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.

Roof

- Approximate U-values:
  - 25 mm insulation: \(1.1 \text{ W/m}^2\text{/°C}\) – where we started
  - 100 mm insulation: \(0.3 \text{ W/m}^2\text{/°C}\) – what we had until 2007
  - 270 mm insulation: \(0.16 \text{ W/m}^2\text{/°C}\) – what we have now

Walls

- Approximate U-values:
  - Solid brick: \(2.2 \text{ W/m}^2\text{/°C}\)
  - Cavity wall: \(1.0 \text{ W/m}^2\text{/°C}\) – where we started
  - Insulated cavity wall: \(0.6 \text{ W/m}^2\text{/°C}\) – since 1982
- Old houses don’t have cavity walls

Windows and doors

- Approximate U-values:
  - Single glazed: \(5.0 \text{ W/m}^2\text{/°C}\) – where we started
  - Double glazed: \(2.9 \text{ W/m}^2\text{/°C}\) – what we have now (new systems 1.7*)
- Draught-proofing strips can help a lot

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

\(^*\) = current standard

Loft insulation

Cavity wall insulation
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

Lens

- Germanium crystal: transmits $\lambda$ from 8–12 $\mu$m

Raw data

- Sensors: each ‘pixel’ is effectively a thermometer
- Only about $160 \times 120$ or $320 \times 240$ 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
  $\sigma$ is Stefan-Boltzmann constant ($5.67 \times 10^{-8}$ Wm$^{-2}$K$^{-4}$)
  $\varepsilon$ 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!
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
- Leaky door fixed by insulation
- Radiator and thin outer wall

Before

After

Jan. 2010/2011 camera

Eric Eisenhandler • Physics of Energy and the Environment • 2011
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

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

Pub (heating off next door)
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 m² ⇒ 1400 kWh per year – *about 36% efficiency*
  - Evacuated tubes: more efficient but dearer
    - Claim: 4 m² ⇒ 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 m² 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
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

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
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 m², 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 × 1.3 m² = 13 m², **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
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!

Daily generated energy (kWh/day)

Daily consumption (kWh/day)
Solar PV seasonal variation

Huge seasonal variation!
Even more if Dec–Jan compared to June–July

Daily generated energy:
Nov. – Feb. (kWh/day)

Daily generated energy:
May – Aug. (kWh/day)
Solar PV variability

Daily generation (kWh/day):
March 2009 – February 2010

June
Oct
Jan (snow)
Results from the first year of operation

**SOLAR PANELS**
- 1770 kWh generated
- 1050 kWh exported
- 2170 kWh imported
- 720 kWh used locally

**GRID**
- 1120 kWh net usage

**HOUSE**
- 2890 kWh consumed

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

**Annual benefit of system (no longer applicable):**
- Import saving: $720 \times 0.12 = £86$
- Export payment: $1050 \times 0.28 = £294$
- 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:
  \[ 1770 \times £0.413 = £731 \text{ Total generation} \]
  \[ 720 \times £0.100 = £86 \text{ Import saving} \]
  \[ 1050 \times £0.030 = £32 \text{ Export supplement} \]
  \[ \text{Total} = £849 \text{ For 25 years} \]

- ‘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.


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