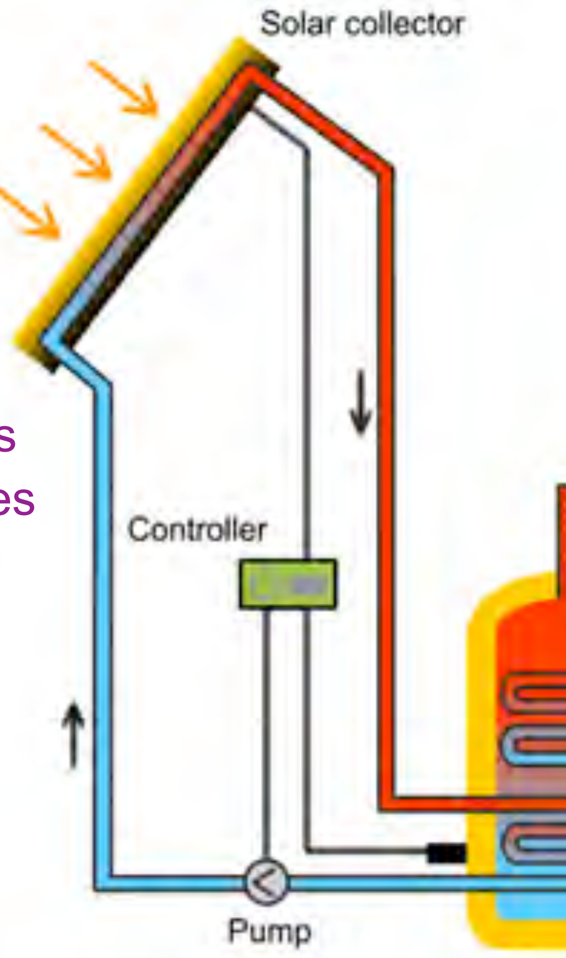
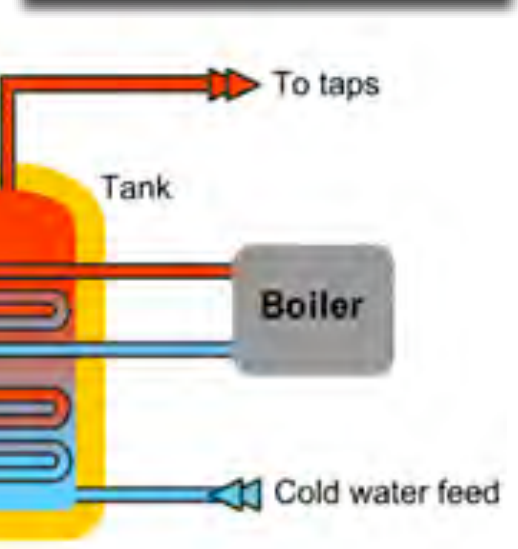
How solar thermal systems work

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

4 m[2] flat-plates – installed September 2007

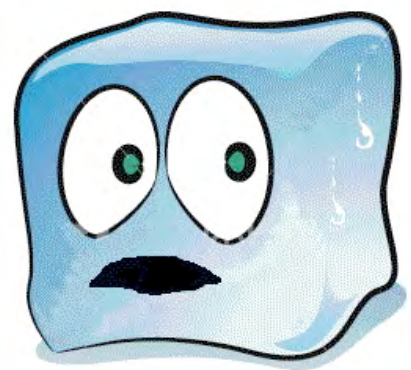
- Bigger hot-water tank: 190 litres
  (enough for over 24 hours)
- Pump uses 30 W; on as long as panels more than 4°C warmer than water at bottom of tank
  - Some pumps are solar-powered
- Controller switches pump; displays status, panel & tank temperatures
- When not enough solar energy, water can be heated by boiler, or by electric immersion heater
- Harder to install if you have a 'combi' boiler, since you need a separate hot-water tank

Controller, pump and hot-water tank

Handling extreme temperatures

What if it gets very cold or very hot?



