- First, fossil fuels are a finite resource
- Second, we're interested in security of energy supply.
- Third, it's very probable that using fossil fuels changes the climate.

Climate change is blamed on several human activities, but the biggest contributor to climate change is the increase in greenhouse effect produced by carbon dioxide (CO_2).

The climate-change motivation

The climate-change motivation is argued in three steps:

one: human fossilfuel burning causes carbon dioxide concentrations to rise;

two: carbon dioxide is a greenhouse gas;

three: increasing the greenhouse effect increases average global temperatures (and has many other effects).

“The burning of fossil fuels sends about seven gigatons of CO_2 per year into the atmosphere, which sounds like a lot.

Yet the biosphere and the oceans send about 1900 gigatons and 36 000 gigatons of CO_2 per year into the atmosphere – . . . one reason why some of us are sceptical about the emphasis put on the role of human fuel-burning in the greenhouse gas effect.

Reducing man-made CO_2 emissions is megalomania, exaggerating man’s significance.

Politicians can’t change the weather

Greenhouse gases include carbon dioxide, methane, and nitrous oxide; each gas has different physical properties; it's conventional to express all gas emissions in "equivalent amounts of carbon dioxide," where "equivalent" means "having the same warming effect over a period of 100 years."

One ton of carbon-dioxide-equivalent may be abbreviated as "1 tCO2e," and one billion tons (one thousand million tons) as "1GtCO2e" (one gigaton).

it’s more likely than not that global temperatures will rise by more than 2 ◦C.

Both scenarios are believed to offer a modest chance of avoiding a 2 ◦C temperature rise above the pre-industrial level. In the lower scenario, the chance that the temperature rise will *exceed* 2 ◦C is estimated to be 9–26%.

In the upper scenario, the chance of exceeding 2 ◦C is estimated to be 16–43%. These possibly-safe emissions trajectories, by the way, involve significantly sharper reductions in emissions than any of the scenarios presented by the Intergovernmental Panel on Climate Change (IPCC), or by the Stern Review (2007)

These possibly-safe trajectories require global emissions to fall by 70% or 85% by 2050. What would this mean for a country like Britain?

If we subscribe to the idea of "contraction and convergence," which means that all countries aim eventually to have equal per-capita emissions, then Britain needs to aim for cuts greater than 85%: it should get down from its current 11 tons of CO2e per year per person to roughly 1 ton per year per person by 2050.

Examples of **factual assertions are "global fossil-fuel burning emits 34** billion tons of carbon dioxide equivalent per year;" and "if CO_2 concentrations are doubled then average temperatures will increase by 1.5–5.8°C in the next 100 years;"

and "a temperature rise of 2°C would cause the Greenland ice cap to melt within 500 years;" and

"the complete melting of the Greenland ice cap would cause a 7-metre sea-level rise."

Examples of **ethical assertions are "it's wrong to exploit global resources** in a way that imposes significant costs on future generations;" and "polluting should not be free;" and "we should take steps to ensure that it's unlikely that CO_2 concentrations will double;" and "politicians should agree a cap on CO_2 emissions;" and "countries with the biggest CO_2 emisssions over the last century have a duty to lead action on climate change;"
and "it is fair to share CO_2 emission rights equally across the world's population."

Australia's identified conventional gas resources have increased more than threefold over the past 20 years. Around 82 per cent of estimated recoverable reserves of conventional gas are located off the west and north-west coast of Australia.

In addition to conventional gas resources, there is a growing commercial utilisation of Australia's resources of coal seam gas. Economically demonstrated resources of coal seam gas are now around one third of those of conventional gas.

Most of these resources are located in the black coal deposits of Queensland and New South Wales.

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Australia's identified uranium resources have more than doubled over the past two decades, and increased by 62 per cent from 2006 to 2010. Most of Australia's uranium resources are located in South Australia, the Northern Territory and Western Australia. The Olympic Dam deposit in South Australia is the world's largest uranium deposit.

At current rates of production, Australia's energy resources are expected to last for many more decades.

The ratio of economic demonstrated resources to current production is estimated at 517 years for brown coal, 128 years for black coal, 66 years for conventional gas, 175 years for coal seam gas and 134 years for uranium.

Australia’s energy consumption is primarily composed of non-renewable energy sources (coal, oil and gas), which represent 95 per cent of total energy consumption.

Renewables, mainly bioenergy (wood and woodwaste, biomass and biogas), account for the remaining 5 per cent.

Electricity

The electricity industry, consisting of generators, transmission and distribution networks, and retailers, is one of Australia's largest industries, contributing 1.4 per cent to Australian industry value added in 2009–10.

Between 1999–2000 and 2009–10, Australia's electricity generation increased at an average rate of 1.4 per cent a year.

However, in 2009–10, electricity generation declined by 1.2 per cent.

Coal power plants emit high levels of CO_2 into the atmosphere during the combustion process, which affects the climate.

Coal mining also interferes significantly with the landscape, and open-cast mines must be re-cultivated. Major efforts, including the development of clean coal technologies to reduce CO_2 emissions, are being made to manage the climate impact of coal power plants.

Coal power plants provide stable and large-scale electricity generation, and the availability of coal is good.

Of the Earth's fossil fuels, coal is the most abundant and widely dispersed, meaning that supplies are readily available and not subject to disruption

Coal power has a competitive production cost.

Fuel costs are low and coal markets are well-functioning.

However, technologies to reduce coal power plant CO_2 emissions are expensive and call for substantial investments.

Australia is a net importer of crude oil and condensate.

In volume terms, Australia's crude oil and condensate production was equivalent to 62 per cent of refinery feedstock in 2010–11. Australia exports 79 per cent of its crude oil and condensate production, with the majority being sourced from the north-west coast of Australia.

Around 83 per cent of input into refineries, which are largely based on the east coast of Australia, is sourced from imports.

Domestic refineries account for around 74 per cent of Australia's refined product consumption. Australia is a net exporter of liquefied petroleum gas (LPG), with net exports equating to around 41 per cent of total production in 2010–11.

Gas (conventional and unconventional) is becoming increasingly important for Australia, both as a domestic energy source and as a source of export income. Australia is a significant exporter of liquefied natural gas (LNG), with around half of all gas production exported. I

n 2010–11, the value of Australian LNG exports was $10.4 billion. Since 1999–2000, domestic gas consumption has increased at an average annual rate of 4 per cent. Gas accounted for 23 per cent of Australian energy consumption, and 15 per cent of electricity generation in 2009–10.

Resources

Australia has around 33 per cent of the world's uranium resources, 10 per cent of world black coal resources, and almost 2 per cent of world conventional gas resources. Australia has only a small proportion of world resources of crude oil.

In addition, Australia has large, widely distributed wind, solar, geothermal, hydroelectricity, ocean energy and bioenergy resources. Except for hydroelectricity, where the available resource is largely developed, and wind energy, where the use of the resource is growing rapidly, Australia's renewable energy resources are largely undeveloped. Many renewable energy resources, particularly solar and wind, are intermittent

The power of raw sunshine at midday on a cloudless day is 1000 W per square metre. That's 1000 W per m^2 of area oriented towards the sun, not

We can turn this raw power into useful power in four ways:

1. Solar thermal: using the sunshine for direct heating of buildings or water.

2. Solar photovoltaic: generating electricity.

3. Solar biomass: using trees, bacteria, algae, corn, soy beans, or oilseed to make energy fuels, chemicals, or building materials.

4. Food: the same as solar biomass, except we shovel the plants into humans or other animals.

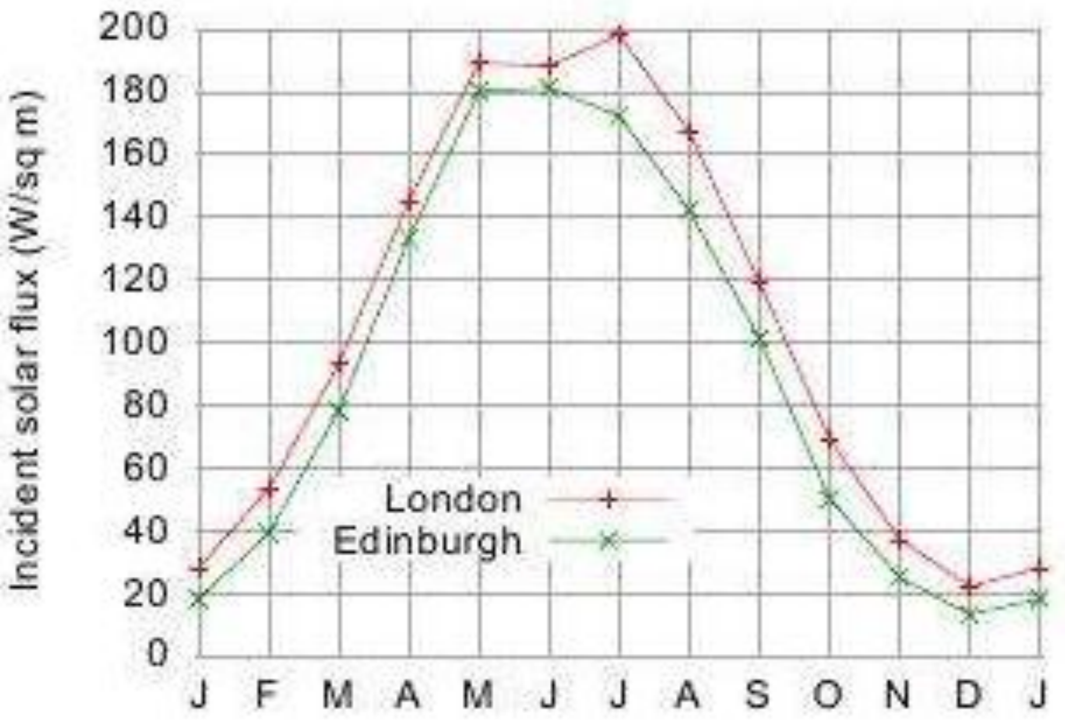


Figure 6.2. Average solar intensity in London and Edinburgh as a function of time of year. The average intensity, per unit land area, is $100\,W/m^2$.

we find solar heating could deliver

$$13\,\text{kWh per day per person.}$$

Solar photovoltaic

Photovoltaic (PV) panels convert sunlight into electricity. Typical solar panels have an efficiency of about 10%; expensive ones perform at 20%. (Fundamental physical laws limit the efficiency of photovoltaic systems to at best 60% with perfect concentrating mirrors or lenses, and 45% without concentration. A mass-produced device with efficiency greater than 30% would be quite remarkable.) The average power delivered by south-facing 20%-efficient photovoltaic panels in Britain would be

$$20\% \times 110\,\text{W/m}^2 = 22\,\text{W/m}^2.$$

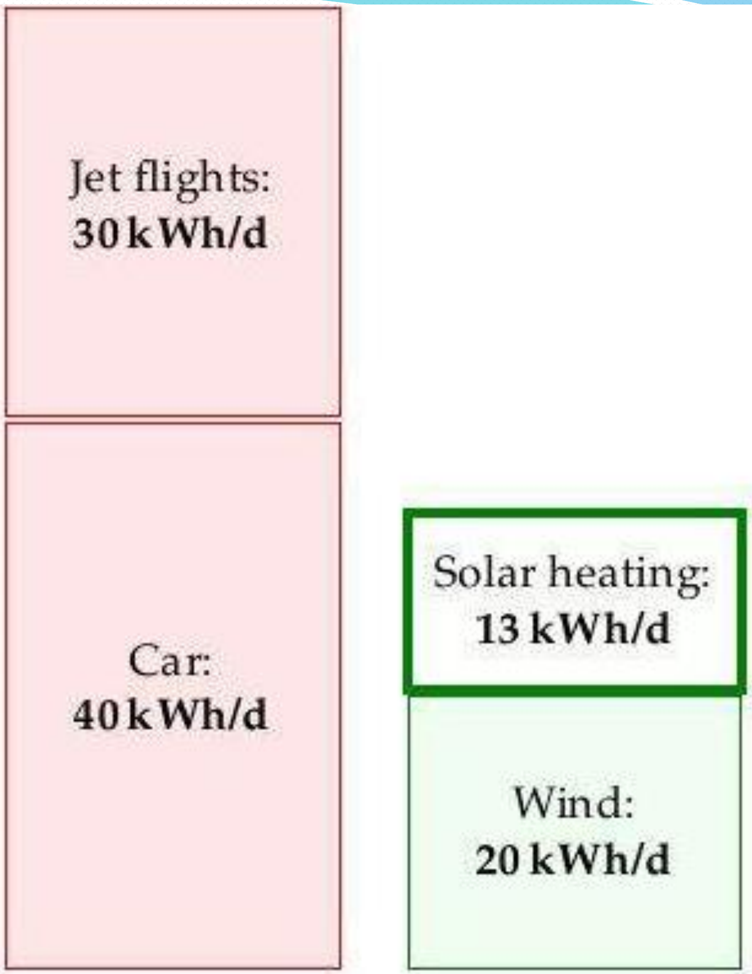


Figure 6.4. Solar thermal: a 10 m^2 array of thermal panels can deliver (on average) about 13 kWh per day of thermal energy.

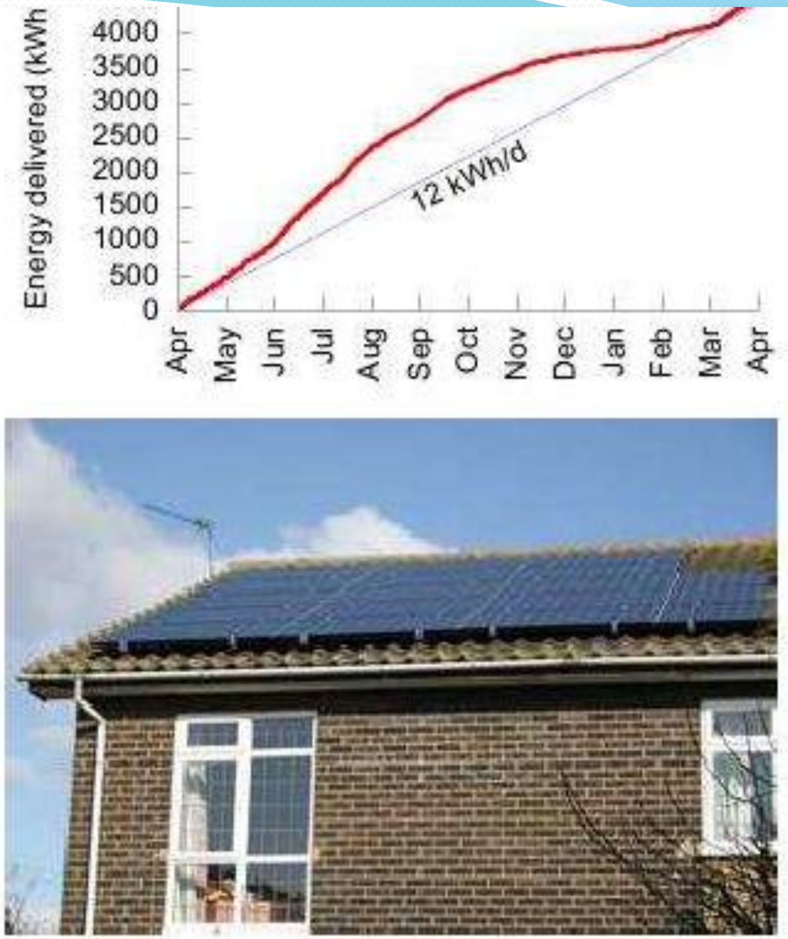


Figure 6.5. Solar photovoltaics: data from a 25-m^2 array in Cambridgeshire in 2006. The peak power delivered by this array is about 4 kW. The average, year-round, is 12 kWh per day. That's 20 W per square metre of panel.

Fantasy time: solar farming

If a breakthrough of solar technology occurs and the cost of photovoltaics came down enough that we could deploy panels all over the countryside, what is the maximum conceivable production? Well, if we covered 5% of the UK with 10%-efficient panels, we'd have

$$
\begin{aligned}
& 10\% \times 100\,\mathrm{W/m^2} \times 200\,\mathrm{m^2} \text{ per person} \\
\simeq\ & 50\,\mathrm{kWh/day/person}.
\end{aligned}
$$

I assumed only 10%-efficient panels, by the way, because I imagine that solar panels would be mass-produced on such a scale only if they were very cheap, and it's the lower-efficiency panels that will get cheap first. The power density (the power per unit area) of such a solar farm would be

$$10\% \times 100\,\mathrm{W/m^2} = 10\,\mathrm{W/m^2}.$$

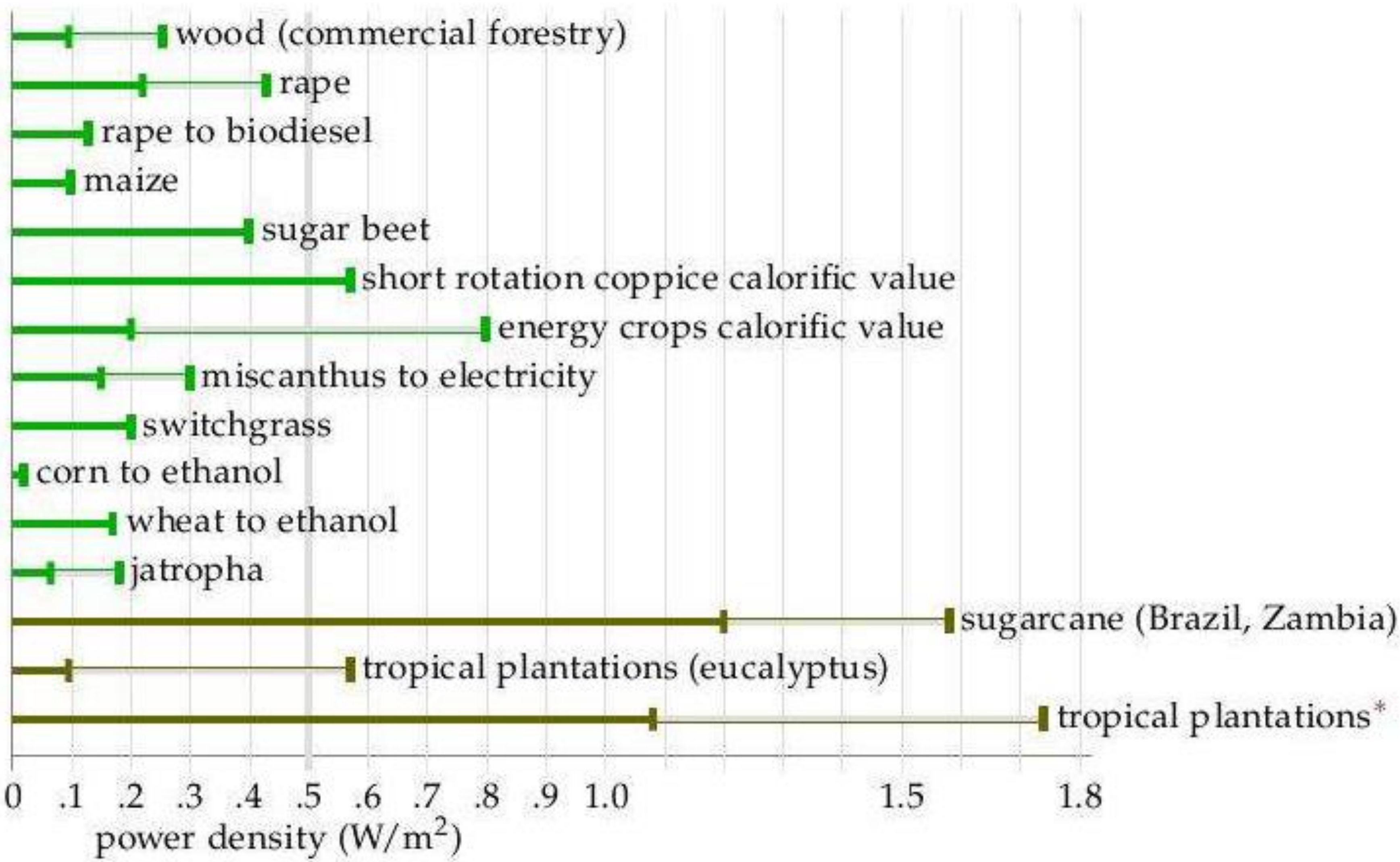
Figure 6.7. A solar photovoltaic farm: the 6.3 MW (peak) Solarpark in Mühlhausen, Bavaria. Its average power per unit land area is expected to be about $5\,\mathrm{W/m^2}$. Photo by SunPower.

All available bioenergy solutions involve first growing green stuff, and then doing something with the green stuff. How big could the energy collected by the green stuff possibly be? There are four main routes to get energy from solar-powered biological systems:

1. We can grow specially-chosen plants and burn them in a power station that produces electricity or heat or both. We'll call this "coal substitution."

2. We can grow specially-chosen plants (oil-seed rape, sugar cane, or corn, say), turn them into ethanol or biodiesel, and shove that into cars, trains, planes or other places where such chemicals are useful. Or we might cultivate genetically-engineered bacteria, cyanobacteria, or algae that directly produce hydrogen, ethanol, or butanol, or even electricity. We'll call all such approaches "petroleum substitution."

3. We can take by-products from other agricultural activities and burn them in a power station. The by-products might range from straw (a by-product of Weetabix) to chicken poo (a by-product of McNuggets). Burning by-products is coal substitution again, but using ordinary plants, not the best high-energy plants. A power station that burns agricultural by-products won't deliver as much power per unit area of farmland as an optimized biomass-growing facility, but it has the



wood (commercial forestry)
rape
rape to biodiesel
maize
sugar beet
short rotation coppice calorific value
energy crops calorific value
miscanthus to electricity
switchgrass
corn to ethanol
wheat to ethanol
jatropha
sugarcane (Brazil, Zambia)
tropical plantations (eucalyptus)
tropical plantations*
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.5 1.8
power density (W/m2)

currently devoted to agriculture. So the maximum power available, ignoring all the additional costs of growing, harvesting, and processing the greenery, is

$$0.5\,\text{W/m}^2 \times 3000\,\text{m}^2 \text{ per person} \quad = \quad 36\,\text{kWh/d per person.}$$

Wow. That's not very much, considering the outrageously generous assumptions we just made, to try to get a big number. If you wanted to get biofuels for cars or planes from the greenery, all the other steps in the chain from farm to spark plug would inevitably be inefficient. I think it'd be optimistic to hope that the overall losses along the processing chain would be as small as 33%. Even burning dried wood in a good wood boiler loses 20% of the heat up the chimney. So surely the true potential power from biomass and biofuels cannot be any bigger than 24 kWh/d per person. And don't forget, we want to use some of the greenery to make food for us and for our animal companions.