- Fluid for panels is in a closed loop – does not mix with the hot water
- Uses 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 *vaporise* – pump turns off at 140°C and there is an expansion tank for the vapour
- Hot water is *never* heated beyond 60°C, for safety – pump turns off

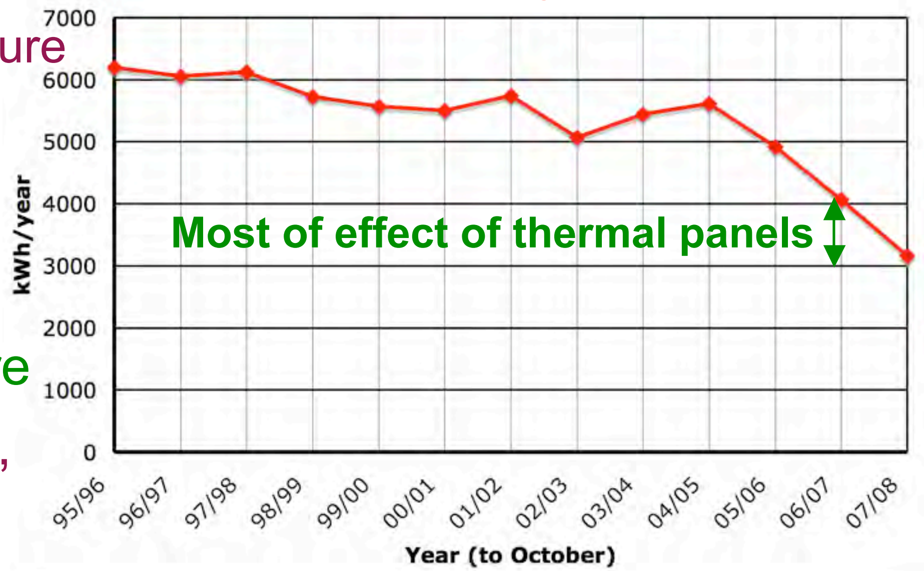
Solar thermal performance

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 gas/oil, but harder to measure

Annual electricity consumption



Cost

- Simple flat-plate systems typically about £3500–£4000
- Evacuated tubes roughly £1000 more
- Pay-back time perhaps 15–20 years, *but see later*

Proposed Renewable Heat Incentive

General points

- Previous up-front grants (e.g. for solar thermal) have ended
- Want to increase renewable heating at all scales
  - Target is 12% of UK heating from renewables by 2020
  - Hopefully, this will help make the technologies cheaper
  - Claims to be a world first, so no models to base it on – *unlike Feed-in Tariff*
  - Make renewable systems a reasonable investment, but 'incentivise', not reward – *so systems installed before some date (July 2009?) will get nothing at all*
- Public consultation closed in April 2010, aimed to start 1 April 2011
  - But DECC has not even responded to the consultation yet
  - They now say it will start 'some time in 2011'
  - Proposals will change; in the meantime the industry and customers can't plan!

Renewable heat technologies

- Technologies covered (in original proposal)
  - solar thermal water-heating
  - heat pumps (ground, air or water source)
  - geothermal heating
  - 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 – in general, higher for small ones
- Installer and system must be government approved

Air-source heat pump

Renewable heat tariffs

How the tariffs might work

- Major problem – 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, but for new systems the rates will decline with time as prices get cheaper
- Some domestic examples *(rates from original proposals, not final!)*:
  - 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 ours (if new) might get £250–£350 per year

Warning!

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 always tell you about government support, because that requires:
  - Government (MCS)-approved equipment ***and*** installation company
- System may or may not be competently installed, and may or may not work reliably and well
- Even if legitimate, watch out for very high prices
- Spreading to solar photovoltaics as 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

  When we started, the UK did not yet have a 'feed-in' 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 – we got interested when this went up first to 20p per kWh and then 28p per kWh for export

PV panel orientation

Roof direction

- An unshaded roof facing south, with a pitch of 30°–35°, is ideal

  But pitches between 25° and 50° make little difference to the energy collected

- **Southeast** or **southwest:** reduces the energy collected by **4–8%**
- **East** or **west:** reduces it by about **20%**
- **Northeast**, **northwest**, and especially **north**: solar is not recommended

Roof overshadowing

- Solar panels do work without direct sunlight, but output is *greatly* reduced

  Some newer models do a *bit* better – *but cost more*

- Problems if the roof is partly screened by trees (particularly in summer) or shaded by structures for much of the time