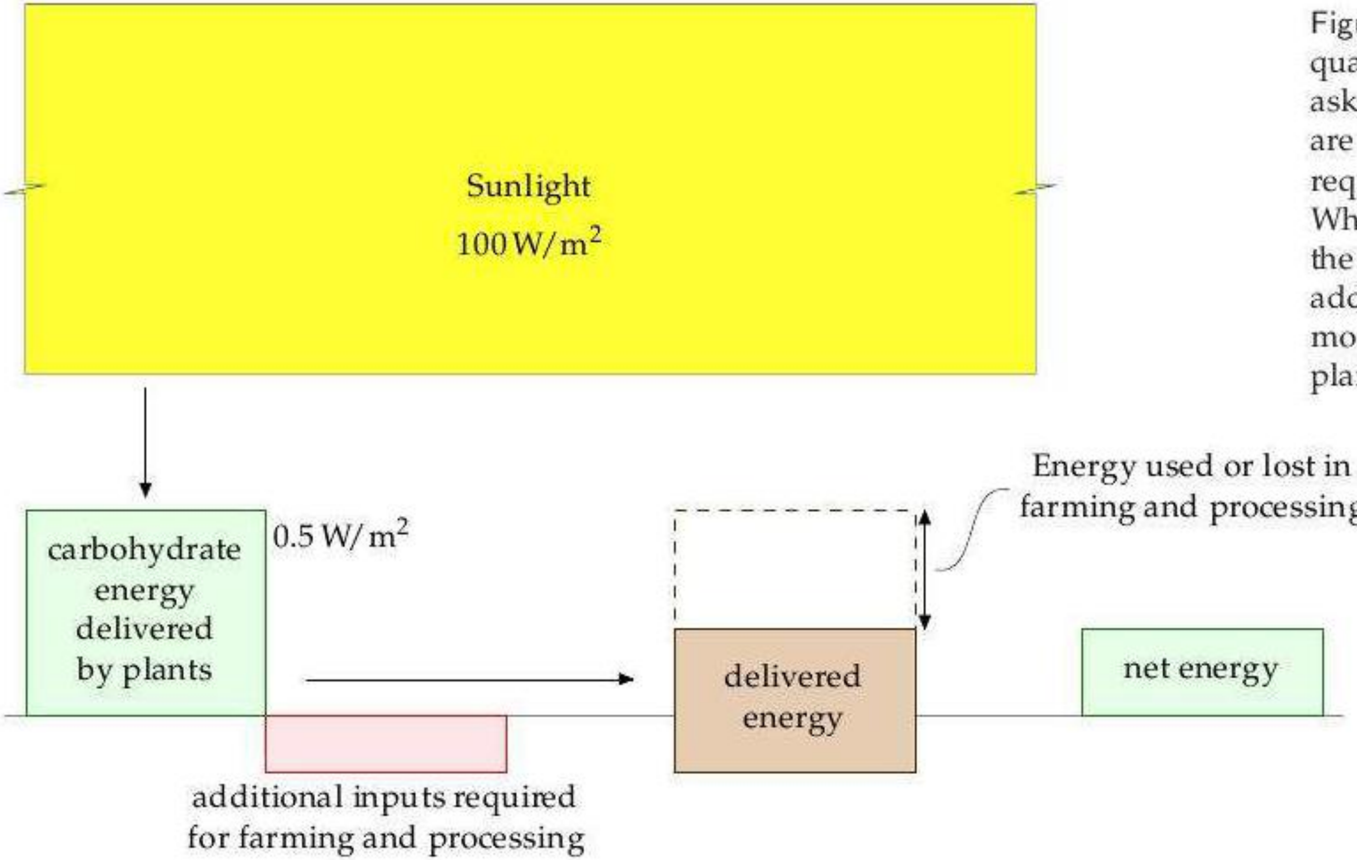


Figure 6.14. This figure illustrates the quantitative questions that must be asked of any proposed biofuel. What are the additional energy inputs required for farming and processing? What is the delivered energy? What is the *net* energy output? Often the additional inputs and losses wipe out most of the energy delivered by the plants.

In this example scenario, the ZCA2020 Plan system design would be adjusted by:

• using smart grid technology to schedule more nonessential demands during the day;

• reducing the number of wind turbines and/or solar thermal storage plants required;

• altering the design of planned solar thermal plants (with storage) by changing the ratio of mirror field to storage and turbine size appropriately; and

• adding more heat storage to existing solar thermal plants.

Smaller scale solar technologies, i.e. solar panels on roofs, play a valuable role in reducing grid electricity demand, and are well-suited to applications such as negating air conditioner demand during hot weather. Electricity demand spikes during hot weather are a major source of high price events and brown/blackouts on Australian electricity grids.

Solar hot water systems are well-suited to being combined with heat pump boosting systems. Solar hot water is able to be stored for later use, meaning that daily variations in radiation are not as much of an issue as for solar photovoltaics.

The Plan recommends the use of small-scale solar for point-of-demand use to displace grid electricity requirements. The full costings of these will be included in the Buildings sector report.

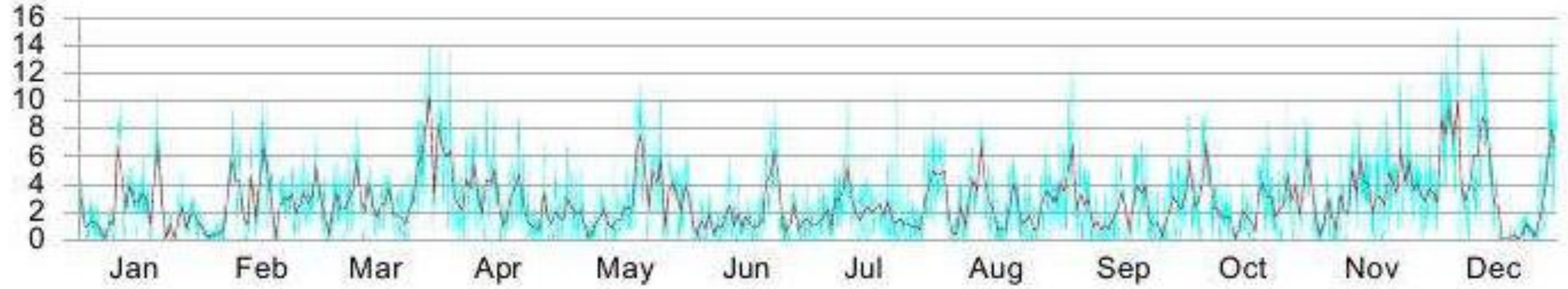
Although solar PV currently only provides a small amount of the world's energy, it is the world's fastest growing energy source, increasing at around 48% pa since 2002, to a cumulative total of 15,200 MW in 200870

How much wind power could we plausibly generate?

We can make an estimate of the potential of *on-shore* (land-based) wind in the United Kingdom by multiplying the average power per unit land-area of a wind farm by the area per person in the UK:

$$\text{power per person} = \text{wind power per unit area} \times \text{area per person.}$$

Chapter B (p263) explains how to estimate the power per unit area of a wind farm in the UK. If the typical windspeed is 6 m/s (13 miles per hour, or 22 km/h), the power per unit area of wind farm is about 2 W/m^2.



generate

$$2\,\mathrm{W/m^2} \times 4000\,\mathrm{m^2/person} = 8000\,\mathrm{W\ per\ person},$$

if wind turbines were packed across the *whole* country, and assuming $2\,\mathrm{W/m^2}$ is the correct power per unit area. Converting to our favourite power units, that's 200 kWh/d per person.

Let's be realistic. What fraction of the country can we really imagine covering with windmills? Maybe 10%? Then we conclude: if we covered the windiest 10% of the country with windmills (delivering $2\,\mathrm{W/m^2}$), we would be able to generate 20 kWh/d per person, which is ***half*** of the power used by driving an average fossil-fuel car 50 km per day.

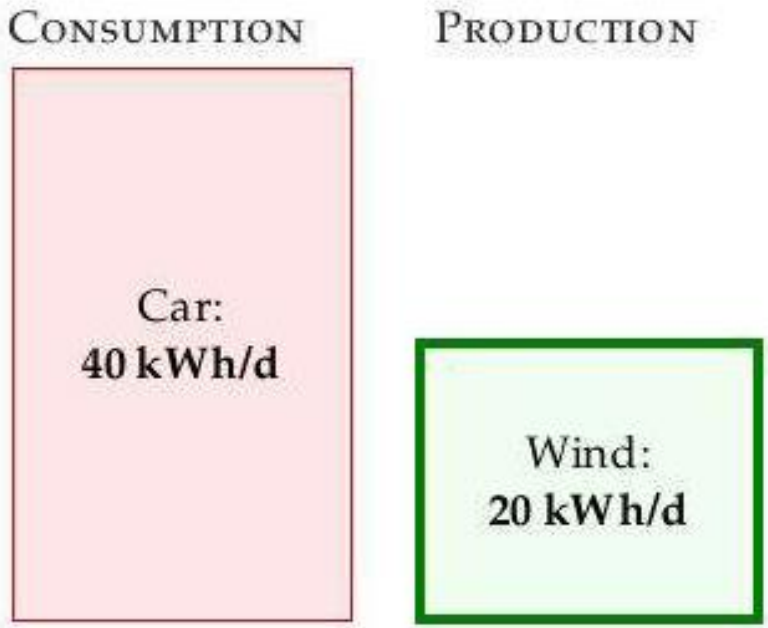


Figure 4.3. Chapter 4's conclusion: the maximum plausible production from on-shore windmills in the United Kingdom is 20 kWh per day per person.

POWER PER UNIT AREA	
wind farm (speed 6 m/s)	2 W/m^2

Table 4.4. Facts worth remembering: wind farms.

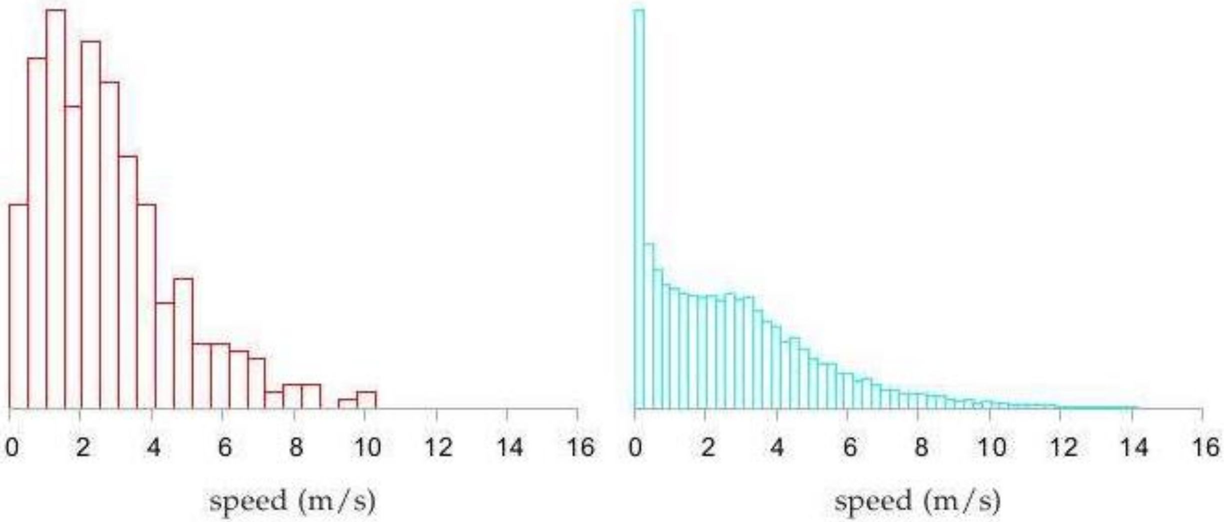
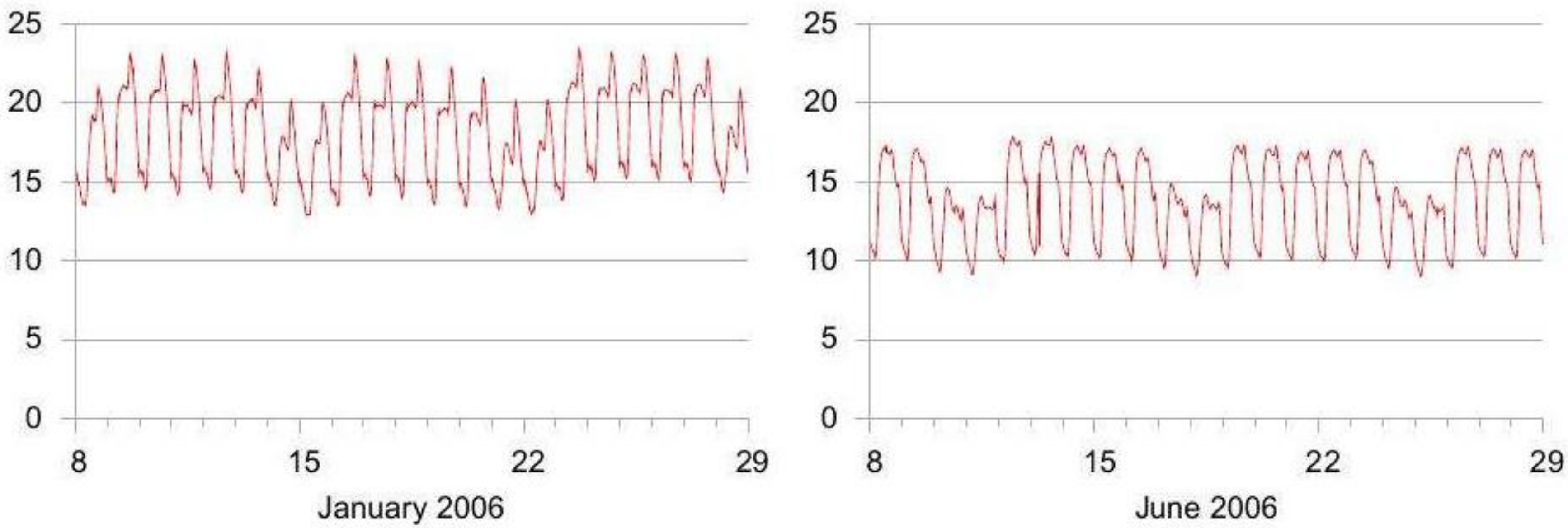


Figure 4.6. Histogram of Cambridge average wind speed in metres per second: daily averages (left), and half-hourly averages (right).

26 *Fluctuations and storage*

The wind, as a direct motive power, is wholly inapplicable to a system of machine labour, for during a calm season the whole business of the country would be thrown out of gear. Before the era of steam-engines, windmills were tried for draining mines; but though they were powerful machines, they were very irregular, so that in a long tract of calm weather the mines were drowned, and all the workmen thrown idle.

William Stanley Jevons, 1865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and-onable either. They are usually on all the time, and their delivered power can be turned down and up only on a timescale of hours. This is a problem because, on an electricity network, consumption and production must be exactly equal all the time. The electricity grid can't *store* energy. To have an energy plan that adds up every minute of every day, we therefore need *something easily turn-off-and-onable*. It's commonly assumed that the easily turn-off-and-onable something should be a *source* of power that gets turned off and on to compensate for the fluctuations of supply relative to demand (for example, a fossil fuel power station!). But another equally effective way to match supply and demand would be to have an easily turn-off-and-onable *demand* for power – a sink of power that can be turned off and on at the drop of a hat.

Critics of wind power say: "Wind power is intermittent and unpredictable, so it can make no contribution to security of supply; if we create lots of wind power, we'll have to maintain lots of fossil-fuel power plant to replace the wind when it drops." Headlines such as "Loss of wind causes Texas power grid emergency" reinforce this view. Supporters of wind energy play down this problem: "Don't worry – *individual* wind farms may be intermittent, but taken together, the *sum* of all wind farms in different locations is much less intermittent."

Let's quantify the fluctuations in country-wide wind power. The two issues are short-term changes, and long-term lulls. Let's find the fastest short-term change in a month of Irish wind data. On 11th February 2007, the Irish wind power fell steadily from 415 MW at midnight to 79 MW at 4am. That's a slew rate of 84 MW per hour for a country-wide fleet of capacity 745 MW. (By slew rate I mean the rate at which the delivered power fell or rose – the slope of the graph on 11th February.) OK: if we scale British wind power up to a capacity of 33 GW (so that it delivers 10 GW on average), we can expect to have occasional slew rates of

$$84\,\mathrm{MW/h} \times \frac{33\,000\,\mathrm{MW}}{745\,\mathrm{MW}} = 3700\,\mathrm{MW/h},$$

assuming Britain is like Ireland. So we need to be able to either power *up* replacements for wind at a rate of 3.7 GW per hour – that's 4 nuclear power stations going from no power to full power every hour, say – *or* we need to be able to suddenly turn *down* our *demand* at a rate of 3.7 GW per hour.

OK, before we start looking for solutions, we need to quantify wind's other problem: long-term lulls. At the start of February 2007, Ireland had a country-wide lull that lasted five days. This was not an unusual event, as you can see in figure 26.2. Lulls lasting two or three days happen several times a year.

There are two ways to get through lulls. Either we can store up energy somewhere before the lull, or we need to have a way of reducing demand during the entire lull. (Or a mix of the two.) If we have 33 GW of wind turbines delivering an average power of 10 GW then the amount of energy we must either store up in advance or do without during a five-day lull is

$$10\,\text{GW} \times (5 \times 24\,\text{h}) = 1200\,\text{GWh}.$$

(The gigawatt-hour (GWh) is the cuddly energy unit for nations. Britain's electricity consumption is roughly 1000 GWh per day.)

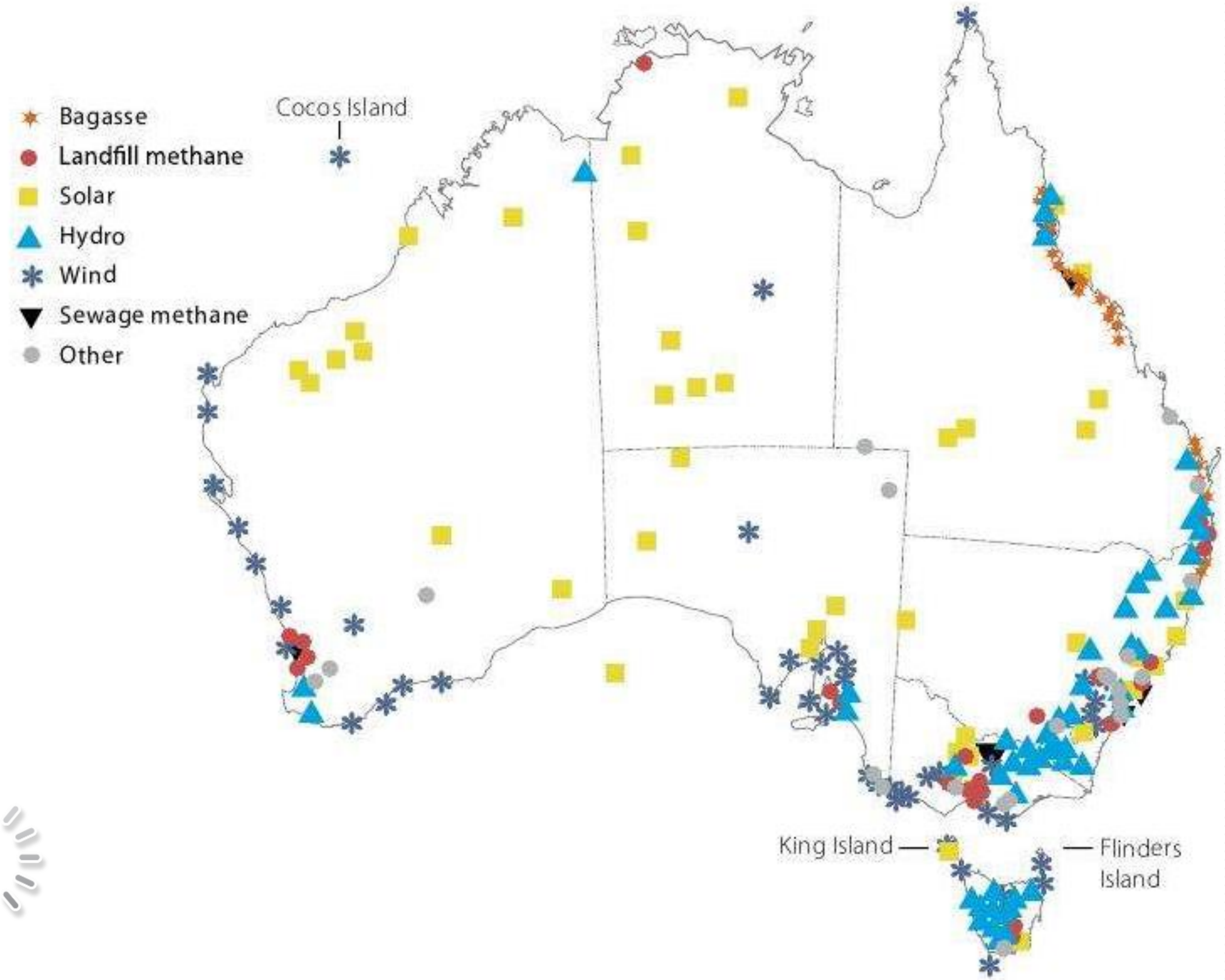
To personalize this quantity, an energy store of 1200 GWh for the nation is equivalent to an energy store of 20 kWh per person. Such an energy store would allow the nation to go without 10 GW of electricity for 5 days; or equivalently, every individual to go without 4 kWh per day of electricity for 5 days.

Table 14: Australia's energy production, by renewable energy source[a]

	2005-06	2006-07	2007-08	2008-09	2009-10
	PJ	PJ	PJ	PJ	PJ
Bagasse	109.1	110.8	111.9	103.4	88.2
Biogas and biofuels	9.4	10.2	20.5	18.6	21.2
Hydroelectricity	57.7	52.3	43.4	39.8	45.1
Solar hot water	2.4	6.0	6.5	8.2	10.1
Solar electricity	0.4	0.4	0.4	0.6	1.0
Wind	6.2	9.4	11.1	13.7	17.3
Wood and woodwaste	90.3	92.8	96.0	102.9	103.4
Total	**275.5**	**281.9**	**289.8**	**287.2**	**286.3**

a Includes both electricity and heat.

Source: ABARES 2011, Australian Energy Statistics.

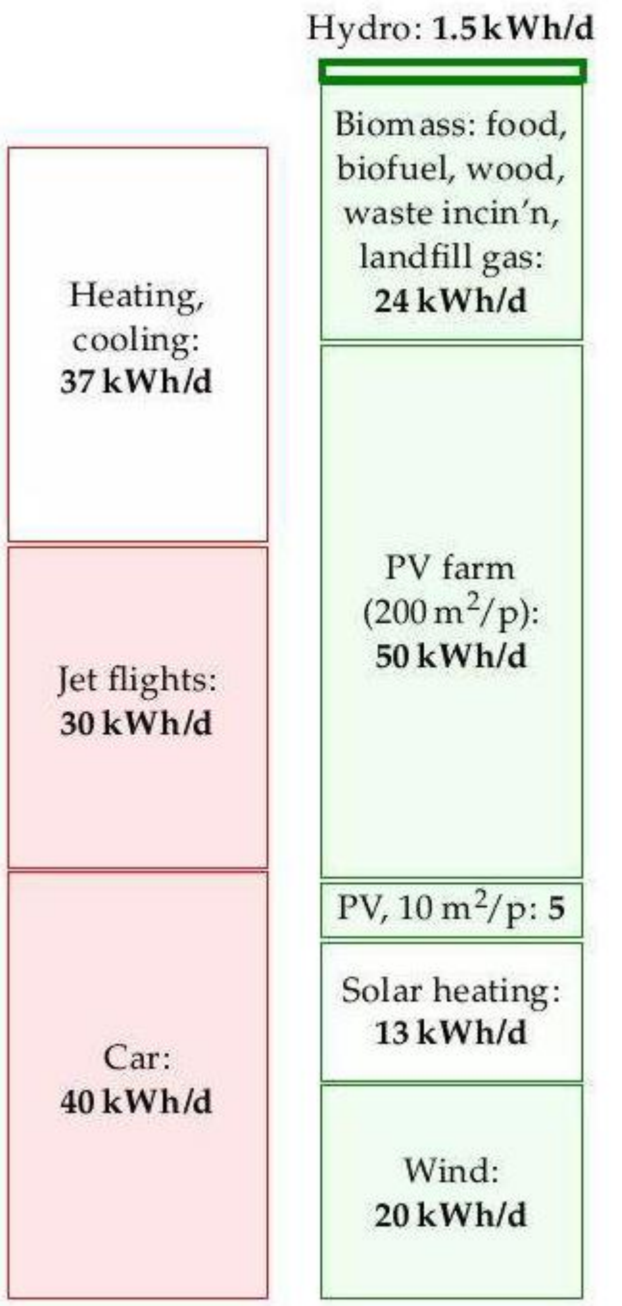


Source: Geoscience Australia.

To make hydroelectric power, you need altitude, and you need rainfall. Let's estimate the total energy of all the rain as it runs down to sea-level.

Let's do the lowlands first. To estimate the gravitational power of lowland rain, we multiply the rainfall in Bedford (584 mm per year) by the density of water (1000 kg/m^3), the strength of gravity (10 m/s^2) and the typical lowland altitude above the sea (say 100 m). The power per unit area works out to 0.02 W/m^2. That's the power per unit area of land on which rain falls.

When we multiply this by the area per person (2700 m^2, if the lowlands are equally shared between all 60 million Brits), we find an average raw power of about 1 kWh per day per person. This is the absolute upper limit for lowland hydroelectric power, if every river were dammed and every drop perfectly exploited. Realistically, we will only ever dam rivers with substantial height drops, with catchment areas much smaller than the whole country. Much of the water evaporates before it gets anywhere near a turbine, and no hydroelectric system exploits the full potential energy of the water. We thus arrive at a firm conclusion about lowland water power. People may enjoy making "run-of-the-river" hydro and other small-scale hydroelectric schemes, but such lowland facilities can never deliver more than 1 kWh per day per person.


Hydro: 1.5 kWh/d
Biomass: food, biofuel, wood, waste incin'n, landfill gas: 24 kWh/d
Heating, cooling: 37 kWh/d
PV farm (200 m²/p): 50 kWh/d
Jet flights: 30 kWh/d
PV, 10 m²/p: 5
Solar heating: 13 kWh/d
Car: 40 kWh/d
Wind: 20 kWh/d

running them at a steady speed. OK, leaving cost to one side, the crucial question is how big a turn-off-and-onable resource we might have. If all municipal waste were incinerated, and an equal amount of agricultural waste were incinerated, then the average power from these sources would be about 3 GW. If we built capacity equal to *twice* this power, making incinerators capable of delivering 6 GW, and thus planning to have them operate only half the time, these would be able to deliver 6 GW throughout periods of high demand, then zero in the wee hours. These power stations could be designed to switch on or off within an hour, thus coping with slew rates of 6 GW per hour – but only for a maximum slew range of 6 GW! That's a helpful contribution, but not enough slew range in itself, if we are to cope with the fluctuations of 33 GW of wind.

What about hydroelectricity? Britain's hydroelectric stations have an average load factor of 20% so they certainly have the potential to be turned on and off. Furthermore, hydro has the wonderful feature that it can be turned on and off very quickly. Glendoe, a new hydro station with a capacity of 100 MW, will be able to switch from off to on in 30 seconds, for example. That's a slew rate of 12 GW per hour in just one power station! So a sufficiently large fleet of hydro power stations should be able to cope with the slew introduced by enormous wind farms. However, the capacity of the British hydro fleet is *not* currently big enough to make much contribution to our slew problem (assuming we want to cope with the rapid loss of say 10 or 33 GW of wind power). The total capacity of traditional hydroelectric stations in Britain is only about 1.5 GW.

Pumped storage

Pumped storage systems use cheap electricity to shove water from a downhill lake to an uphill lake; then regenerate electricity when it's valuable, using turbines just like the ones in hydroelectric power stations.

station	power (GW)	head (m)	volume (million m^3)	energy stored (GWh)
Ffestiniog	0.36	320–295	1.7	1.3
Cruachan	0.40	365–334	11.3	10
Foyers	0.30	178–172	13.6	6.3
Dinorwig	1.80	542–494	6.7	9.1

Table 26.4. Pumped storage facilities in Britain. The maximum energy storable in today's pumped storage systems is about 30 GWh.

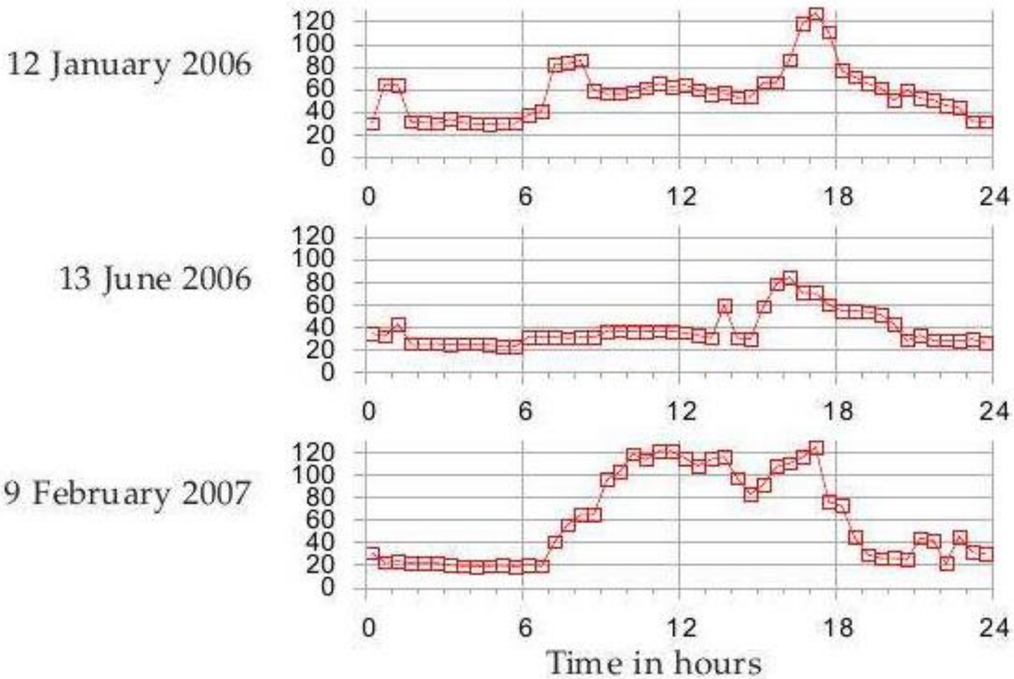


Figure 26.5. How pumped storage pays for itself. Electricity prices, in £ per MWh, on three days in 2006 and 2007.

Figure 26.6. Llyn Stwlan, the upper reservoir of the Ffestiniog pumped storage scheme in north Wales. Energy stored: 1.3 GWh. Photo by Adrian Pingstone.

Britain has four pumped storage facilities, which can store 30 GWh between them (table 26.4, figure 26.6). They are typically used to store excess electricity at night, then return it during the day, especially at moments of peak demand – a profitable business, as figure 26.5 shows. The Dinorwig power station – an astonishing cathedral inside a mountain in Snowdonia – also plays an insurance role: it has enough oomph to restart the national grid in the event of a major failure. Dinorwig can switch on, from 0 to 1.3 GW power, in 12 seconds.

Dinorwig is the Queen of the four facilities. Let's review her vital statistics. The total energy that can be stored in Dinorwig is about 9 GWh. Its upper lake is about 500 m above the lower, and the working volume of 7 million m^3 flows at a maximum rate of 390 m^3/s, allowing power delivery at 1.7 GW for 5 hours. The efficiency of this storage system is 75%.

If all four pumped storage stations are switched on simultaneously, they can produce a power of 2.8 GW. They can switch on extremely fast, coping with any slew rate that demand-fluctuations or wind-fluctuations could come up with. However the capacity of 2.8 GW is not enough to replace 10 GW or 33 GW of wind power if it suddenly went missing. Nor is the total energy stored (30 GWh) anywhere near the 1200 GWh we are interested in storing in order to make it through a big lull. Could pumped

Can we store 1200 GWh?

We are interested in making much bigger storage systems, storing a total of 1200 GWh (about 130 times what Dinorwig stores). And we'd like the capacity to be about 20 GW – about ten times bigger than Dinorwig's. So here is the pumped storage solution: we have to imagine creating roughly 12 new sites, each storing 100 GWh – roughly ten times the energy stored in Dinorwig. The pumping and generating hardware at each site would be the same as Dinorwig's.

Assuming the generators have an efficiency of 90%, table 26.7 shows a few ways of storing 100 GWh, for a range of height drops. (For the physics behind this table, see this chapter's endnotes.)

Ways to store 100 GWh		
drop from upper lake	working volume required (million m^3)	example size of lake area depth
500 m	40	$2\,km^2 \times 20\,m$
500 m	40	$4\,km^2 \times 10\,m$
200 m	100	$5\,km^2 \times 20\,m$
200 m	100	$10\,km^2 \times 10\,m$
100 m	200	$10\,km^2 \times 20\,m$
100 m	200	$20\,km^2 \times 10\,m$

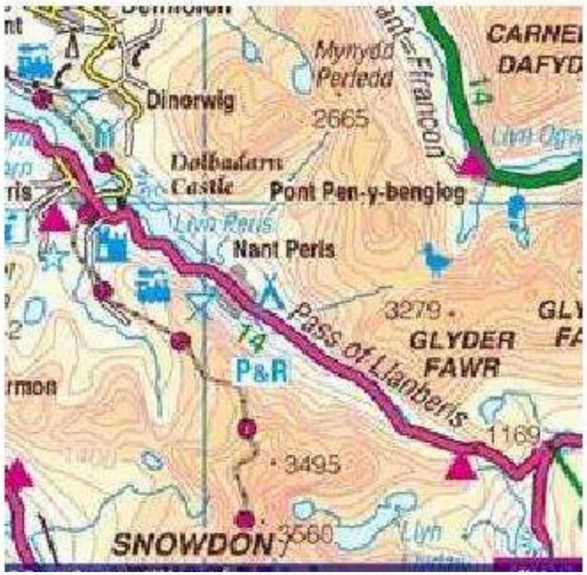


Figure 26.9. Dinorwig, in the Snowdonia National Park, compared with Loch Sloy and Loch Lomond. The upper maps show 10 km by 10 km areas. In the lower maps the blue grid is made of 1 km squares. Images produced from Ordnance Survey's Get-a-map service www.ordnancesurvey.co.uk/getamap. Images reproduced with permission of Ordnance Survey. © Crown Copyright 2006.

Dinorwig is the home of a 9 GWh storage system, using Marchlyn Mawr (615E, 620N) and Llyn Peris (590E, 598N) as its upper and lower reservoirs.

Loch Sloy illustrates the sort of location where a 40 GWh storage system could be created.

Figure 26.11. Okinawa pumped-storage power plant, whose lower reservoir is the ocean. Energy stored: 0.2 GWh. Photo by courtesy of J-Power. www.ieahydro.org.

Let's recap our options. We can balance fluctuating demand and fluctuating supply by switching on and off power *generators* (waste incinerators and hydroelectric stations, for example); by *storing* energy somewhere and regenerating it when it's needed; or by switching *demand* off and on.

The most promising of these options, in terms of scale, is switching on and off the power demand of electric-vehicle charging. 30 million cars, with 40 kWh of associated batteries each (some of which might be exchangeable batteries sitting in filling stations) adds up to 1200 GWh. If freight delivery were electrified too then the total storage capacity would be bigger still.

The idea of modifying the rate of production of stuff to match the power of a renewable source is not new. Many aluminium production plants are located close to hydroelectric power stations; the more it rains, the more aluminium is produced. Wherever power is used to create stuff that is storable, there's potential for switching that power-demand on and off in a smart way. For example, reverse-osmosis systems (which make

countries (though not Britain). Another storable product is heat. If, as suggested in Chapter 21, we electrify buildings' heating and cooling systems, especially water-heating and air-heating, then there's potential for lots of easily-turn-off-and-onable power demand to be attached to the grid. Well-insulated buildings hold their heat for many hours, so there's flexibility in the timing of their heating. Moreover, we could include large thermal reservoirs in buildings, and use heat-pumps to pump heat into or out of those reservoirs at times of electricity abundance; then use a second set of heat pumps to deliver heat or cold from the reservoirs to the places where heating or cooling are wanted.

Controlling electricity demand automatically would be easy. The simplest way to do this is to have devices such as fridges and freezers listen to the frequency of the mains. When there is a shortage of power on the grid, the frequency drops below its standard value of 50 Hz; when there is a power excess, the frequency rises above 50 Hz. (It's just like a dynamo on a bicycle: when you switch the lights on, you have to pedal harder to supply the extra power; if you don't then the bike goes a bit slower.) Fridges can be modified to nudge their internal thermostats up and down just a little in response to the mains frequency, in such a way that, without ever jeopardizing the temperature of your butter, they tend to take power at times that help the grid.

To provide flexibility to the electricity-grid's managers, who perpetually turn power stations up and down to match supply to demand, many industrial users of electricity are on special contracts that allow the managers to switch off those users' demand at very short notice. In South Africa (where there are frequent electricity shortages), radio-controlled demand-management systems are being installed in hundreds of thousands of homes, to control air-conditioning systems and electric water heaters.

16 Geothermal

Geothermal energy comes from two sources: from radioactive decay in the crust of the earth, and from heat trickling through the mantle from the earth's core. The heat in the core is there because the earth used to be red-hot, and it's still cooling down and solidifying; the heat in the core is also being topped up by tidal friction: the earth flexes in response to the gravitational fields of the moon and sun, in the same way that an orange changes shape if you squeeze it and roll it between your hands.

Geothermal is an attractive renewable because it is "always on," independent of the weather; if we make geothermal power stations, we can switch them on and off so as to follow demand.

Figure 16.2. Some granite.

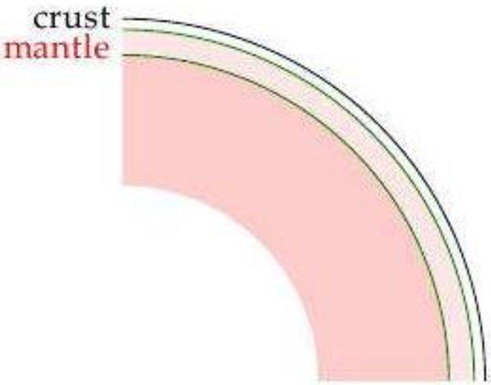


Figure 16.1. An earth in section.

The difficulty with making *sustainable* geothermal power is that the speed at which heat travels through solid rock limits the rate at which heat can be sustainably sucked out of the red-hot interior of the earth. It's like trying to drink a crushed-ice drink through a straw. You stick in the straw, and suck, and you get a nice mouthful of cold liquid. But after a little more sucking, you find you're sucking air. You've extracted all the liquid from the ice around the tip of the straw. Your initial rate of sucking wasn't sustainable.

If you stick a straw down a 15-km hole in the earth, you'll find it's nice and hot there, easily hot enough to boil water. So, you could stick two straws down, and pump cold water down one straw and suck from the other. You'll be sucking up steam, and you can run a power station. Limitless power? No. After a while, your sucking of heat out of the rock will have reduced the temperature of the rock. You weren't sucking sustainably. You now have a long wait before the rock at the tip of your straws warms up again. A possible attitude to this problem is to treat geothermal heat the same way we currently treat fossil fuels: as a resource to be mined rather than collected sustainably. Living off geothermal heat in this way

Figure 16.3. Geothermal power in Iceland. Average geothermal electricity generation in Iceland (population, 300 000) in 2006 was 300 MW (24 kWh/d per person). More than half of Iceland's electricity is used for aluminium production. Photo by Gretar Ívarsson.

As I said before, geothermal energy comes from two sources: from radioactive decay in the crust of the earth, and from heat trickling through the mantle from the earth's core. In a typical continent, the heat flow from the centre coming through the mantle is about $10\,\mathrm{mW/m^2}$. The heat flow at the surface is $50\,\mathrm{mW/m^2}$. So the radioactive decay has added an extra $40\,\mathrm{mW/m^2}$ to the heat flow from the centre.

So at a typical location, the maximum power we can get per unit area is $50\,\mathrm{mW/m^2}$. But that power is not high-grade power, it's low-grade heat that's trickling through at the ambient temperature up here. We presumably want to make electricity, and that's why we must drill down. Heat is useful only if it comes from a source at a higher temperature than the ambient temperature. The temperature increases with depth as shown in figure 16.4, reaching a temperature of about 500 °C at a depth of 40 km. Between depths of 0 km where the heat flow is biggest but the rock temperature is too low, and 40 km, where the rocks are hottest but the heat flow is 5 times smaller (because we're missing out on all the heat generated from radioactive decay) there is an optimal depth at which we should suck. The exact optimal depth depends on what sort of sucking and power-station machinery we use. We can bound the maximum sustainable power one milliwatt (1 mW) is 0.001 W.

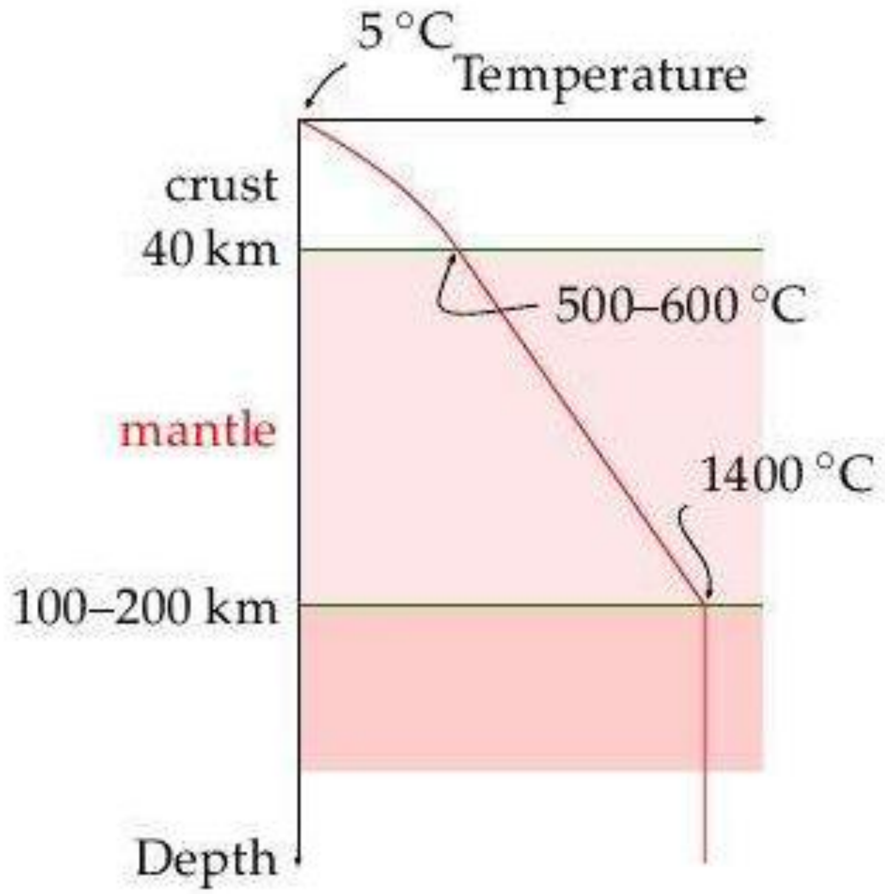


Figure 16.4. Temperature profile in a typical continent.

For the temperature profile shown in figure 16.4, I calculated that the optimal depth is about 15 km. Under these conditions, an ideal heat engine would deliver 17 mW/m^2. At the world population density of 43 people per square km, that's 10 kWh per person per day, if *all* land area were used. In the UK, the population density is 5 times greater, so wide-scale geothermal power of this sustainable-forever variety could offer at most 2 kWh per person per day.

This is the sustainable-forever figure, ignoring hot spots, assuming perfect power stations, assuming every square metre of continent is exploited, and assuming that drilling is free. And that it is possible to drill 15-km-deep holes.

Geothermal power as mining

The other geothermal strategy is to treat the heat as a resource to be mined. In "enhanced geothermal extraction" from hot dry rocks (figure 16.5), we first drill down to a depth of 5 or 10 km, and fracture the rocks by pumping in water. (This step may create earthquakes, which don't go down well with the locals.) Then we drill a second well into the fracture zone. Then we pump water down one well and extract superheated water or steam from the other. This steam can be used to make electricity or to deliver heat. What's the hot dry rock resource of the UK? Sadly, Britain is not well

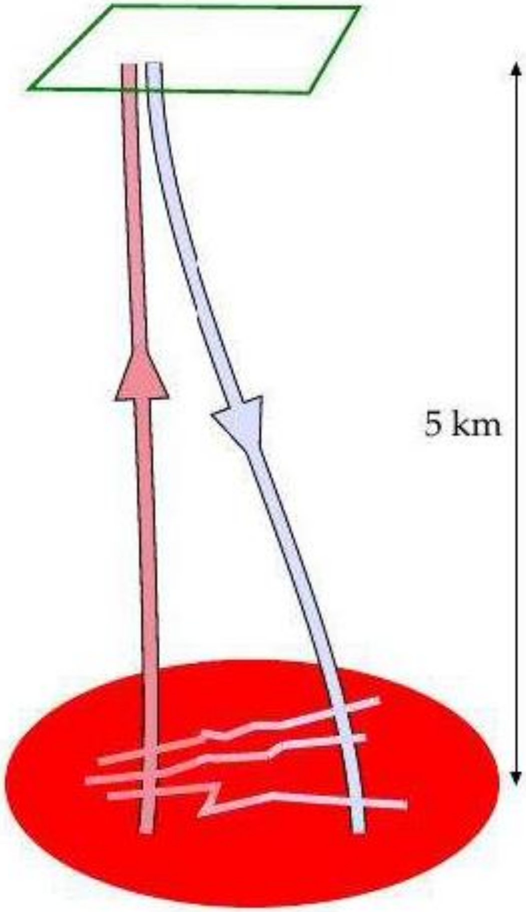


Figure 16.5. Enhanced geothermal extraction from hot dry rock. One well is drilled and pressurized to create fractures. A second well is drilled into the far side of the fracture zone. Then cold water is pumped down one well and heated water (indeed, steam) is sucked up the other.

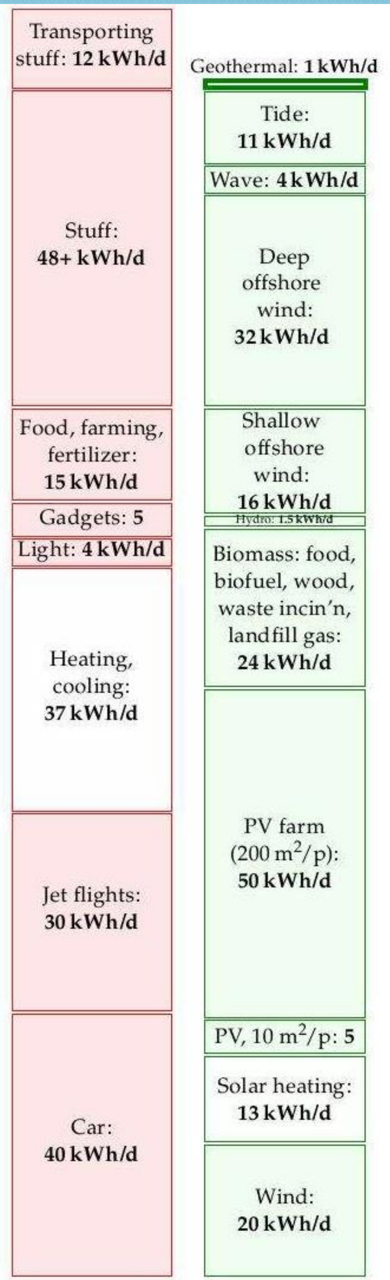


Figure 16.6. Geothermal.

What is geothermal energy?

Energy is classified as renewable and non-renewable. Renewable means it can be replenished quickly or can be supplied almost continuously like energy from the sun, wind, water waves, biomass and hot rocks. Non-renewable resources are those that are used faster before they can be replenished such as the fossil fuels coal, oil and natural gas.

Geothermal is considered a form of renewable energy as heat is continuously produced from deep in the earth.

What are the major types of geothermal energy resources?

There are four main types of geothermal energy resources:

Hydrothermal Resources are located at depths between 100 metres to 4.5 kilometres below the earth's surface. They are created when hot water or steam is formed in fractured or porous rock. The geothermal energy from this can be captured by drilling into the acquifer and extracting the hot water or steam which can then be used for electricity generation or direct heating.

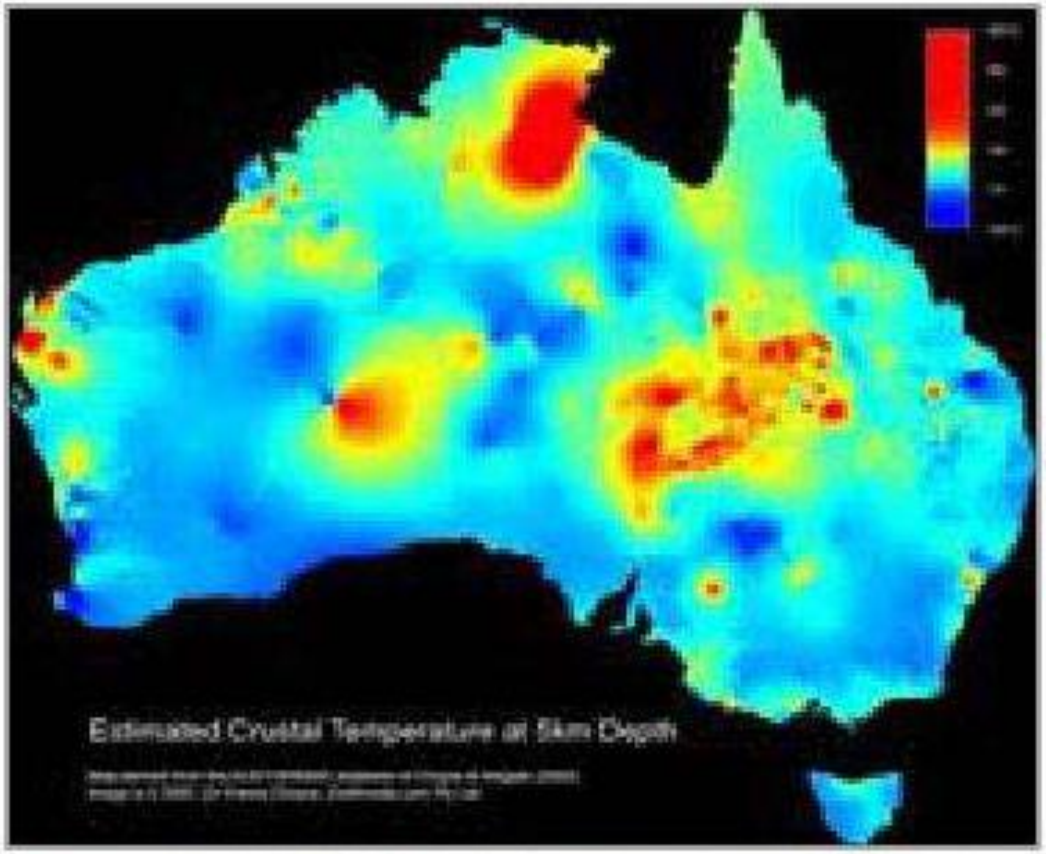
Geopressured resources are deep reservoirs found at 3 to 6 kilometres under the surface. They consist of high-pressured hot water that contains dissolved methane.