  Even shading that looks minor can have a very big effect on output, because the panels are usually connected in series

- Could consider mounting panels on a shed, garage or pergola

Solar PV options

Choosing a system

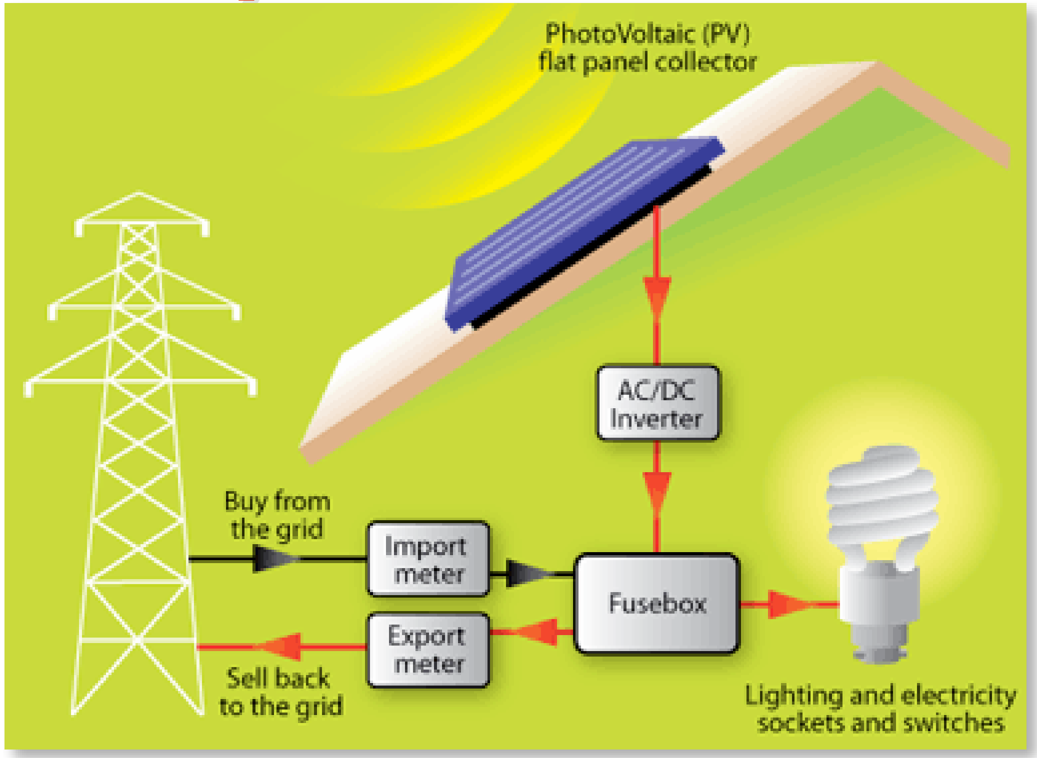
- Got quotes from 3 companies on 8 systems using 5 brands of panels
  - Wide range: 1.3–2.5 kWp (i.e. peak), 10.5 to 17.6 m^2, 12.4% to 17.2% efficiency
  - Estimated yields from 1040 to 2100 kWh/year
  - Not like solar thermal, which is relatively low-tech and you just want enough capacity for your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

- 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, $10 \times 1.3\,m^2 = 13\,m^2$, **1.8 kWp** at 20°C, 13.7% efficient
  - Cost £9500 (panels are now cheaper – current price would be about £8000 for a 2.0 or 2.2 kWp system)
    - Got government grant of £2500 minus £400 already received for solar thermal