Hot Dry Rocks refers to an area of hot rocks that contain little or no water. This resource is more accessible than other geothermal resources

Magma although the largest geothermal resource is the least accessible and is found at depths 3km-10 km under the earth's surface.

How is geothermal energy created from hot dry rocks?

Injection wells are drilled down into the hot rocks, surrounding rocks are fractured and an artificial reservoir is created. Cold water is pumped into the reservoir which becomes super heated by the hot rocks.



Estimated crustal temperature at 5k depth
Source: Geoscience Australia

What are the advantages and disadvantages of geothermal energy?

Advantages	Disadvantages
Geothermal power stations have a very low land area requirement	Geothermal energy produces some pollutants, mainly carbon dioxide, hydrogen sulphide, sulphur dioxide and methane.
A geothermal power plant emits low levels of sulphur dioxides and between 1,000 and 2,000 times less carbon dioxide than a fossil fuel plant.	There is the potential for geothermal production to cause ground subsidence.
Geothermal resources can be sourced locally if the geology is suitable.	Sources of geothermal energy are often located in remote areas away from the electricity grid
Geothermal power stations are designed to operate 24 hours a day.	Local depletion of heat energy can occur at some sites

Where is geothermal energy used in Australia?

The Birdsville Geothermal power station

Currently Australia's only geothermal power station is located in Birdsville western Queensland[1]. The power station allows geothermal power to meet the town's electricity demand at night and during winter. The Queensland government is investing in research to investigate the amount of energy that could be obtained from these 'hot rocks'.

What are energy crops?

Energy crops are an important type of bioenergy. This refers to crops grown specifically for energy production. This can include both annual and perennial crops; and both agricultural and non-agricultural crops.

In Australia, non-agricultural energy crops include:

- oil mallee eucalyptus
- native grasses

What makes energy crops for bioenergy so unique from other renewable energy sources?

Energy crops are unique because they don't just produce renewable energy – they also provide other environmental and economic benefits. In excess of creating renewable energy, energy crops also provide:

- Rural & regional benefits
- Distributed baseload power
- Competitive cost proven renewable energy generation

First, let's clarify where waves come from: *sun makes wind and wind makes waves.*

Most of the sunlight that hits our planet warms the oceans. The warmed water warms the air above it, and produces water vapour. The warmed air rises; as it rises it cools, and the water eventually re-condenses, forming clouds and rain. At its highest point, the air is cooled down further by the freezing blackness of space. The cold air sinks again. This great solar-powered pump drives air round and round in great convection rolls. From our point of view on the surface, these convection rolls produce the winds. Wind is second-hand solar energy. As wind rushes across open water, it generates waves. Waves are thus third-hand solar energy. (The waves that crash on a beach are nothing to do with the tides.)

In open water, waves are generated whenever the wind speed is greater than about 0.5 m/s. The wave crests move at about the speed of the wind that creates them, and in the same direction. The *wavelength* of the waves (the distance between crests) and the *period* (the time between crests) depend on the speed of the wind. The longer the wind blows for, and the greater the expanse of water over which the wind blows, the greater the *height* of the waves stroked up by the wind. Thus since the prevailing winds over the Atlantic go from west to east, the waves arriving on the Atlantic coast of Europe are often especially big. (The waves on the east coast of the British Isles are usually much smaller, so my estimates of potential wave power will focus on the resource in the Atlantic Ocean.)

If waves travelling in a particular direction encounter objects that absorb energy from the waves – for example, a row of islands with sandy beaches – then the seas beyond the object are calmer. The objects cast a shadow, and there's less energy in the waves that get by. So, whereas sunlight delivers a power per unit *area*, waves deliver a power per unit *length* of coastline. You can't have your cake and eat it. You can't collect wave energy two miles off-shore *and* one mile off-shore. Or rather, you can try, but the two-mile facility will absorb energy that would have gone to the one-mile facility, and it won't be replaced. The fetch required for wind to stroke up big waves is thousands of miles.

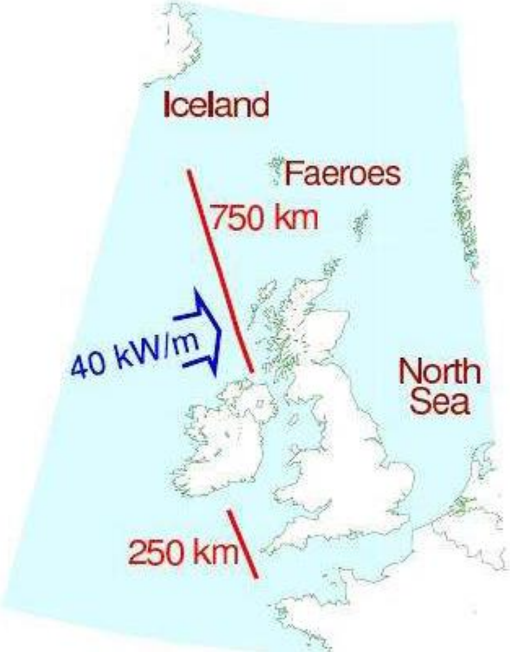


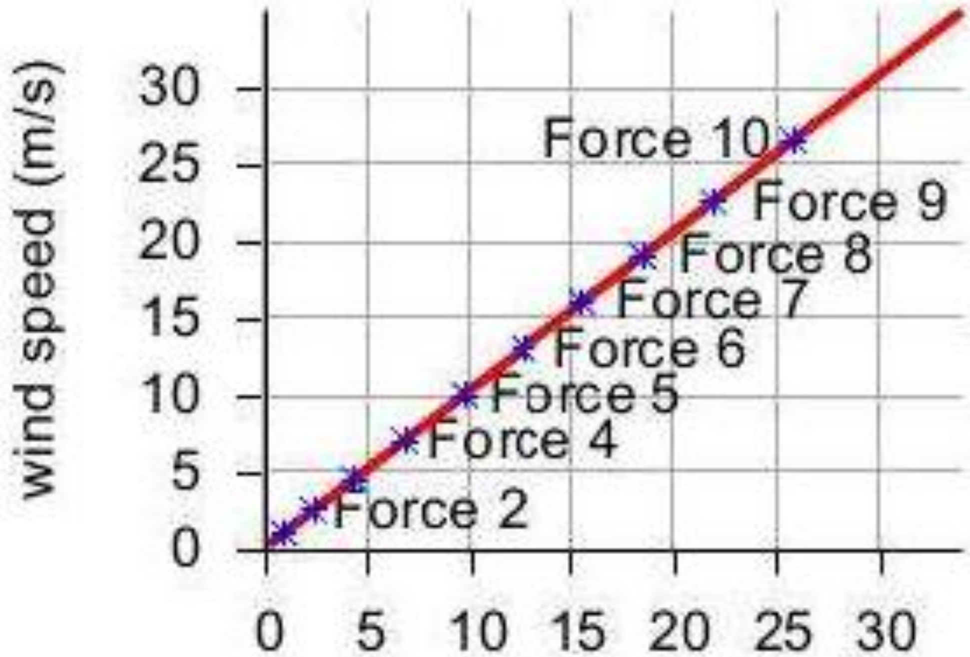
Figure 12.1. A Pelamis wave energy collector is a sea snake made of four sections. It faces nose-on towards the incoming waves. The waves make the snake flex, and these motions are resisted by hydraulic generators. The peak power from one snake is 750 kW; in the best Atlantic location one snake would deliver 300 kW on average. Photo from Pelamis wave power www.pelamiswave.com.

The power of Atlantic waves has been measured: it's about 40 kW per metre of exposed coastline. That sounds like a lot of power! If everyone owned a metre of coastline and could harness their whole 40 kW, that would be plenty of power to cover modern consumption. However, *our population is too big*. There is not enough Atlantic-facing coastline for everyone to have their own metre.

As the map on p73 shows, Britannia rules about 1000 km of Atlantic coastline (one million metres), which is 1/60 m per person. So the total raw incoming power is 16 kWh per day per person. If we extracted all this power, the Atlantic, at the seaside, would be as flat as a millpond. Practical systems won't manage to extract all the power, and some of the power will inevitably be lost during conversion from mechanical energy to electricity. Let's assume that brilliant wave-machines are 50%-efficient at turning the incoming wave power into electricity, and that we are able to pack wave-machines along 500 km of Atlantic-facing coastline. That would mean we could deliver 25% of this theoretical bound. That's 4 kWh per day per person. As usual, I'm intentionally making pretty extreme assumptions

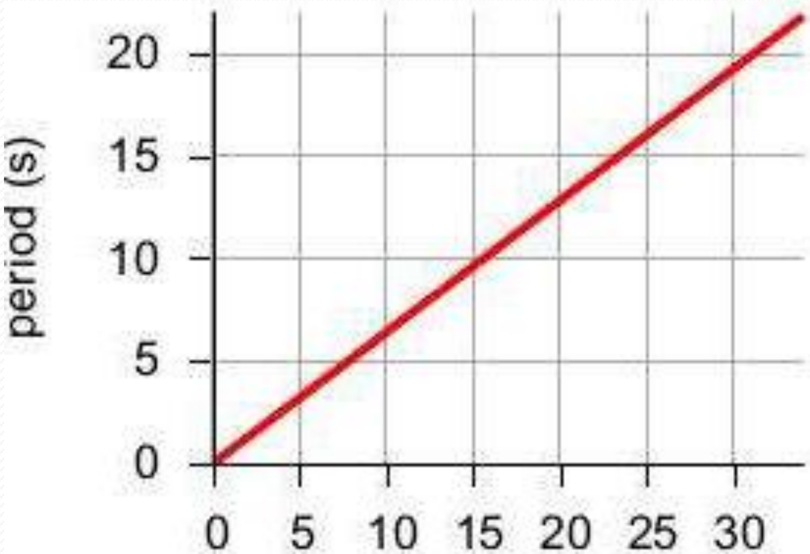
The physics of deep-water waves

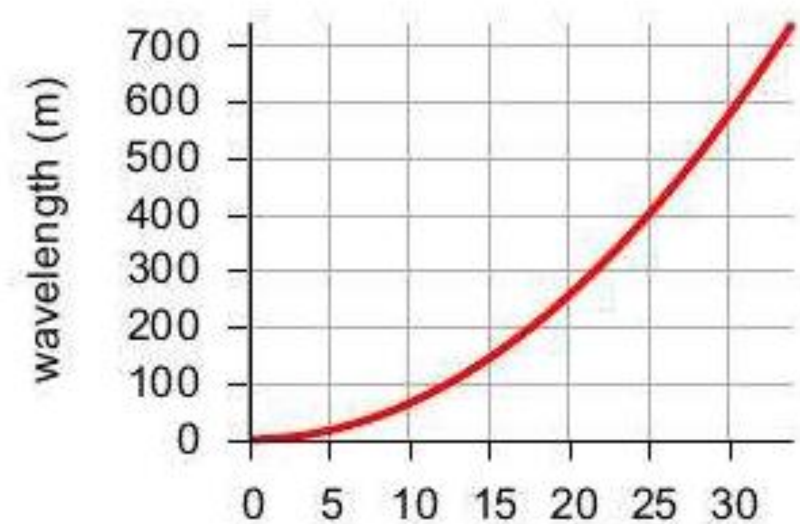
Waves contain energy in two forms: potential energy, and kinetic energy. The potential energy is the energy required to move all the water from the troughs to the crests. The kinetic energy is associated with the water moving around.



Our rough calculation of the power in ocean waves will require three ingredients: an estimate of the period T of the waves (the time between crests), an estimate of the height h of the waves, and a physics formula that tells us how to work out the speed v of the wave from its period.

The wavelength λ and period of the waves (the distance and time respectively between two adjacent crests) depend on the speed of the wind that creates the waves, as shown in figure F.1. The height of the waves doesn't depend on the windspeed; rather, it depends on how long the wind has been caressing the water surface.

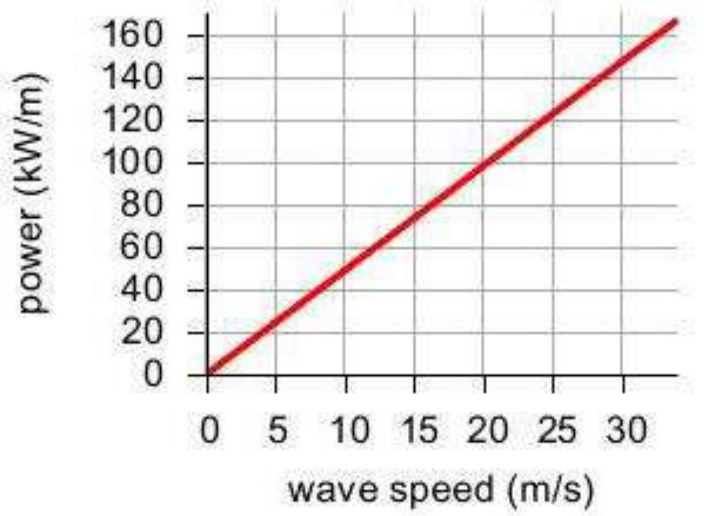


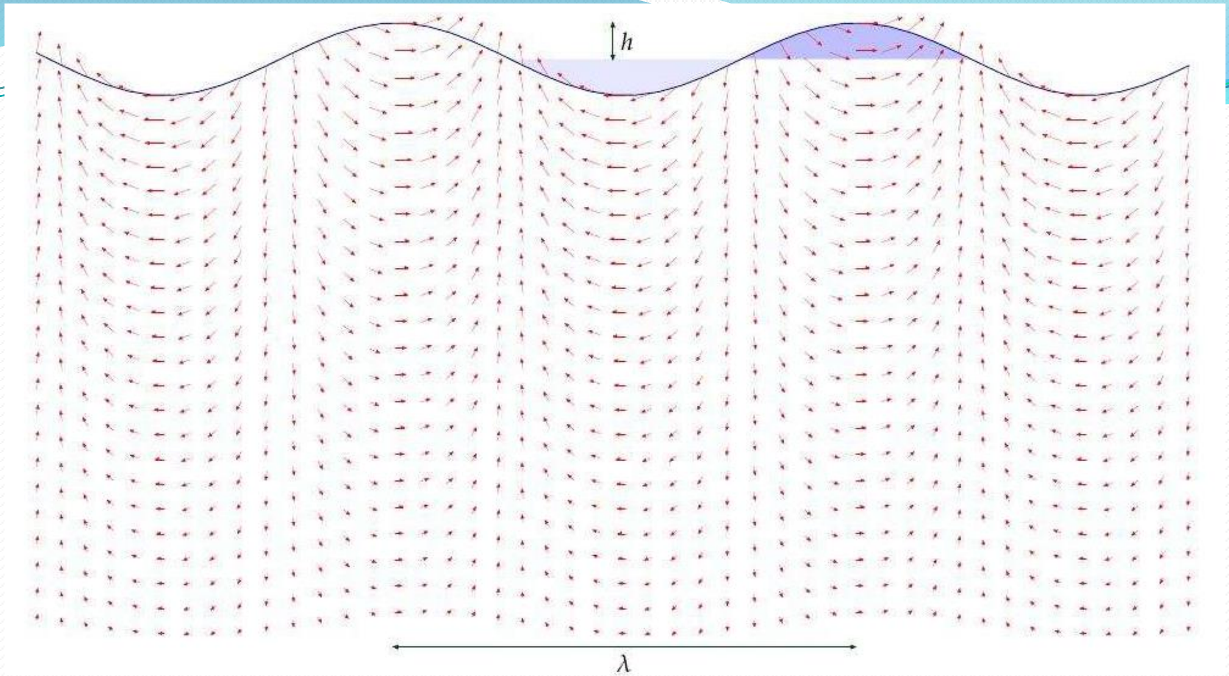


You can estimate the period of ocean waves by recalling the time between waves arriving on an ocean beach. Is 10 seconds reasonable? For the height of ocean waves, let's assume an amplitude of 1 m, which means 2 m from trough to crest. In waves this high, a man in a dinghy can't see beyond the nearest crest when he's in a trough; I think this height is bigger than average, but we can revisit this estimate if we decide it's important. The speed of deep-water waves is related to the time T between crests by the physics formula (see Faber (1995), p170):

$$v = \frac{gT}{2\pi},$$

where g is the acceleration of gravity ($9.8\,\text{m/s}^2$). For example, if $T = 10$ seconds, then $v = 16\,\text{m/s}$. The wavelength of such a wave – the distance between crests – is $\lambda = vT = gT^2/2\pi = 160\,\text{m}$.





For a wave of wavelength λ and period T, if the height of each crest and depth of each trough is $h = 1\,\mathrm{m}$, the potential energy passing per unit time, per unit length, is

$$P_{\text{potential}} \simeq m^{*} g \bar{h} / T, \tag{F.1}$$

where m^{*} is the mass per unit length, which is roughly $\frac{1}{2}\rho h(\lambda/2)$ (approximating the area of the shaded crest in figure F.2 by the area of a triangle), and $\bar{h}$ is the change in height of the centre-of-mass of the chunk of elevated water, which is roughly h. So

$$P_{\text{potential}} \simeq \frac{1}{2}\rho h \frac{\lambda}{2} g h / T. \tag{F.2}$$

(To find the potential energy properly, we should have done an integral here; it would have given the same answer.) Now λ/T is simply the speed at which the wave travels, v, so:

$$P_{\text{potential}} \simeq \frac{1}{4}\rho g h^2 v. \tag{F.3}$$

Waves have kinetic energy as well as potential energy, and, remarkably, these are exactly equal, although I don't show that calculation here; so the

$$P_{\text{total}} \simeq \frac{1}{2}\rho g h^2 v.$$

$$P_{\text{total}} = \frac{1}{4}\rho g h^2 v.$$

Plugging in $v = 16\,\text{m/s}$ and $h = 1\,\text{m}$, we find

$$P_{\text{total}} = \frac{1}{4}\rho g h^2 v = 40\,\text{kW/m}.$$

Deep-water devices

How effective are real systems at extracting power from waves? Stephen Salter's "duck" has been well characterized: a row of 16-m diameter ducks, feeding off Atlantic waves with an average power of 45 kW/m, would deliver 19 kW/m, including transmission to central Scotland (Mollison, 1986).

The Pelamis device, created by Ocean Power Delivery, has taken over the Salter duck's mantle as the leading floating deep-water wave device. Each snake-like device is 130 m long and is made of a chain of four segments, each 3.5 m in diameter. It has a maximum power output of 750 kW. The Pelamises are designed to be moored in a depth of about 50 m. In a wavefarm, 39 devices in three rows would face the principal wave direction, occupying an area of ocean, about 400 m long and 2.5 km wide (an area of 1 km^2). The effective cross-section of a single Pelamis is 7 m (i.e., for good waves, it extracts 100% of the energy that would cross 7 m). The company says that such a wave-farm would deliver about 10 kW/m.

Shallow-water devices

Typically 70% of energy in ocean waves is lost through bottom-friction as the depth decreases from 100 m to 15 m. So the average wave-power per unit length of coastline in shallow waters is reduced to about 12 kW/m. The Oyster, developed by Queen's University Belfast and Aquamarine Power Ltd [`www.aquamarinepower.com`], is a bottom-mounted flap, about 12 m high, that is intended to be deployed in waters about 12 m deep, in areas where the average incident wave power is greater than 15 kW/m. Its peak power is 600 kW. A single device would produce about 270 kW in wave heights greater than 3.5 m. It's predicted that an Oyster would have a bigger power per unit mass of hardware than a Pelamis.

Oysters could also be used to directly drive reverse-osmosis desalination facilities. "The peak freshwater output of an Oyster desalinator is between 2000 and 6000 m^3/day." That production has a value, going by the Jersey facility (which uses 8 kWh per m^3), equivalent to 600–2000 kW of electricity

Power density of tidal pools

To estimate the power of an artificial tide-pool, imagine that it's filled rapidly at high tide, and emptied rapidly at low tide. Power is generated in both directions, on the ebb and on the flood. (This is called two-way generation or double-effect generation.) The change in potential energy of the water, each six hours, is mgh, where h is the change in height of the centre of mass of the water, which is half the range. (The range is the difference in height between low and high tide; figure G.1.) The mass per unit area covered by tide-pool is $\rho \times (2h)$, where ρ is the density of water ($1000\,\mathrm{kg/m^3}$). So the power per unit area generated by a tide-pool is

$$\frac{2\rho h g h}{6\,\text{hours}},$$

assuming perfectly efficient generators. Plugging in $h = 2\,\mathrm{m}$ (i.e., range 4 m), we find the power per unit area of tide-pool is $3.6\,\mathrm{W/m^2}$. Allowing for an efficiency of 90% for conversion of this power to electricity, we get

$$\text{power per unit area of tide-pool} \simeq 3\,\mathrm{W/m^2}.$$

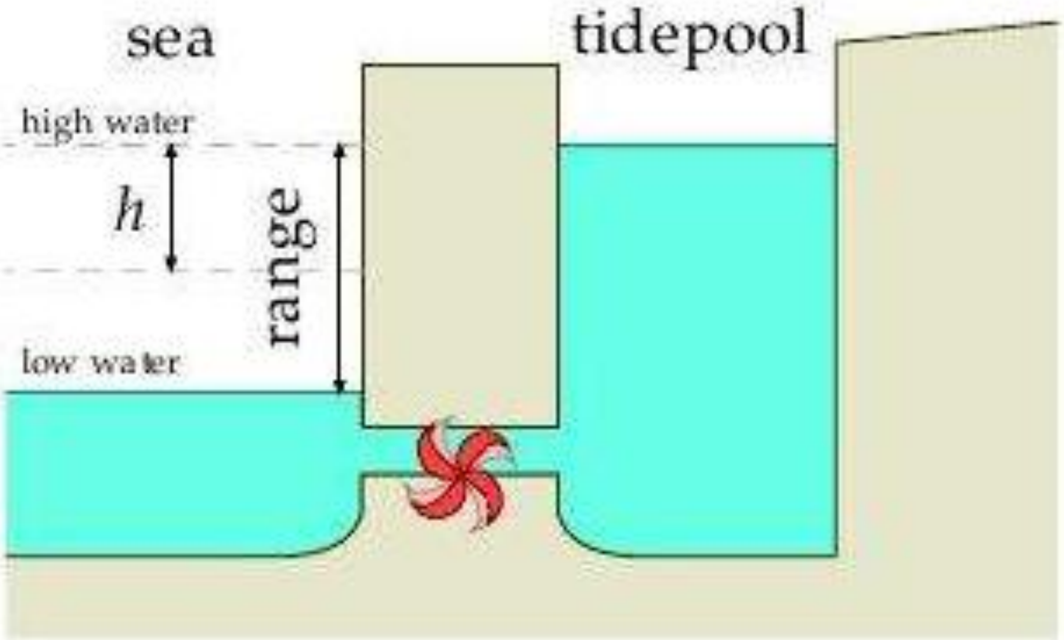
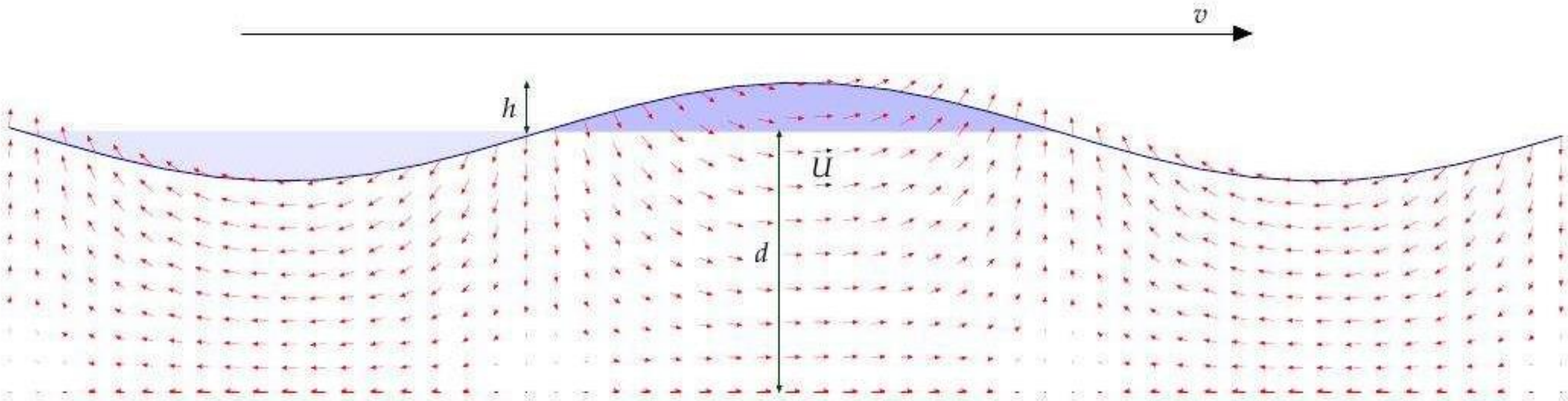


Figure G.1. A tide-pool in cross section. The pool was filled at high tide, and now it's low tide. We let the water out through the electricity generator to turn the water's potential energy into electricity.

So to generate 1 GW of power (on average), we need a tide-pool with an area of about 300 km^2. A circular pool with diameter 20 km would do the trick. (For comparison, the area of the Severn estuary behind the proposed barrage is about 550 km^2, and the area of the Wash is more than 400 km^2.

If a tide-pool produces electricity in one direction only, the power per unit area is halved. The average power density of the tidal barrage at La Rance, where the mean tidal range is 10.9 m, has been 2.7 W/m^2 for decades (p87).



travelling waves in water of depth d that is shallow compared to the wave-length of the waves (figure G.2). The power per unit length of wavecrest of shallow-water tidal waves is

$$\rho g^{3/2} \sqrt{d} h^2 / 2. \qquad \text{(G.1)}$$

Figure G.2. A shallow-water wave. Just like a deep-water wave, the wave has energy in two forms: potential energy associated with raising water out of the light-shaded troughs into the heavy-shaded crests; and kinetic energy of all the water moving

h (m)	$\rho g^{3/2}\sqrt{d}h^2/2$ (kW/m)
0.9	125
1.0	155
1.2	220
1.5	345
1.75	470
2.0	600
2.25	780

Table G.3. Power fluxes (power per unit length of wave crest) for depth $d = 100\,\text{m}$.

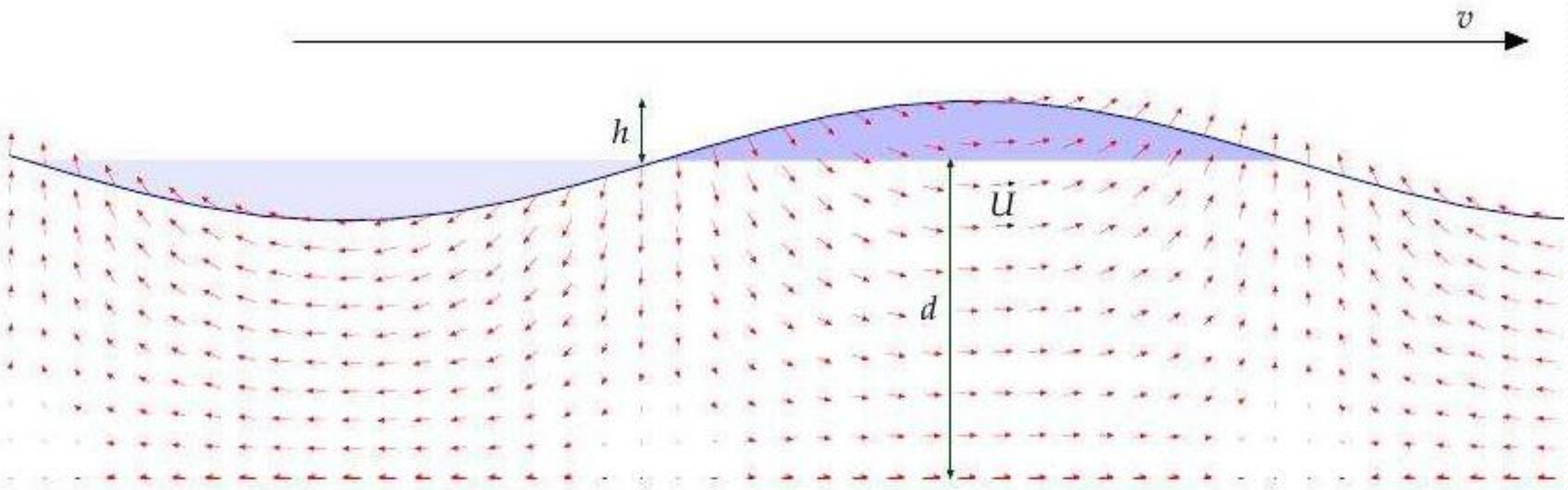


Figure G.2 shows a model for a tidal wave travelling across relatively shallow water. This model is intended as a cartoon, for example, of tidal crests moving up the English channel or down the North Sea. It's important to distinguish the speed U at which the water itself moves (which might be about 1 mile per hour) from the speed v at which the high tide moves, which is typically 100 or 200 miles per hour.

The water has depth d. Crests and troughs of water are injected from the left hand side by the 12-hourly ocean tides. The crests and troughs move with velocity

$$v = \sqrt{gd}. \tag{G.2}$$

We assume that the wavelength is much bigger than the depth, and we neglect details such as Coriolis forces and density variations in the water. Call the vertical amplitude of the tide h. For the standard assumption of nearly-vorticity-free flow, the horizontal velocity of the water is near-constant with depth. The horizontal velocity U is proportional to the surface displacement and can be found by conservation of mass:

$$U = vh/d. \tag{G.3}$$

If the depth decreases, the wave velocity v reduces (equation (G.2)). For the present discussion we'll assume the depth is constant. Energy flows from left to right at some rate. How should this total tidal power be estimated? And what's the *maximum* power that could be extracted?

The peak kinetic-energy flux at any section is

$$K_{BV} = \frac{1}{2}\rho A U^3, \tag{G.4}$$

where A is the cross-sectional area. (This is the formula for kinetic energy flux, which we encountered in Chapter B.)

on swings.) So to compute the total energy all we need to do is compute one of the two – the potential energy per wavelength, or the kinetic energy per wavelength – then double it. The potential energy of a wave (per wavelength and per unit width of wavefront) is found by integration to be

$$\frac{1}{4}\rho g h^2 \lambda. \tag{G.5}$$

So, doubling and dividing by the period, the true power of this model shallow-water tidal wave is

$$\text{power} = \frac{1}{2}(\rho g h^2 \lambda) \times w/T = \frac{1}{2}\rho g h^2 v \times w, \tag{G.6}$$

where w is the width of the wavefront. Substituting $v = \sqrt{gd}$,

$$\text{power} = \rho g h^2 \sqrt{gd} \times w/2 = \rho g^{3/2} \sqrt{d} h^2 \times w/2. \tag{G.7}$$

Let's compare this power with the kinetic-energy flux K_{BV}. Strikingly, the two expressions scale differently with the amplitude h. Using the amplitude conversion relation (G.3), the crest velocity (G.2), and $A = wd$, we can re-express the kinetic-energy flux as

$$K_{BV} = \frac{1}{2}\rho A U^3 = \frac{1}{2}\rho w d (vh/d)^3 = \rho \left(g^{3/2}/\sqrt{d}\right) h^3 \times w/2. \tag{G.8}$$

So the kinetic-energy-flux method suggests that the total power of a shallow-water wave scales as amplitude *cubed* (equation (G.8)); but the correct formula shows that the power scales as amplitude *squared* (equation (G.7)).

The ratio is

$$\frac{K_{\mathrm{BV}}}{\text{power}} = \frac{\rho w \left(g^{3/2} / \sqrt{d} \right) h^3}{\rho g^{3/2} h^2 \sqrt{d} w} = \frac{h}{d}. \tag{G.9}$$

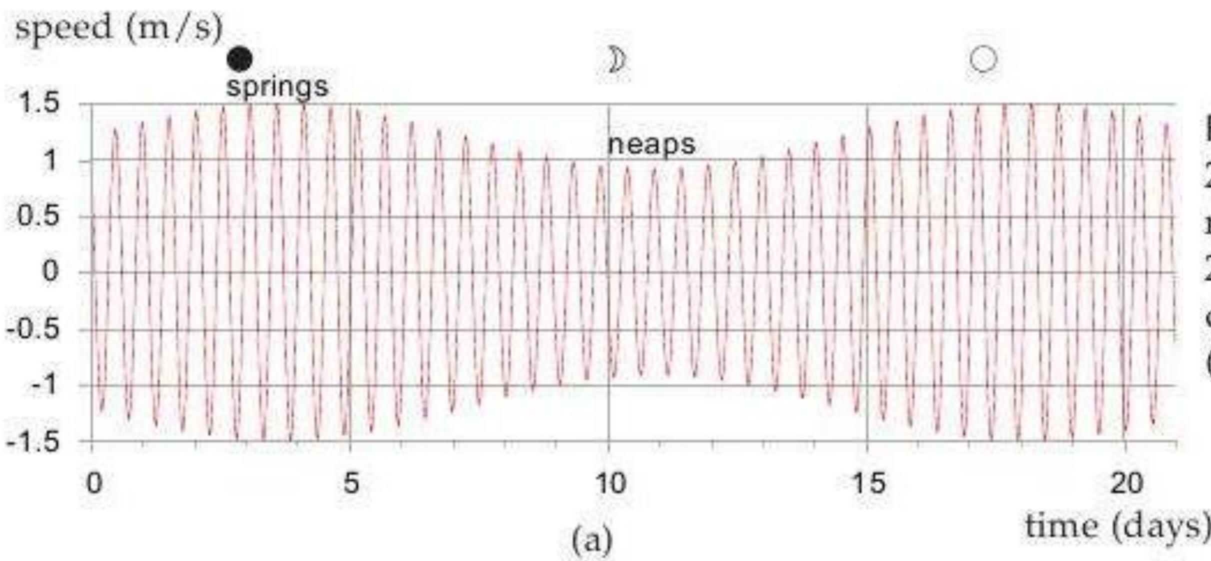
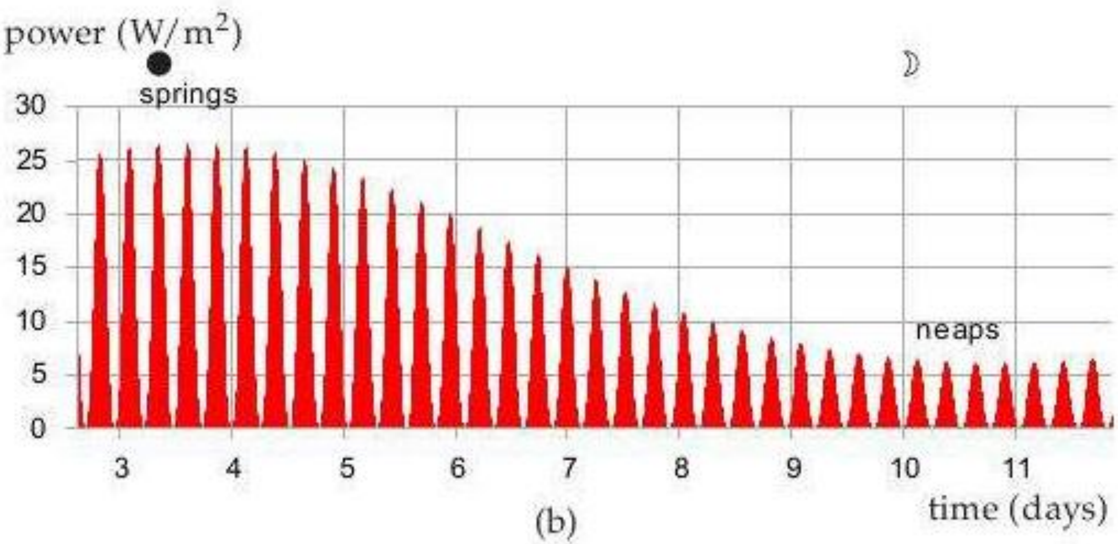


Figure G.5. (a) Tidal current over a 21-day period at a location where the maximum current at spring tide is 2.9 knots (1.5 m/s) and the maximum current at neap tide is 1.8 knots (0.9 m/s).



(b) The power per unit sea-floor area over a nine-day period extending from spring tides to neap tides. The power peaks four times per day, and has a maximum of about 27 W/m^2. The average power of the tide farm is 6.4 W/m^2.

Let's assume that the rules for laying out a sensible tide farm will be similar to those for wind farms, and that the efficiency of the tidemills will be like that of the best windmills, about 1/2. We can then steal the formula for the power of a wind farm (per unit land area) from p265. The power per unit sea-floor area is

$$\frac{\text{power per tidemill}}{\text{area per tidemill}} = \frac{\pi}{200}\frac{1}{2}\rho U^3$$

Using this formula, table G.6 shows this tide farm power for a few tidal currents.

U (m/s)	U (knots)	tide farm power (W/m^2)
0.5	1	1
1	2	8
2	4	60
3	6	200
4	8	500
5	10	1000

Table G.6. Tide farm power density (in watts per square metre of sea-floor) as a function of flow speed U. (1 knot = 1 nautical mile per hour = 0.514 m/s.) The power density is computed using $\frac{\pi}{200}\frac{1}{2}\rho U^3$ (equation (G.10)).

v (m/s)	v (knots)	Friction power density (W/m^2) $R_1 = 0.01$	$R_1 = 0.003$	tide farm power density (W/m^2)
0.5	1	1.25	0.4	1
1	2	10	3	8
2	4	80	24	60
3	6	270	80	200
4	8	640	190	500
5	10	1250	375	1000

Table G.9. Friction power density $R_1 \rho U^3$ (in watts per square metre of sea-floor) as a function of flow speed, assuming $R_1 = 0.01$ or 0.003. Flather (1976) uses $R_1 = 0.0025$–0.003; Taylor (1920) uses 0.002. (1 knot = 1 nautical mile per hour = 0.514 m/s.) The final column shows the tide farm power estimated in table G.6. For further reading see Kowalik (2004), Sleath (1984).

Table 15: Capacity of renewable electricity generation in Australia, 2010

	Hydro MW	Wind MW	Bioenergy MW	Solar PV [a] MW	Solar thermal MW	Geothermal MW	Wave MW	Total MW
NSW	4 677	234	166	328	3	0	0	5 408
Tas	2 316	142	5	8	0	0	0	2 471
Vic	803	432	113	152	0	0	0.2	1 500
Qld	669	12	429	256	0	0.1	0	1 366
SA	4	1 151	20	130	0	0	0	1 305
WA	30	204	33	141	0	0	0.1	408
ACT	1	0	4	19	0	0	0	25
NT	0	0	1	6	0	0	0	7
Australia	**8 501**	**2 175**	**772**	**1 041**	**3**	**0.1**	**0.3**	**12 492**

a Includes small-scale Solar PV.

Source: Clean Energy Council 2011, Clean Energy Australia Report 2011.

Sustainable energy is the sustainable provision of energy that meets the needs of the present without compromising the ability of future generations to meet their needs.

Technologies that promote sustainable energy include renewable energy sources, such as

hydroelectricity, solar energy, wind energy, wave power, geothermal energy, artificial photosynthesis, and tidal power, and also technologies designed to improve energy efficiency.

Energy efficiency and renewable energy are said to be the *twin pillars* of sustainable energy.[1]

Some ways in which *sustainable energy* has been defined are:

"Effectively, the provision of energy such that it meets the needs of the present without compromising the ability of future generations to meet their own needs.

...Sustainable Energy has two key components: renewable energy and energy efficiency." –
"]

Dynamic harmony between equitable availability of energy-intensive goods and services to all people and the preservation of the earth for future generations."

And, "the solution will lie in finding sustainable energy sources and more efficient means of converting and utilizing energy.“

"Any energy generation, efficiency & conservation source where: Resources are available to enable massive scaling to become a significant portion of energy generation, long term, preferably 100 years.." – *Invest,* a green technology non-profit organization.[3]

"Energy which is replenishable within a human lifetime and causes no long-term damage to the environment.

Green Energy is energy that can be extracted, generated, and/or consumed without any significant negative impact to the environment. The planet has a natural capability to recover which means pollution that does not go beyond that capability can still be termed green.

Green power is a subset of renewable energy and represents those renewable energy resources and technologies that provide the highest environmental benefit.

The U.S. Environmental Protection Agency defines green power as electricity produced from solar, wind, geothermal, biogas, biomass, and low-impact small hydroelectric sources.

Customers often buy green power for avoided environmental impacts and its greenhouse gas reduction benefits.[5]

Renewable energy technologies are essential contributors to sustainable energy as they generally contribute to world energy security, reducing dependence on fossil fuel resources,[6] and providing opportunities for mitigating greenhouse gases.

First-generation technologies emerged from the industrial revolution at the end of the 19th century and include hydropower, biomass combustion, and geothermal power and heat. Some of these technologies are still in widespread use.

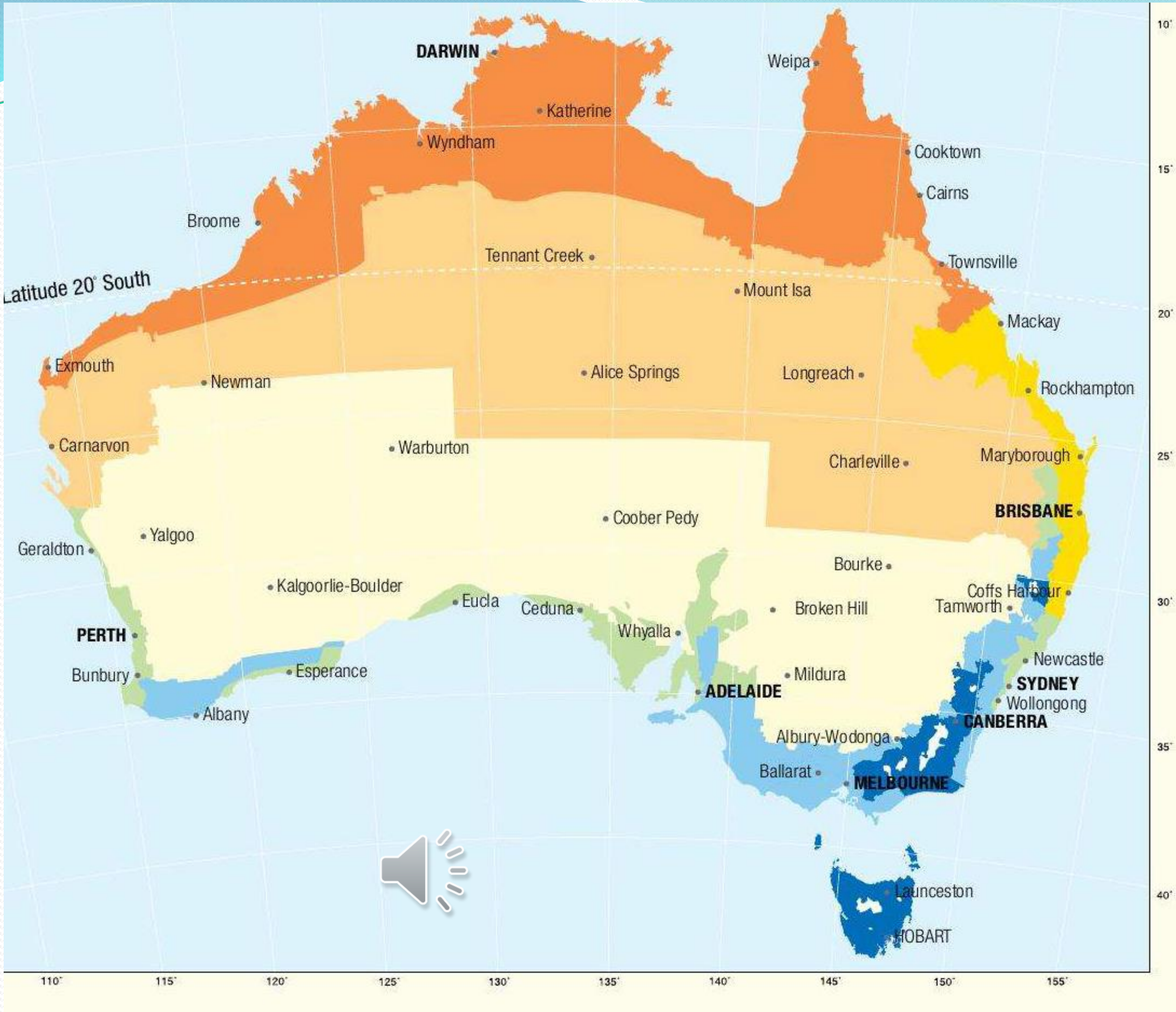
Second-generation technologies include solar heating and cooling, wind power, modern forms of bioenergy, and solar photovoltaics. These are now entering markets as a result of research, development and demonstration (RD&D) investments since the 1980s. The initial investment was prompted by energy security concerns linked to the oil crises (1973 and 1979) of the 1970s but the continuing appeal of these renewables is due, at least in part, to environmental benefits. Many of the technologies reflect significant advancements in materials.

Third-generation technologies are still under development and include advanced biomass gasification, biorefinery technologies, concentrating solar thermal power, hot dry rock geothermal energy, and ocean energy. Advances in nanotechnology may also play a major role.

A moderately active person with a weight of 65 kg consumes food with a chemical energy content of about 2600 "Calories" per day. A "Calorie," in food circles, is actually 1000 chemist's calories (1 kcal). 2600 "Calories" per day is about 3 kWh per day. Most of this energy eventually escapes from the body as heat, so one function of a typical person is to act as a space heater with an output of a little over 100 W, a medium-power lightbulb. Put 10 people in a small cold room, and you can switch off the 1 kW convection heater.

How much energy do we actually consume in order to get our 3 kWh per day? If we enlarge our viewpoint to include the inevitable upstream costs of food production, then we may find that our energy footprint is substantially bigger. It depends if we are vegan, vegetarian or carnivore.

The vegan has the smallest inevitable footprint: 3 kWh per day of energy from the plants he eats.



DARWIN
Weipa
Katherine
Wyndham
Cooktown
Cairns
Broome
Tennant Creek
Townsville
Latitude 20° South
Mount Isa
Mackay
Exmouth
Newman
Alice Springs
Longreach
Rockhampton
Carnarvon
Warburton
Charleville
Maryborough
BRISBANE
Coober Pedy
Yalgoo
Geraldton
Bourke
Kalgoorlie-Boulder
Coffs Harbour
Eucla
Ceduna
Broken Hill
Tamworth
PERTH
Whyalla
Newcastle
Mildura
Bunbury
Esperance
ADELAIDE
SYDNEY
Wollongong
Albany
CANBERRA
Albury-Wodonga
Ballarat
MELBOURNE
Launceston
HOBART
10°
15°
20°
25°
30°
35°
40°
110°
115°
120°
125°
130°
135°
140°
145°
150°
155°

Passive design is design that does not require mechanical heating or cooling. Homes that are passively designed take advantage of natural climate to maintain thermal comfort.

Incorporating the principles of passive design in your home:

> Significantly improves comfort.

> Reduces or eliminates heating and cooling bills.

> Reduces greenhouse gas emissions from heating, cooling, mechanical ventilation and lighting.

Design for Climate

4.3 Orientation

A home that is well positioned on its site delivers significant lifestyle and environmental benefits. Correct orientation assists passive heating and cooling, resulting in improved comfort and decreased energy bills.

The information is presented in three parts:

> Principles of good orientation.

> Orientation for passive solar heating.

> Orientation for passive cooling.

4.4 Shading

Shading of glass is a critical consideration in passive design. Unprotected glass is the single greatest source of heat gain in a well insulated home.

Shading requirements vary according to climate and house orientation.

4.5 Passive solar Heating

Passive solar heating is about keeping the summer sun out and letting the winter sun in. It is the least expensive way to heat your home.