How solar PV systems work

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 PV performance

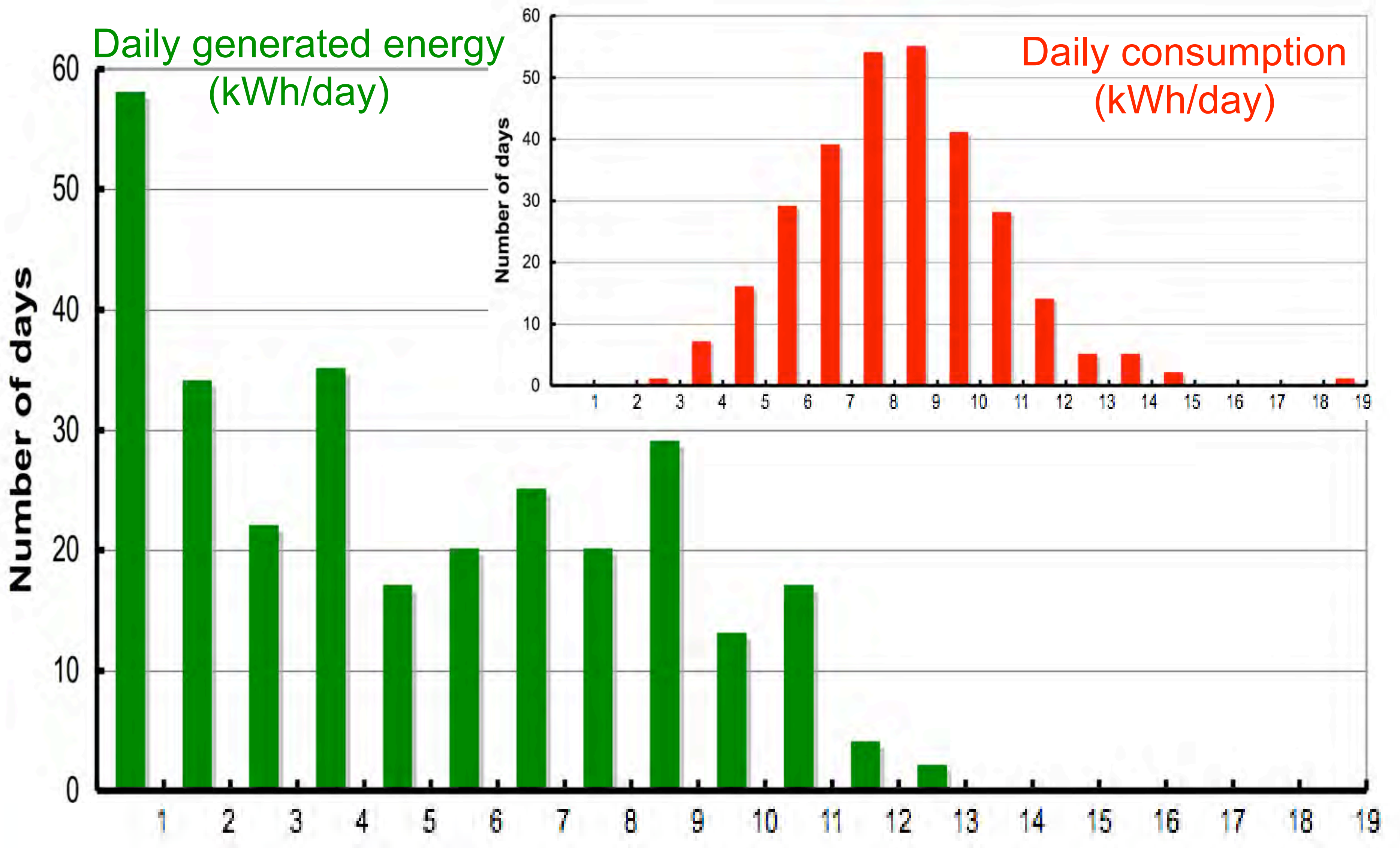
Performance

- 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 PV daily yield

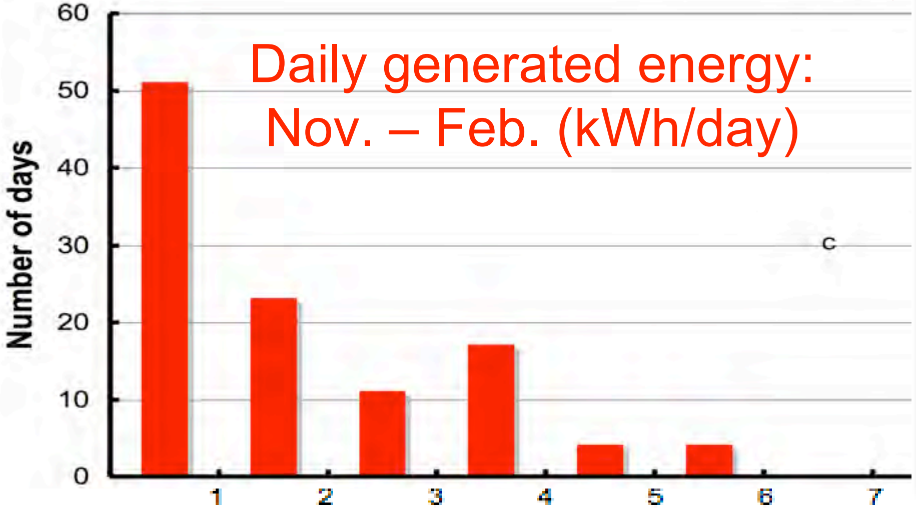
Day-to-day generation varies a lot!