The fact sheet explains how the following key elements of passive solar heating are applied.

> Northerly orientation of window areas.

> Passive shading of glass.

> Thermal mass for storing heat.

> Minimising heat loss with insulation, draught sealing and advanced glazing.

> Using floor plan zoning to get heating to where it is most needed and keeping it there.

4.6 Passive Cooling

Passive cooling is the least expensive means of cooling your home. It is appropriate for all Australian climates.

This fact sheet explains how to design and modify homes to achieve summer comfort and minimise or eliminate energy use for cooling.

Four key approaches are examined:

> Envelope design for passive cooling.

> Natural cooling sources.

> Hybrid cooling systems.

> Adapting lifestyle.

4.7 Insulation

Insulation is an essential component of passive design. It improves building envelope performance by minimising heat loss and heat gain through walls, roof and floors.

Topics covered include:

> Insulation types and their applications.

> Recommended insulation levels for different climates.

> Strategies for cost effective insulation solutions.

4.9 Thermal Mass

Externally insulated, dense materials like concrete, bricks and other masonry are used in passive design to absorb, store and re-release thermal energy. This moderates internal temperatures by averaging day/night (diurnal) extremes, therefore increasing comfort and reducing energy costs.

Topics covered include:

> Where and how to use thermal mass.

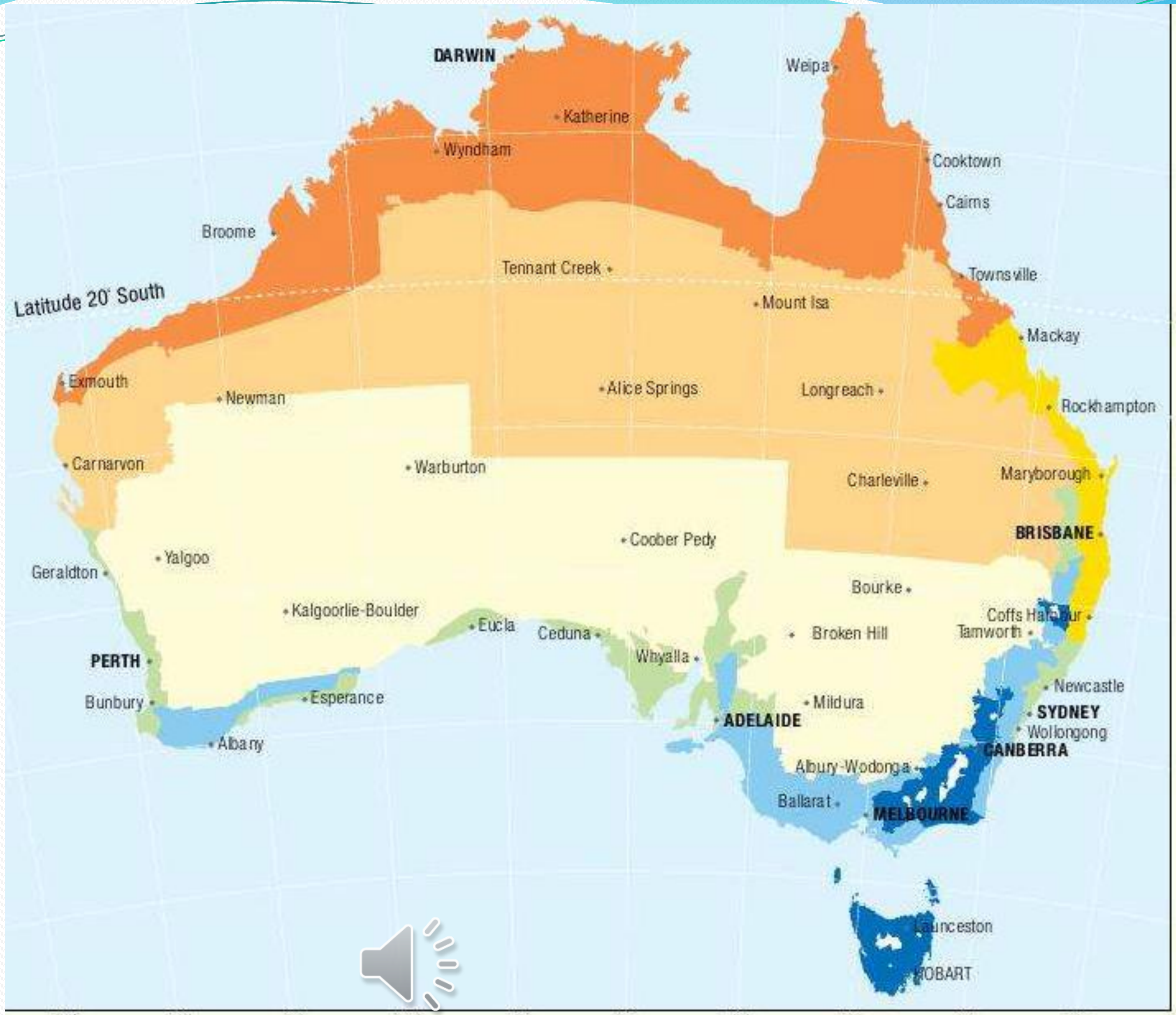
> Thermal mass solutions for different climates and construction types.

> How much thermal mass to use.

4.10 Glazing

Windows and glazing are a very important component of passive design because heat loss and gain in a well insulated home occurs mostly through the windows.

With good passive design, this is used to advantage by trapping winter heat whilst excluding summer sun. Cooling breezes and air movement are encouraged in summer and cold winter winds are excluded.


DARWIN
Katherine
Weipa
Wyndham
Cooktown
Cairns
Broome
Tennant Creek
Townsville
Latitude 20° South
Mount Isa
Mackay
Exmouth
Newman
Alice Springs
Longreach
Rockhampton
Carnarvon
Warburton
Charleville
Maryborough
Coober Pedy
BRISBANE
Geraldton
Yalgoo
Bourke
Kalgoorlie-Boulder
Tamworth
Eucla
Ceduna
Broken Hill
Whyalla
PERTH
Newcastle
Esperance
Mildura
Bunbury
SYDNEY
ADELAIDE
Wollongong
Albany
CANBERRA
Albury-Wodonga
Ballarat
MELBOURNE

ZONE	DESCRIPTION
1	High humid summer, warm winter
2	Warm humid summer, mild winter
3	Hot dry summer, warm winter
4	Hot dry summer, cool winter
5	Warm temperate
6	Mild temperate
7	Cool temperate
8	Alpine

ZONE 1

High humid summer, warm winter

Main characteristics:

Highly humid with a degree of 'dry season'.

High temperatures year round.

Minimum seasonal temperature variation.

Lowest diurnal (day/night) temperature range.

Key design responses:

Employ lightweight (low mass) construction.

Maximise external wall areas (plans with one room depth are ideal) to encourage movement of breezes through the building (cross ventilation). [See: 4.6 Passive Cooling]

Ceiling fans should be used where required.

Site for exposure to breezes and shading all year. [See: 4.3 Orientation]

Shade whole building summer and winter (consider using a fly roof). [See: 4.4 Shading]

Use reflective insulation and vapour barriers. [See: 4.7 Insulation]

Ventilate roof spaces.

Use bulk insulation if mechanically cooling. [See: 4.6 Passive Cooling]

Choose light coloured roof and wall materials.

Elevate building to permit airflow beneath floors.

Consider high or raked ceilings.

Provide screened, shaded outdoor living areas.

Consider creating sleepout spaces.

Design and build for cyclonic conditions.

ZONE 2

Warm humid summer, mild winter

Main characteristics:

High humidity with a definite 'dry season'.

Hot to very hot summers with mild winters.

Distinct summer/winter seasons.

Moderate to low diurnal (day/night) temperature range. This can vary significantly between regions eg inland to coastal.

Key design responses:

Use lightweight construction where diurnal (day/night) temperature range is low and include thermal mass where diurnal range is significant. [See: 4.9 Thermal Mass]

Maximise external wall areas (plans ideally one room deep) to encourage movement of breezes through the building (cross ventilation). [See: 4.6 Passive Cooling]

Site for exposure to breezes. [See: 4.3 Orientation]

Evaporative cooling or ceiling fans should be used if required.

Shade whole building where possible in summer. [See: 4.4 Shading]

Allow passive solar access in winter months only.

Shade all east and west walls and glass year round.

ZONE 2

Warm humid summer, mild winter

Main characteristics:

High humidity with a definite 'dry season'.

Hot to very hot summers with mild winters.

Distinct summer/winter seasons.

Moderate to low diurnal (day/night) temperature range. This can vary significantly between regions eg inland to coastal.

Avoid auxiliary heating as it is unnecessary with good design.

Use reflective and bulk insulation (especially if the house is air-conditioned) and vapour barriers. [See: 4.7 Insulation]

Use elevated construction with enclosed floor space, where exposed to breezes.

Choose light coloured roof and wall materials

Provide screened and shaded outdoor living.

ZONE 3

Hot dry summer, warm winter

Main characteristics:

Distinct wet and dry seasons.

Low rainfall and low humidity.

No extreme cold but can be cool in winter.

Hot to very hot summers common.

Significant diurnal (day/night) range.

Key design responses:

Use passive solar design with insulated thermal mass. [See: 4.9 Thermal Mass]

Maximise cross ventilation. [See: 4.6 Passive Cooling]

Evaporative cooling or ceiling fans should be used if required.

Consider convective (stack) ventilation, which vents rising hot air while drawing in cooler air.

Site home for solar access and exposure to cooling breezes. [See: 4.3 Orientation]

Shade all east and west glass in summer. [See: 4.4 Shading]

Install reflective insulation to keep out heat in summer. [See: 4.7 Insulation]

Use bulk insulation in ceilings and walls.

Build screened, shaded summer outdoor living areas that allow winter sun penetration.

Use garden ponds and water features to provide evaporative cooling.

ZONE 4

Hot dry summer, cool winter

Main characteristics:

Distinct seasons with low humidity all year round.

High diurnal (day/night) temperature range.

Low rainfall.

Very hot summers common with hot, dry winds.

Cool winters with cold dry winds.

Key design responses:

Use passive solar principles with well insulated thermal mass. [See: 4.5 Passive Solar Heating; 4.9 Thermal Mass]

Maximise night time cooling in summer. [See: 4.6 Passive Cooling]

Consider convective (stack) ventilation, which vents rising hot air while drawing in cooler air.

Build more compact shaped buildings with good cross ventilation for summer.

Maximise solar access, exposure to cooling breezes and cool air drainage. Protect from strong, cold winter and dusty summer winds. [See: 4.3 Orientation]

Shade all east and west glass in summer. [See: 4.4 Shading]

Provide shaded outdoor living areas.

Consider adjustable shading to control solar access.

Auxiliary heating may be required. [See: 6.6 Renewable Energy]

Use evaporative cooling if required.

ZONE 4

Hot dry summer, cool winter

Main characteristics:

Distinct seasons with low humidity all year round.

High diurnal (day/night) temperature range.

Low rainfall.

Very hot summers common with hot, dry winds.

Cool winters with cold dry winds.

Avoid air-conditioning. [See: 6.2 Heating and Cooling]

Use reflective insulation to keep out summer heat. [See: 4.7 Insulation]

Use bulk insulation for ceilings, walls and exposed floors.

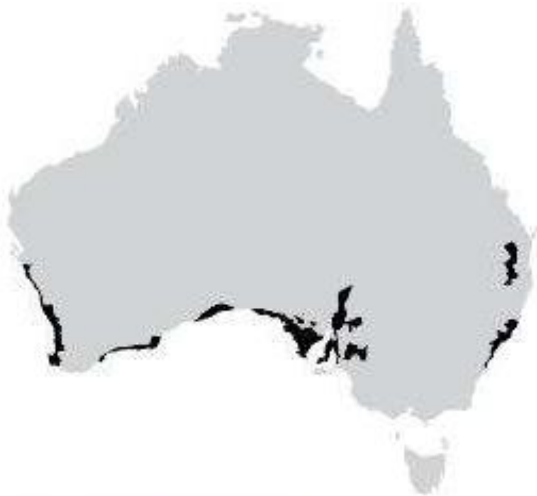
Consider double glazing.

Use ponds and water in shaded courtyards to provide evaporative cooling.

Draught seal thoroughly. Use airlocks to entries.

ZONE 5

Warm temperate



Main characteristics:

Low diurnal (day/night) temperature range near coast to high diurnal range inland.

Four distinct seasons. Summer and winter can exceed human comfort range. Spring and autumn are ideal for human comfort.

Mild winters with low humidity.

Hot to very hot summers with moderate humidity.

Key design responses:

Use passive solar principles. [See: 4.5 Passive Solar Heating; 4.6 Passive Cooling]

Use insulated thermal mass. [See: 4.9 Thermal Mass]

Use high insulation levels. [See; 4.7 Insulation]

Maximise solar access in winter. [See: 4.5 Passive Solar Heating]

Minimise all east and west glazing. Use adjustable shading. [See: 4.4 Shading]

Use double glazing to insulate windows. [See: 4.10 Glazing]

Minimise east and west wall areas.

Use cross ventilation and passive cooling in summer. [See: 4.6 Passive Cooling]

Use convective ventilation and circulation.

Site homes for solar access and exposure to cooling breezes.

ZONE 5

Warm temperate

Main characteristics:

Low diurnal (day/night) temperature range near coast to high diurnal range inland.

Four distinct seasons. Summer and winter can exceed human comfort range. Spring and autumn are ideal for human comfort.

Mild winters with low humidity.

Hot to very hot summers with moderate humidity.

Draught seal and use airlock entries.

No auxiliary heating or cooling is required in these climates with good design.

Use reflective insulation for summer heat.

Use bulk insulation to walls, ceilings and exposed floors.

ZONE 6

Mild temperate

Main characteristics:

Low diurnal (day/night) temperature range near coast to high diurnal range inland.

Four distinct seasons. Summer and winter can exceed human comfort range. Spring and autumn are ideal for human comfort.

Mild to cool winters with low humidity.

Hot to very hot summers, moderate humidity.

Key design responses:

Use passive solar principles. [See: 4.5 Passive Solar Heating; 4.6 Passive Cooling]

High thermal mass solutions are recommended [See: 4.9 Thermal Mass]

Use high insulation levels, especially to thermal mass. [See: 4.7 Insulation]

Maximise north facing walls and glazing, especially in living areas with passive solar access. [See: 4.3 Orientation]

Minimise all east and west glazing.

Use adjustable shading. [See: 4.4 Shading]

Use double glazing and heavy drapes with sealed pelmets to insulate windows.

Minimise external wall areas (especially east and west).

ZONE 6

Mild temperate

Main characteristics:

Low diurnal (day/night) temperature range near coast to high diurnal range inland.

Four distinct seasons. Summer and winter can exceed human comfort range. Spring and autumn are ideal for human comfort.

Mild to cool winters with low humidity.

Hot to very hot summers, moderate humidity.

Use cross ventilation and passive cooling in summer. [See: 4.6 Passive Cooling]

Use convective ventilation and heat circulation.

Site new homes for solar access, exposure to cooling breezes and protection from cold winds.

Draught seal thoroughly and use entry airlocks.

No auxiliary heating or cooling is required in these climates with good design.

Use reflective insulation to keep out summer heat.

Use bulk insulation to walls, ceilings and exposed floors.

ZONE 7

Cool Temperate

Main characteristics:

Low humidity, high diurnal range.

Four distinct seasons. Summer and winter exceed human comfort range, variable spring and autumn conditions.

Cold to very cold winters with majority of rainfall.

Hot dry summers.

Key design responses:

Use passive solar principles. [See: 4.5 Passive Solar Heating]

High thermal mass is strongly recommended. [See: 4.9 Thermal Mass]

Insulate thermal mass including slab edges. [See: 4.7 Insulation]

Maximise north facing walls and glazing, especially in living areas with passive solar access.

Minimise east, west and south facing glazing.

Use adjustable shading. [See: 4.4 Shading]

Use double glazing, insulating frames and/or heavy drapes with sealed pelmets to insulate glass in winter.

Minimise external wall areas (especially east and west).

Use cross ventilation and night time cooling in summer. [See: 4.6 Passive Cooling]

ZONE 7

Cool Temperate

Main characteristics:

Low humidity, high diurnal range.

Four distinct seasons. Summer and winter exceed human comfort range, variable spring and autumn conditions.

Cold to very cold winters with majority of rainfall.

Hot dry summers.

Site new homes for solar access, exposure to cooling breezes and protection from cold winds. [See: 4.3 Orientation]

Draught seal thoroughly and provide airlocks to entries.

Install auxiliary heating in extreme climates. Use renewable energy sources. [See: 6.2 Heating and Cooling; 6.6 Renewable Energy]

Use reflective insulation to keep out heat in summer.

Use bulk insulation to keep heat in during winter. Bulk insulate walls, ceilings and exposed floors.

ZONE 8

Alpine

Main characteristics:

Low humidity, high diurnal range.

Four distinct seasons. Winter can exceed human comfort range.

Cold to very cold winters with majority of rainfall. Some snowfall.

Warm to hot, dry summers, variable spring and autumn conditions.

Key design responses:

Use passive solar principles. [See: 4.5 Passive Solar Heating]

High thermal mass is recommended but must be well insulated. [See: 4.9 Thermal Mass]

Use high levels of insulation. [See: 4.7 Insulation]

Insulate thermal mass including slab edges.

Maximise north facing walls and glazing, especially in living areas with passive solar access.

Minimise east, west and south facing glazing.

Use adjustable shading. [See: 4.4 Shading]

Use double glazing and insulating frames. Augment with heavy drapes and pelmets.

Minimise external wall areas.

ZONE 8

Alpine

Main characteristics:

Low humidity, high diurnal range.

Four distinct seasons. Winter can exceed human comfort range.

Cold to very cold winters with majority of rainfall. Some snowfall.

Warm to hot, dry summers, variable spring and autumn conditions.

Use night time cooling in summer. [See: 4.6 Passive Cooling]

Use convective ventilation and circulation.

Site homes for solar access and protection from cold winds. [See: 4.3 Orientation]

Draught seal thoroughly and airlock entries.

Auxiliary heating may be required. [See: 6.2 Heating and Cooling]

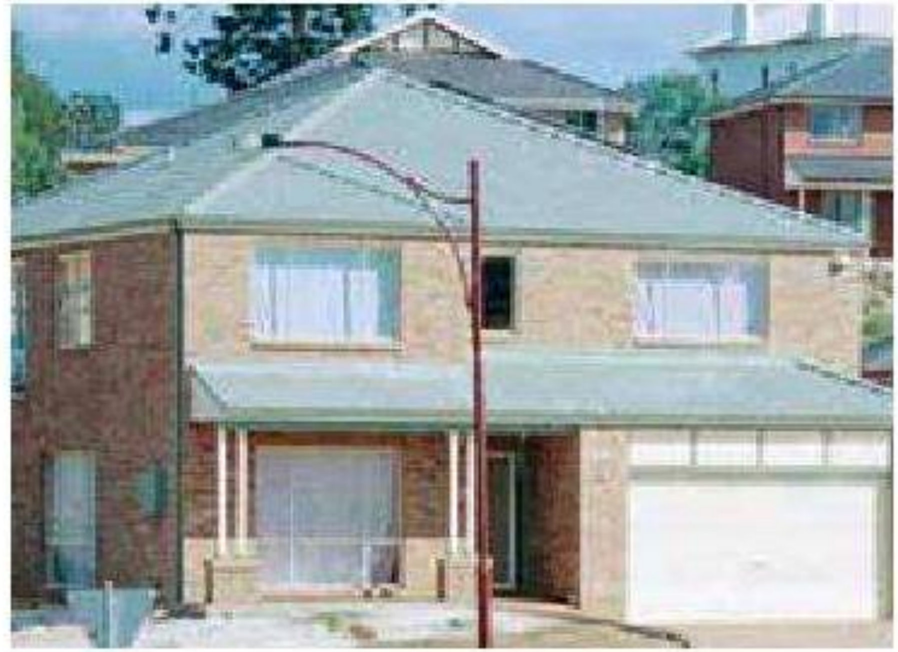
Use reflective insulation to keep out summer heat. [See: 4.7 Insulation]

Use bulk insulation to walls, ceilings and exposed floors.

CLIMATE SENSITIVE DESIGN

The importance of climate sensitive design can not be overrated.

All round shading is appropriate for tropical climates only. This style does not work in warm, cool or cold climates.



Eaveless cold climate designs (borrowed from Europe) do not work in Australia.

HUMAN THERMAL COMFORT

The main factors influencing human comfort are:

> Temperature.

> Humidity.

> Air movement (breeze or draught).

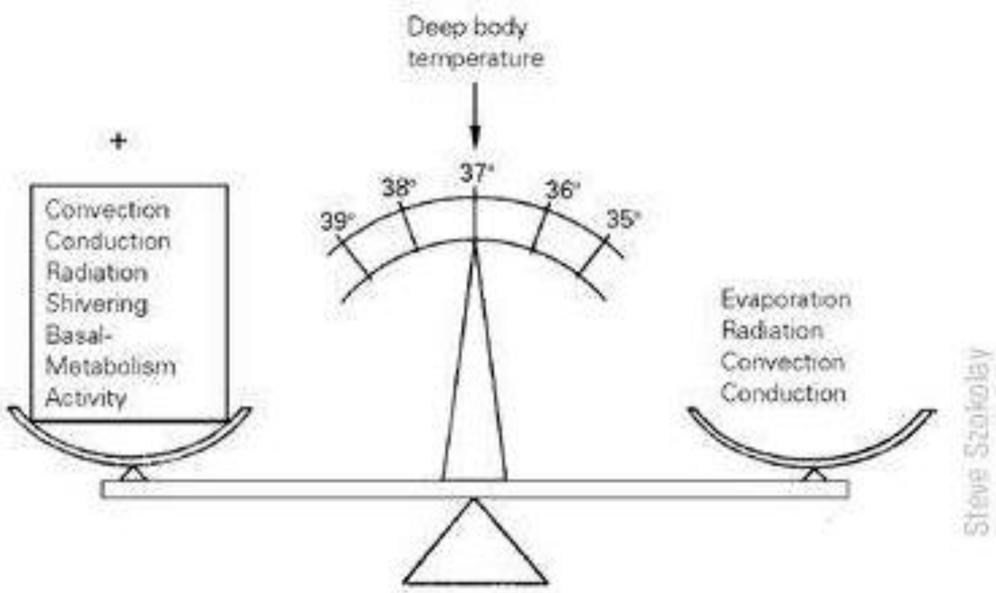
> Exposure to radiant heat sources.

> Cool surfaces to radiate for cooling.

Sound building envelope design will moderate all of these factors except humidity.

To do this effectively, envelope design should be varied to suit the climate. It can significantly improve comfort levels whilst reducing heating and cooling bills.

Humans are comfortable only within a very narrow range of conditions. Human body temperature must remain at a constant 36.9°C. The body generates heat – even while at rest. We must lose heat at the same rate as it is produced or gain heat at the same rate it is lost. The diagram below shows the various ways by which our bodies achieve this.



Losing body heat

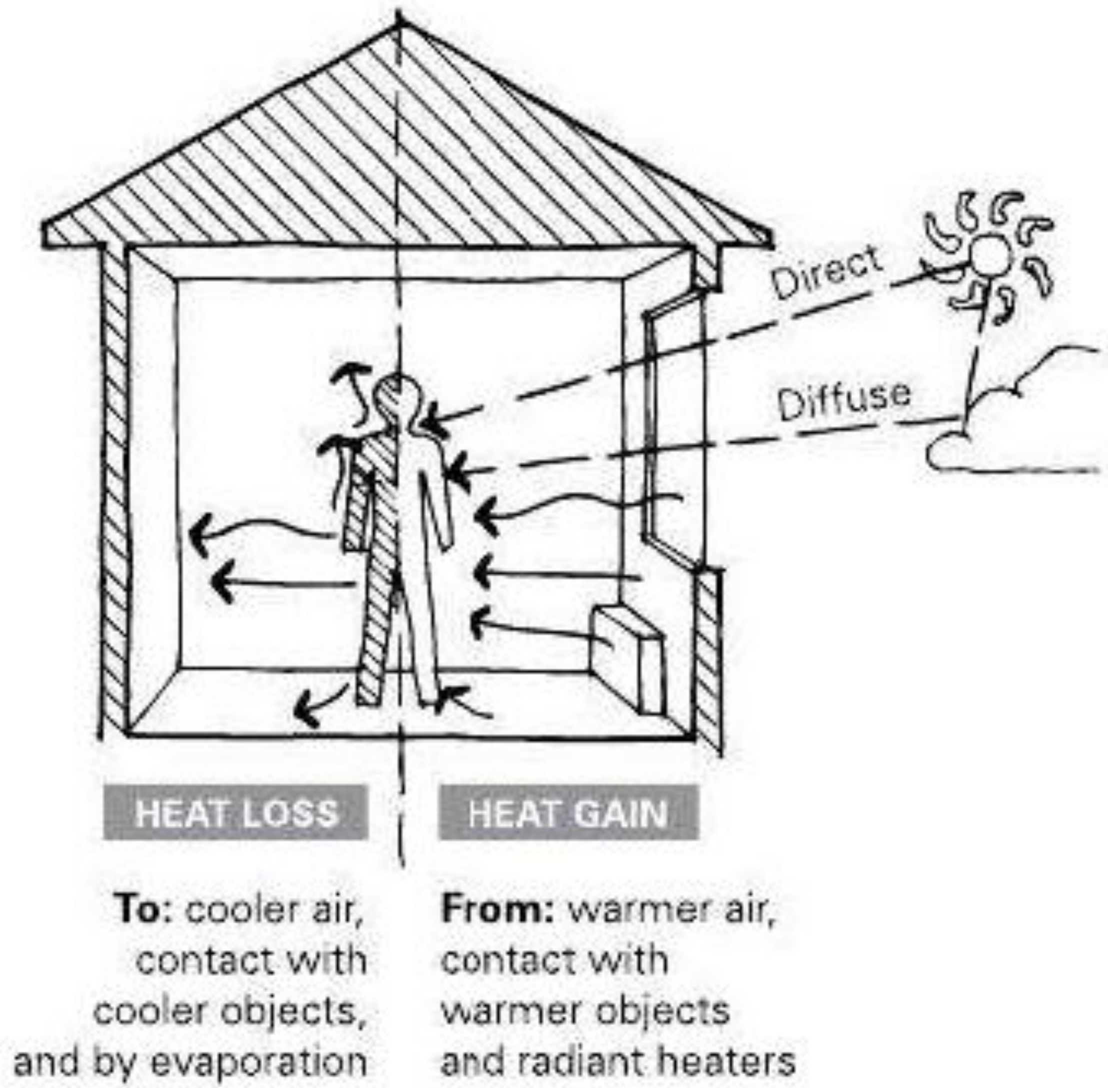
We mainly lose heat through the evaporation of perspiration. High humidity levels reduce evaporation rates. When relative humidity exceeds 60 per cent, our ability to cool is greatly reduced.

Evaporation rates are also influenced by air movement. Generally, a breeze of 0.5m per second provides a one off comfort benefit equivalent to a 3°C temperature reduction.

Gaining body heat

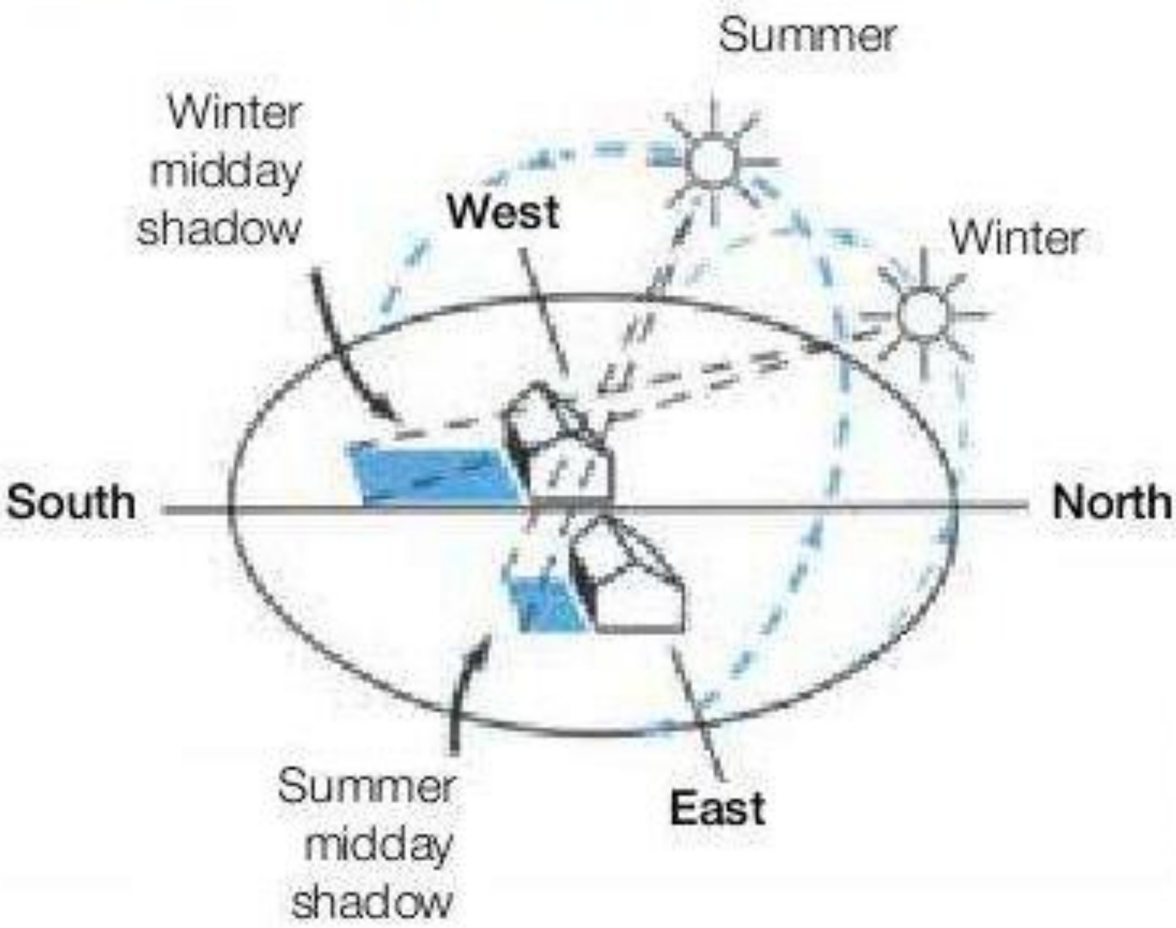
When the heat produced by our bodies is insufficient to maintain body temperature, we insulate by putting on more clothes, shelter from wind and draughts, or shiver (increasing the production of body heat).

This is because we generate most of the heat required from within. A secondary source of heat gain is radiation. As with cooling, radiation is very important to our perception of comfort.

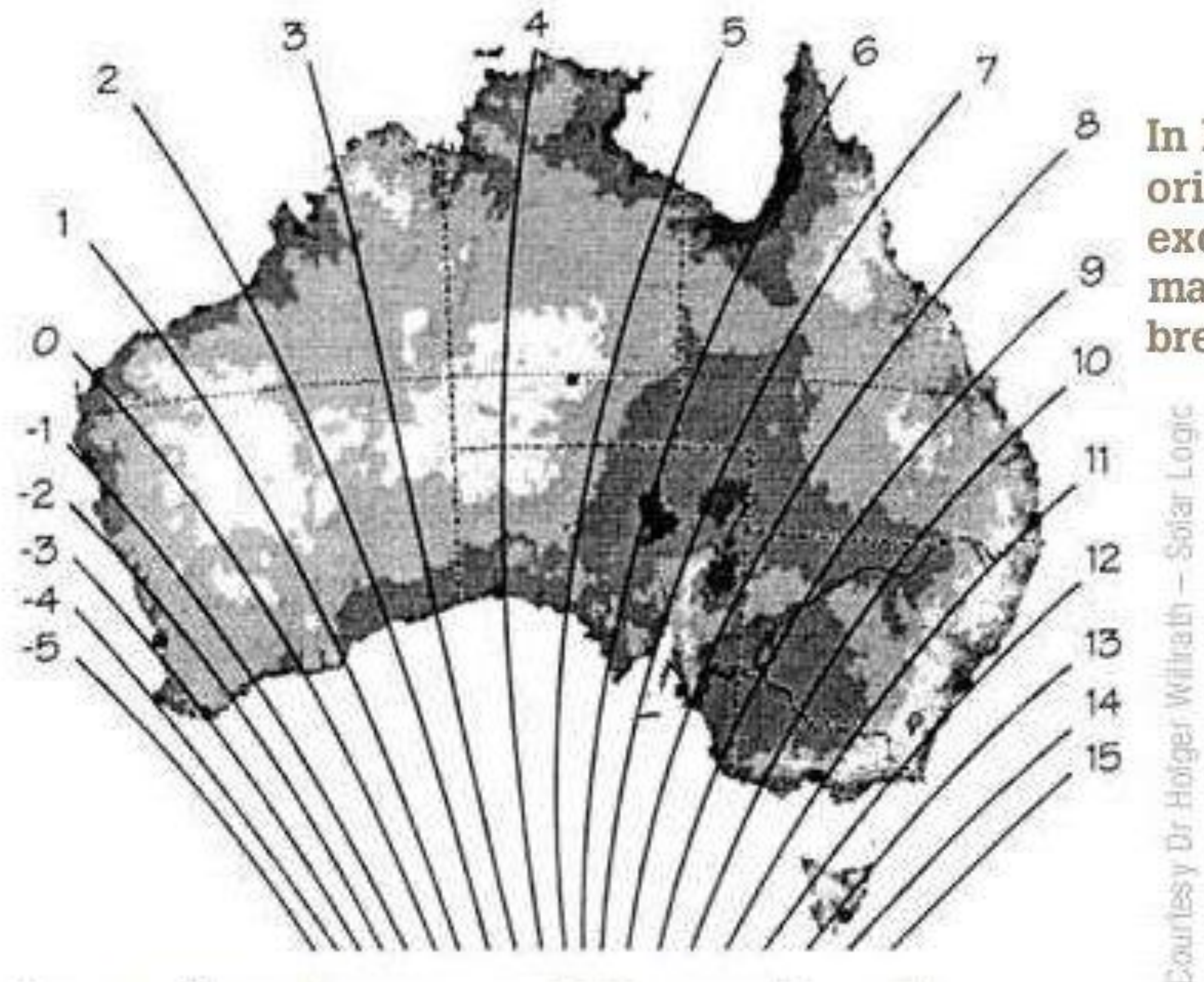


Direct
Diffuse
HEAT LOSS
HEAT GAIN
To: cooler air, contact with cooler objects, and by evaporation
From: warmer air, contact with warmer objects and radiant heaters

ORIENTATION FOR PASSIVE HEATING



- > Temperature ranges- both seasonal and diurnal.
- > Humidity ranges.
- > Direction of cooling breezes, hot winds, cold winds, wet winds.
- > Seasonal characteristics.
- > Impact of local geographic features on climatic conditions. [See: 2.2 Choosing a Site]



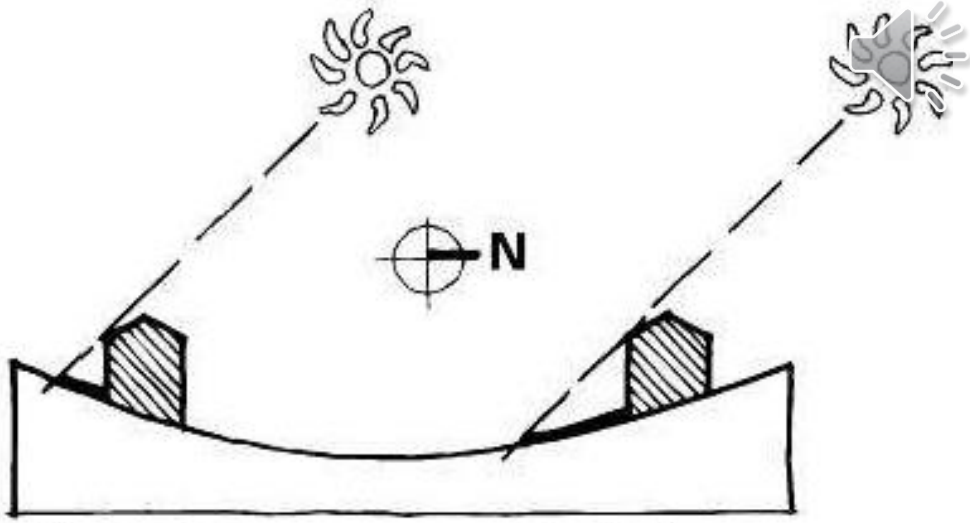
True north as degrees west of magnetic north.

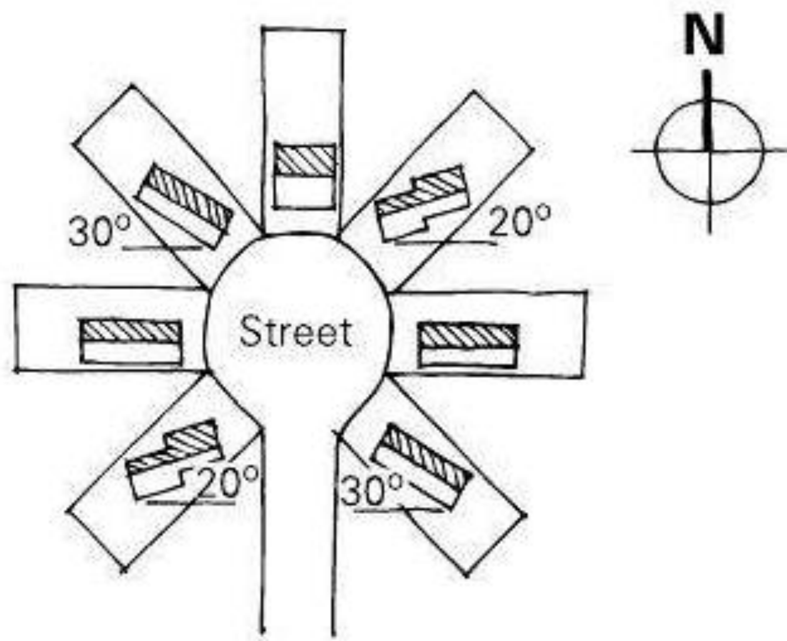
In high humid climates, orientation should aim to exclude sun year round and maximise access to cooling breezes.

The site

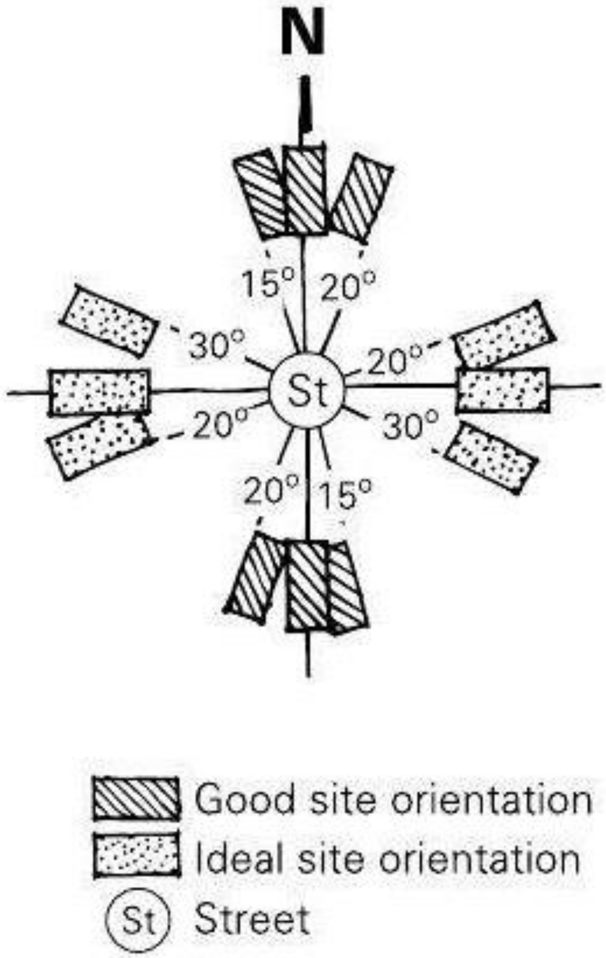
You can achieve good passive solar performance at minimal cost if your site has the right characteristics. Where possible, choose a site that can accommodate north-facing daytime living areas and outdoor spaces.

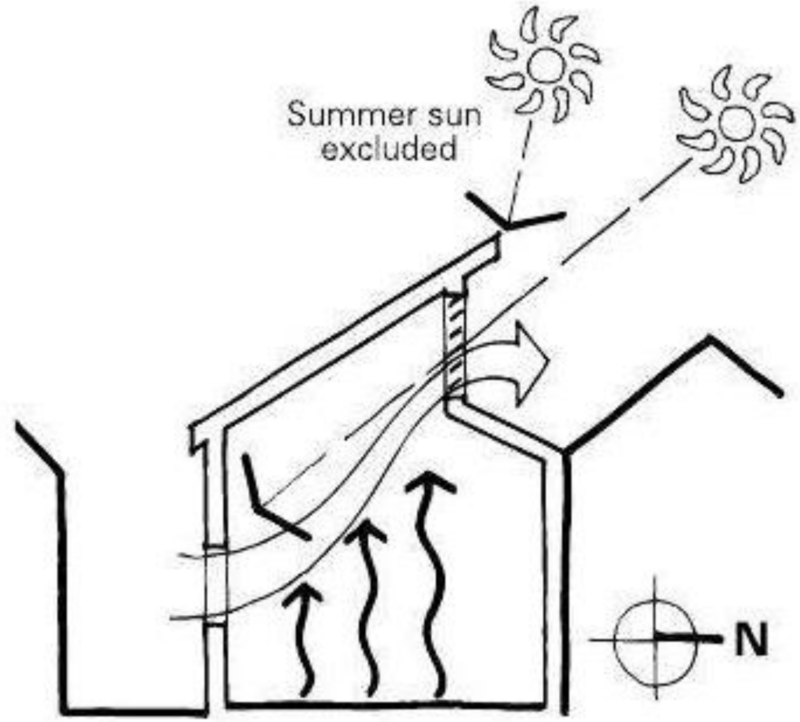
[See: 2.2 Choosing a Site]



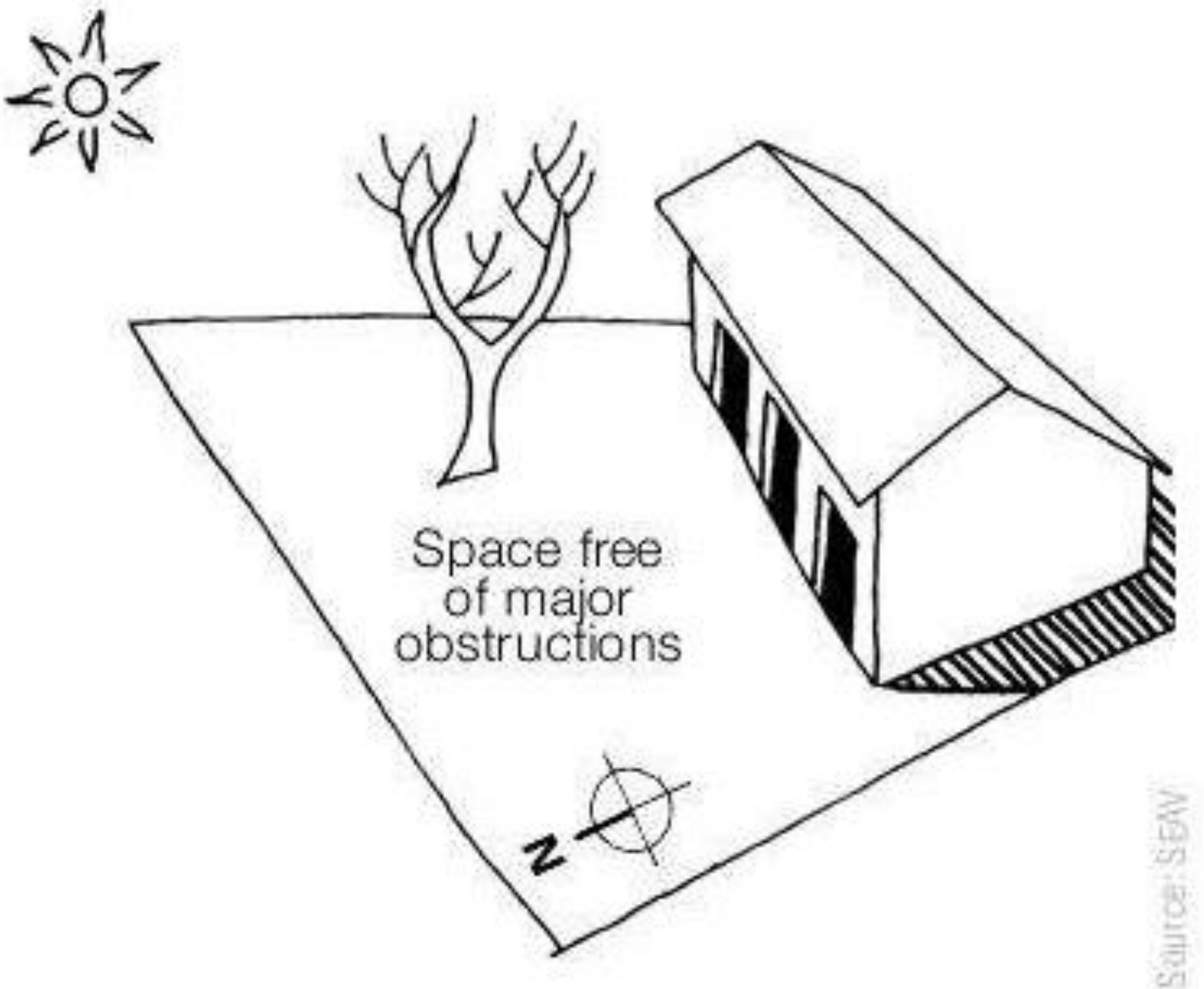


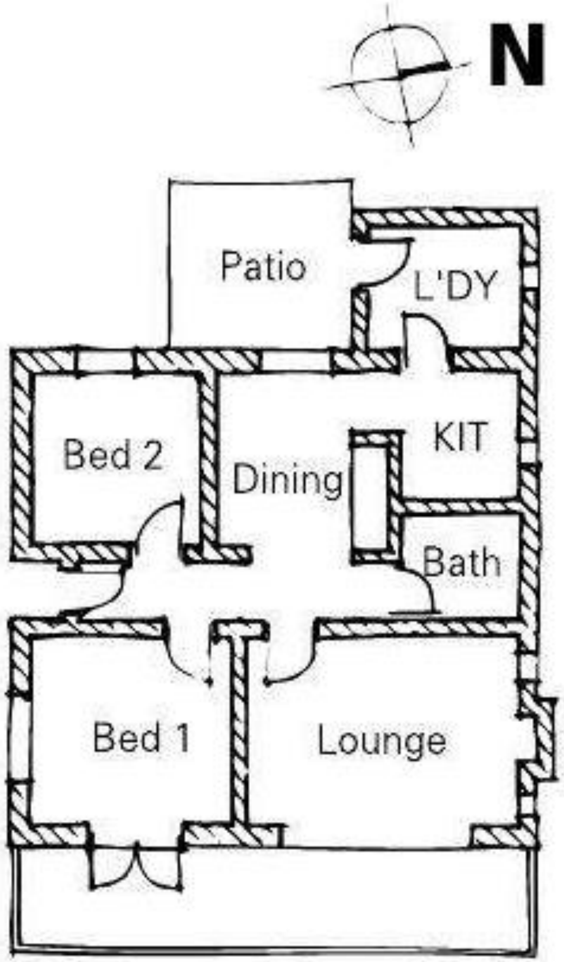
Day time living areas shown shaded.