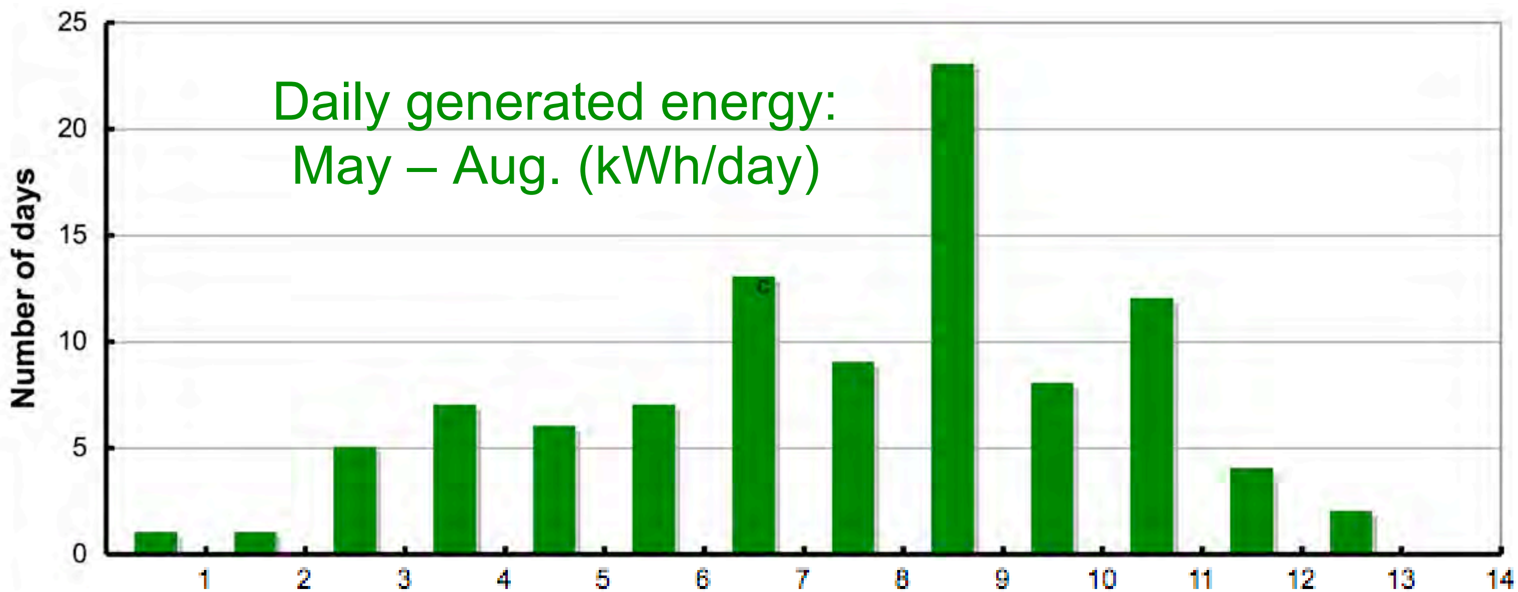


Solar PV seasonal variation

Huge seasonal variation!

Even more if Dec–Jan compared to June–July

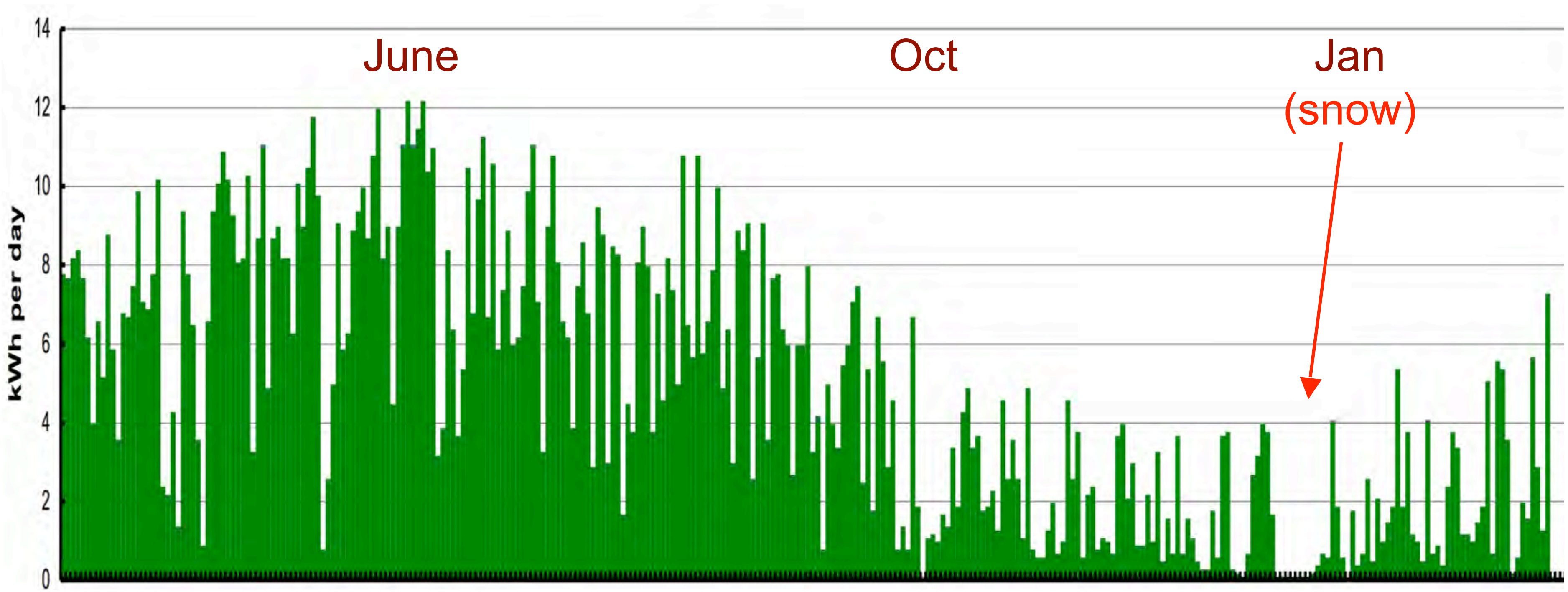




Solar PV variability

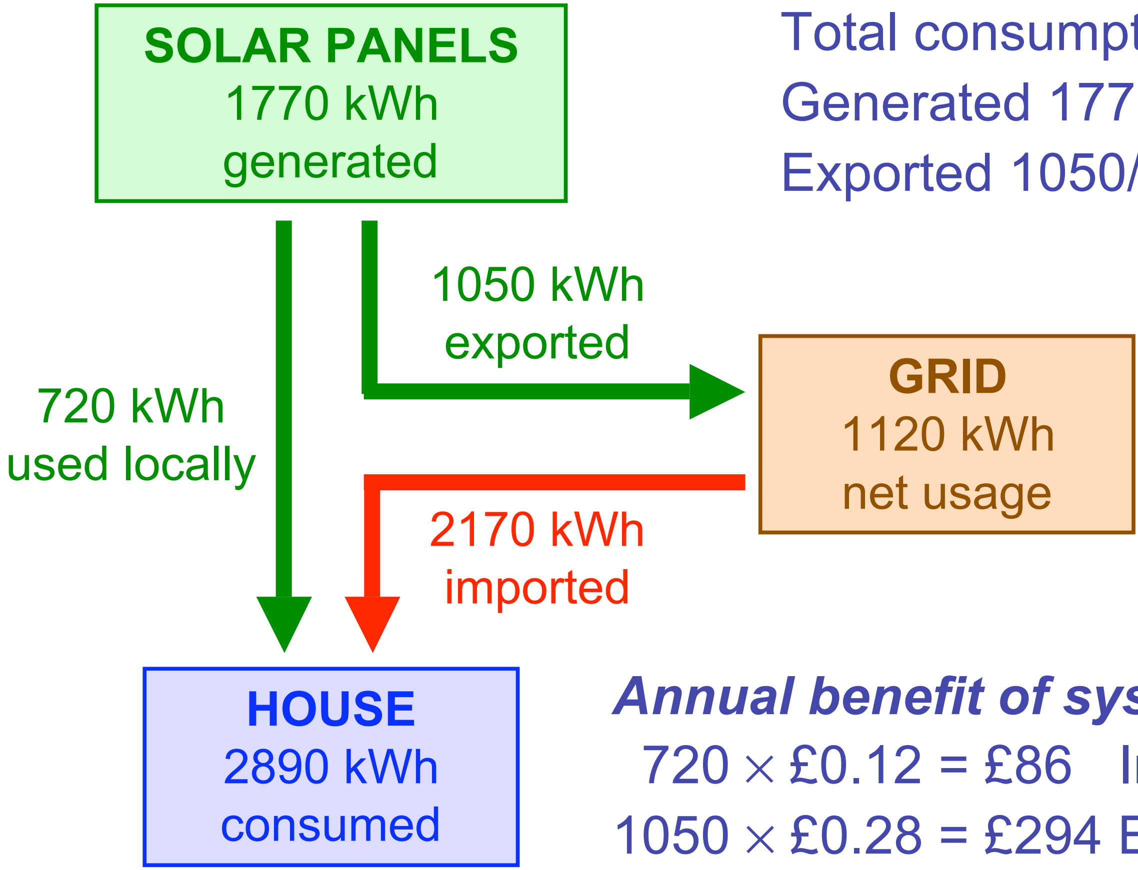
Daily generation (kWh/day):

March 2009 – February 2010



Solar PV annual results

Results from the first year of operation



Total consumption was 2890 kWh
Generated 1770/2890 = 61% of usage
Exported 1050/1770 = 59% of generated

Annual benefit of system *(no longer applicable):*

720 × £0.12 = £86   Import saving
1050 × £0.28 = £294 Export payment
Total = **£380**

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*
- Started 1 April 2010, planned to last 20 years (25 for solar PV)
- Pays owners for total generation + a bit for export (elsewhere just export)

  Local use reduces transmission losses; makes people more aware of their usage
- Technologies covered:
  - solar photovoltaic
  - 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
- Up-front grants have ended
- Installer and system must be government (MCS) approved

Feed-in Tariff rates

Feed-in Tariffs for solar photovoltaics

- Rate for a given system is fixed, but for new systems the rates will decline with time as prices get cheaper
- For systems of less than 4 kW the tariff is

  41.3 p/kWh + 3 p/kWh exported (existing houses)
  36.5 p/kWh + 3 p/kWh exported (new houses)
  9.0 p/kWh + 3 p/kWh exported (older systems)

- Other technologies get lower rates – very detailed list
- Example: what we'd get *per year* from a new system like our existing one:

  1770 × £0.413 = £731 *Total generation*
  720 × £0.100 = £ 86 *Import saving*
  1050 × £0.030 = £ 32 *Export supplement*
  Total = £**849** *For 25 years*

- 'Rent-a-roof' deals widely available – you get a 'free' system and reduced electricity bills, but someone else owns it and collects the Feed-in Tariff

  It would actually be better to borrow the money for your own system

Solar PV update

After Feed-in Tariff started …

- A group purchase of PV systems in our village was organised – *lower price*
- Number of PV systems in the village increased from 8 to 18, including …
- New system on our garage roof in Nov. 2010

  12 x 180 W panels, 2.16 kWp – *panels made in China*

  This (larger) system cost less than our one

  Our total is now 3.96 kWp – must be < 4 kW to get full Feed-in Tariff

  Only our new system gets the full Feed-in Tariff – *the old system does not*

  Payback time ~8 years, and payments will continue for 25 years

New inverter

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`**