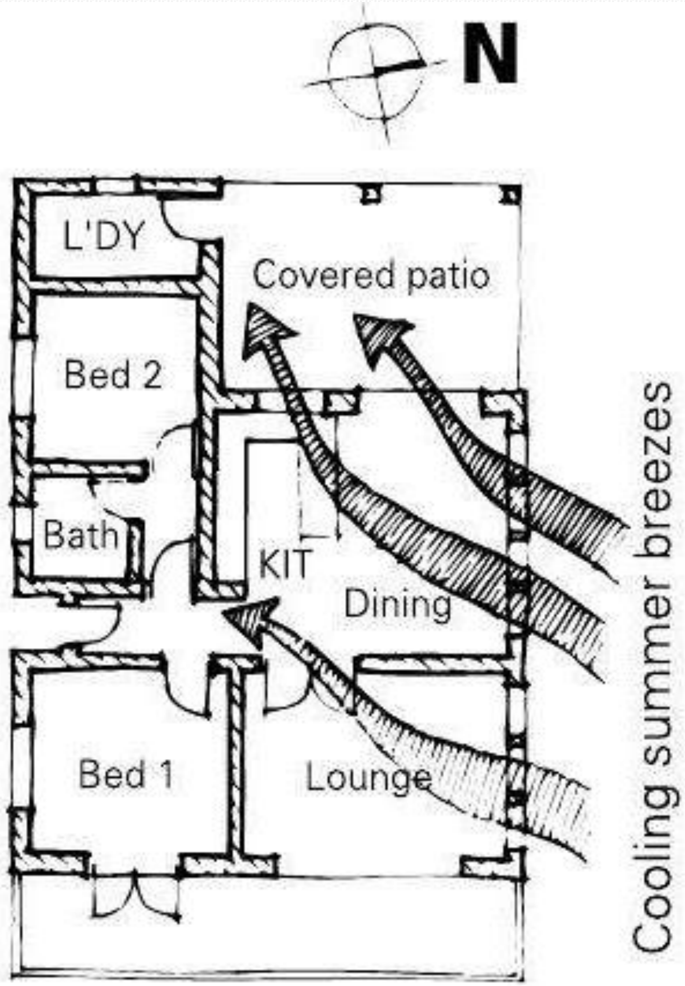


High level openable windows capture winter sun and create cooling currents in summer.

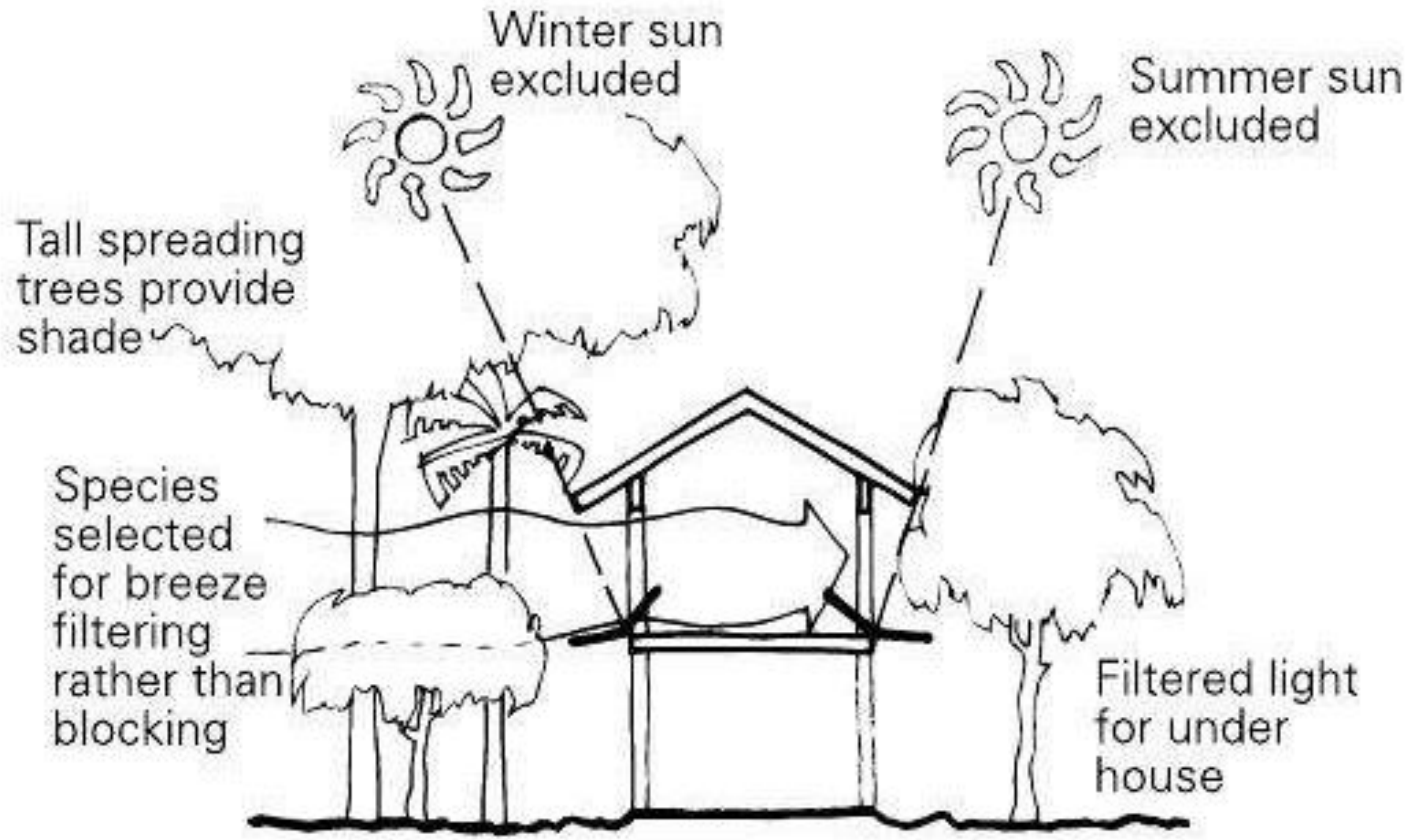

Space free
of major
obstructions
N
Source: SBW



Original floor plan.

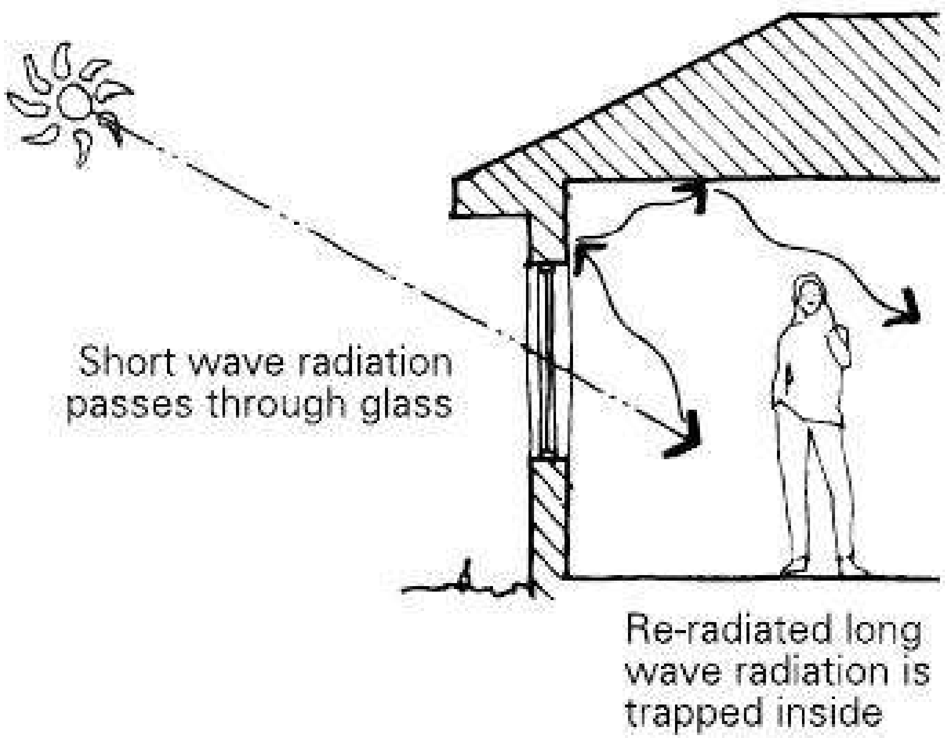


New floor plan.

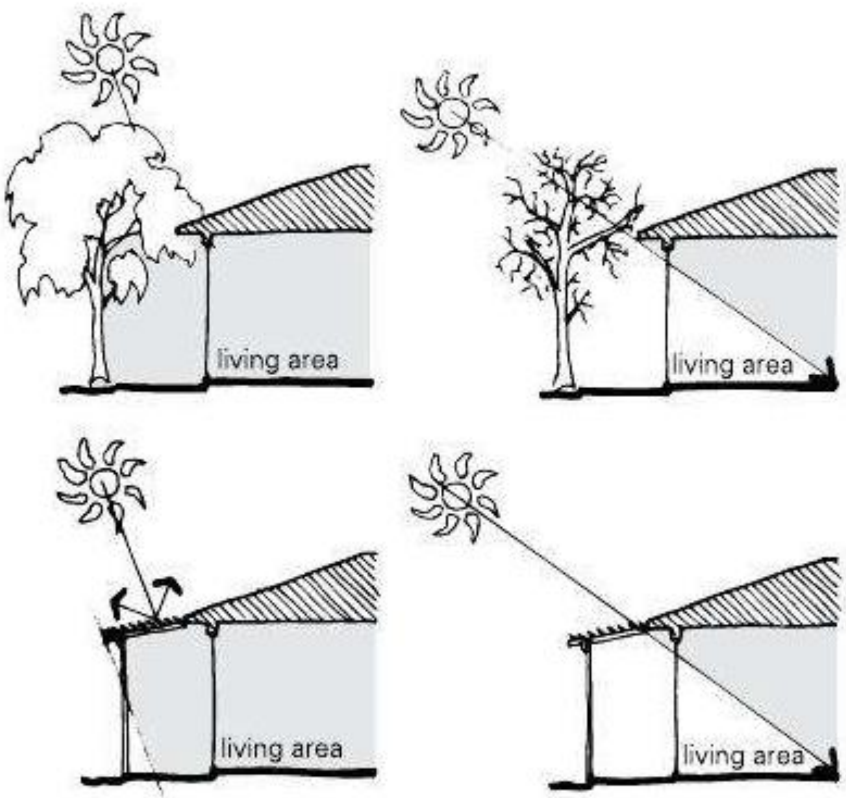

Winter sun
excluded
Summer sun
excluded
Tall spreading
trees provide
shade
Species
selected
for breeze
filtering
rather than
blocking
Filtered light
for under
house

Shading of the building and outdoor spaces reduces summer temperatures, improves comfort and saves energy. Direct sun can generate the same heat as a single bar radiator over each square metre of a surface. Shading can block up to 90 per cent of this heat.

Shading of glass to reduce unwanted heat gain is critical. Unprotected glass is often the greatest source of unwanted heat gain in a home.



ORIENTATION	SUGGESTED SHADING TYPE
NORTH	fixed or adjustable shading placed horizontally above window
EAST and WEST	adjustable vertical screens outside window
NE and NW	adjustable shading
SE and SW	planting



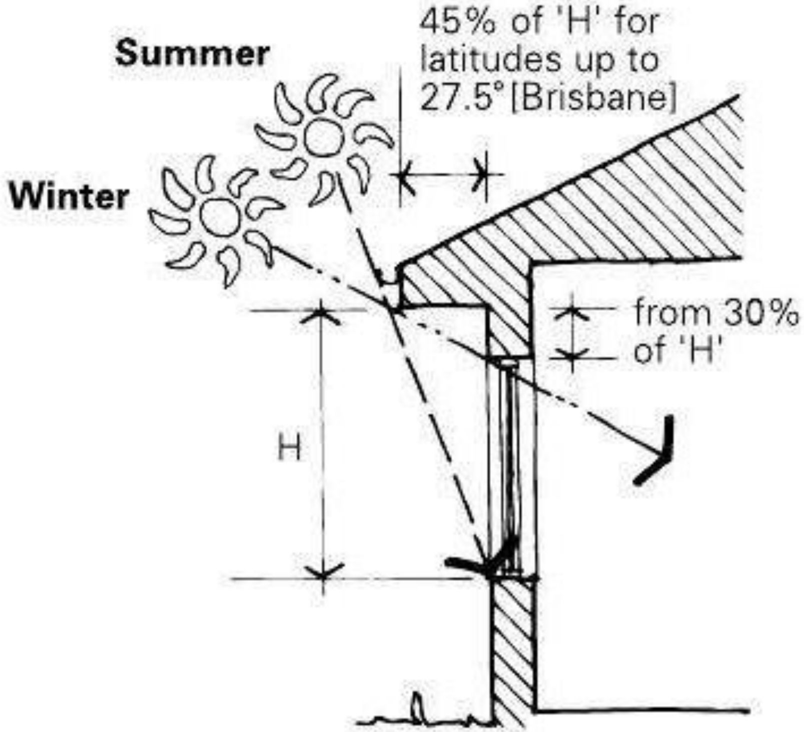
GENERAL GUIDELINES FOR ALL CLIMATES

Use external shading devices over openings. Lighter-coloured shading devices reflect more heat. Internal shading will not prevent heat gain unless it is reflective.

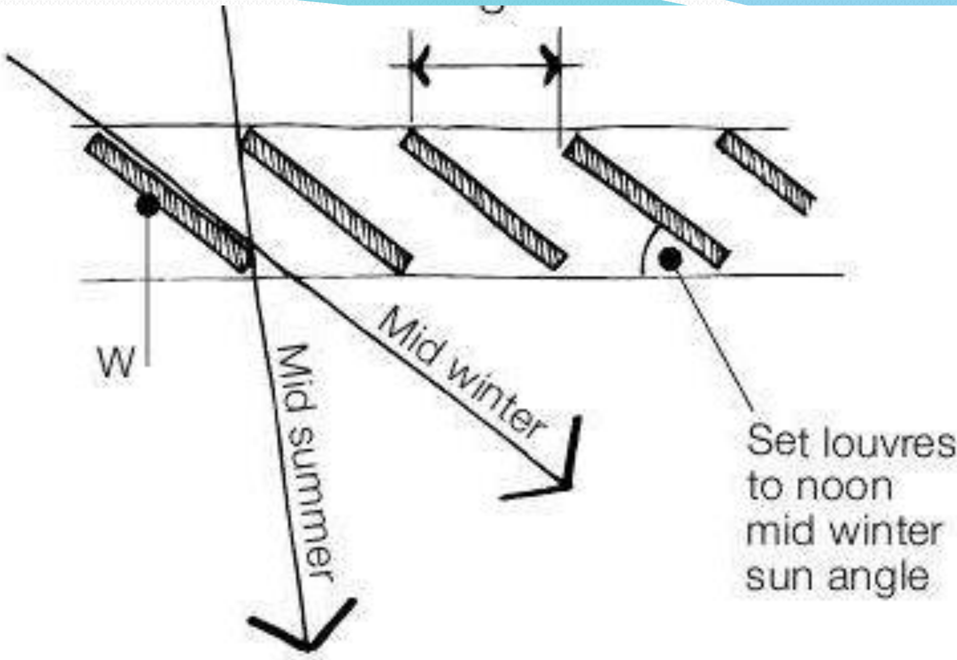
Use plants to shade the building, particularly windows, to reduce unwanted glare and heat gain. Evergreen plants are recommended for high humid and some hot dry climates. For all other climates use deciduous vines or trees to the north, and deciduous or evergreen trees to the east and west.

Eaves

Correctly designed eaves are generally the simplest and least expensive shading method for northern elevations, and are all that is required on most single storey houses.



Rule of thumb for latitude south of and including 27.5ºS.



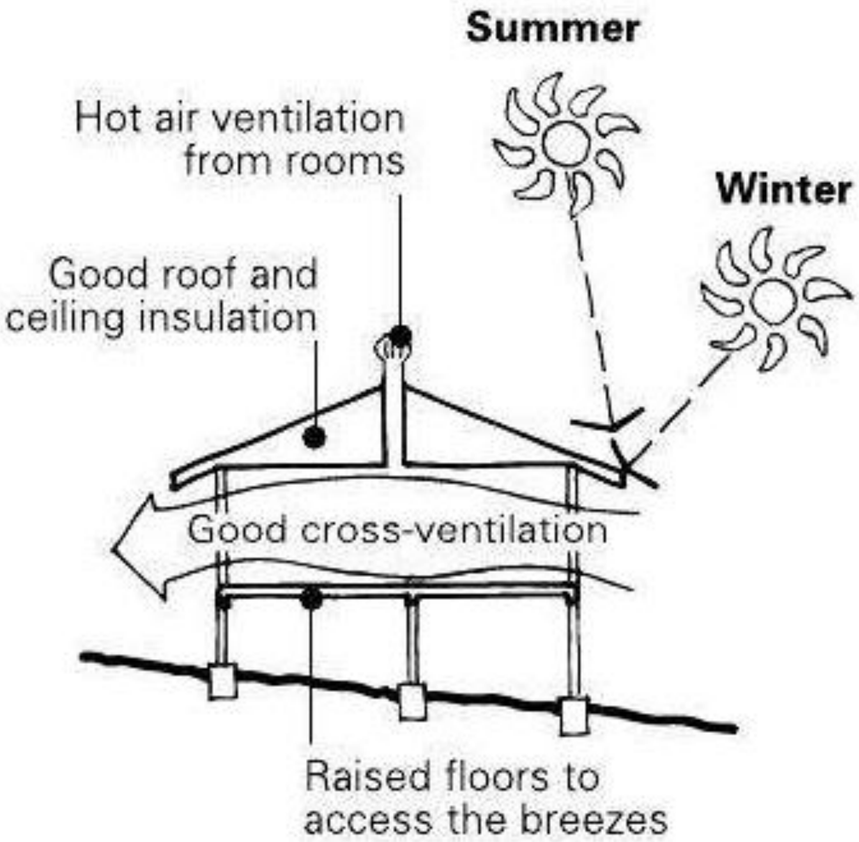
ANGLES OF LOUVRES TO THE HORIZONTAL	
Hobart	24°
Melbourne	29°
Sydney, Canberra, Adelaide	31°
Perth, Broken Hill, Port Augusta	34°
Brisbane, Geraldton	38°

High humid climates

> Shade all external openings and walls including those facing south.

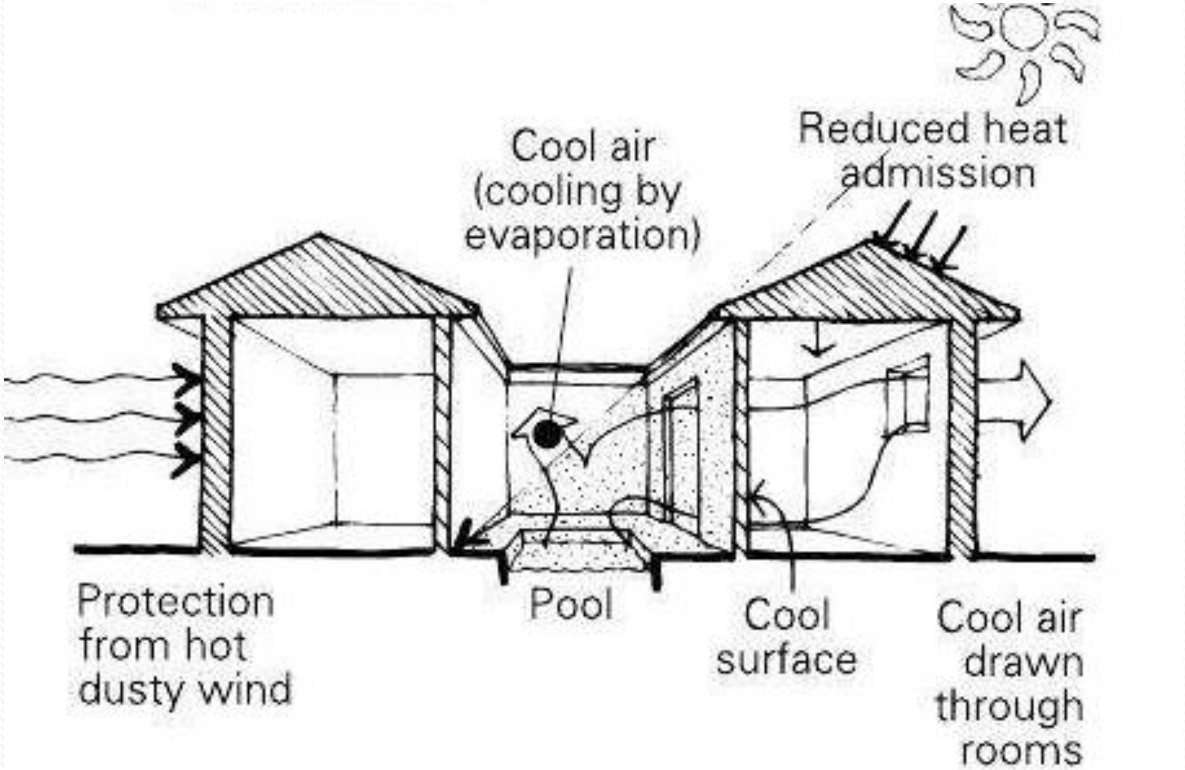
> Use covered outdoor living areas such as verandahs and deep balconies to shade and cool incoming air.

> Use shaded skylights to compensate for any resultant loss of natural daylight.



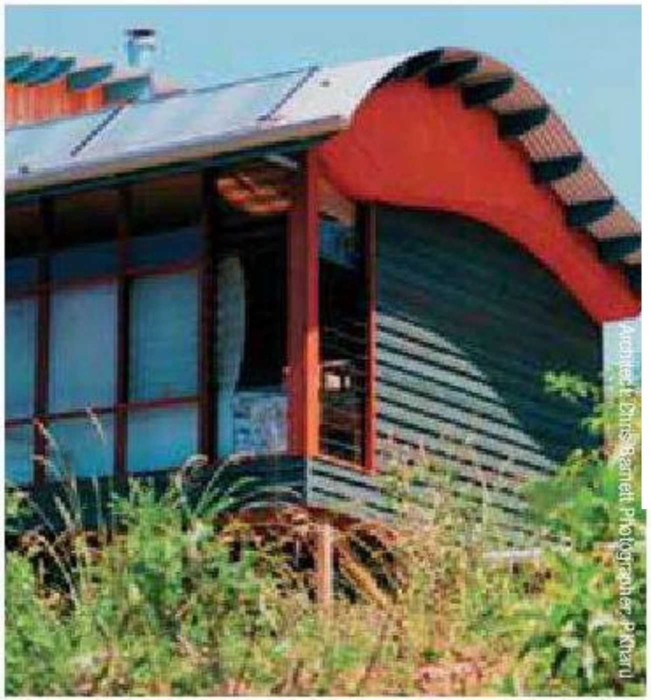
Hot dry climates

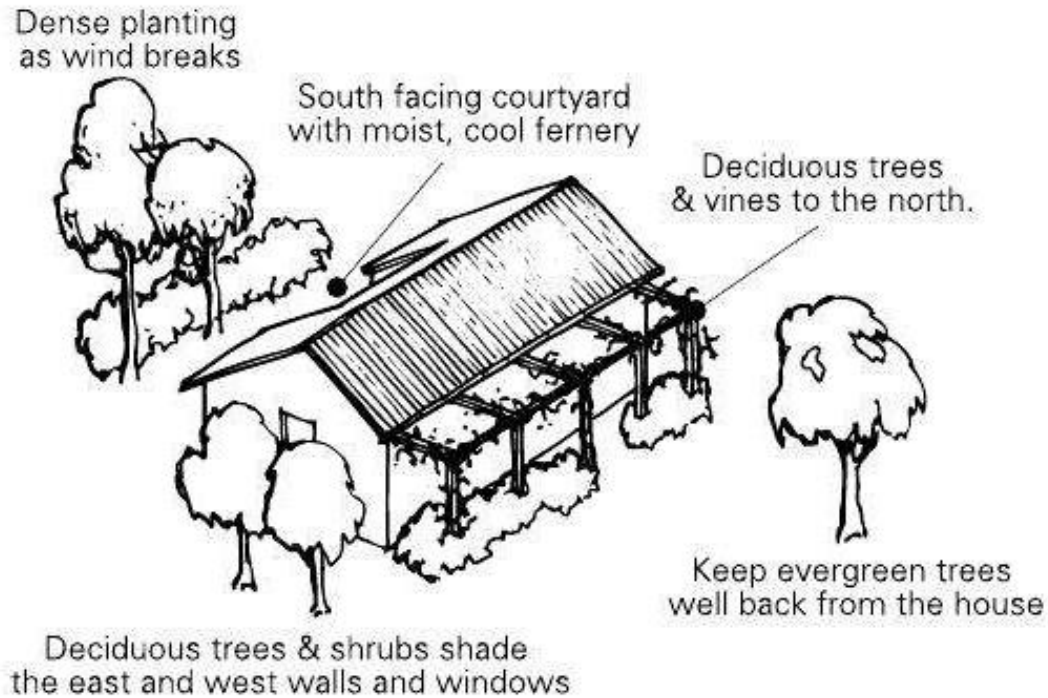
- > Shade all external openings in regions where no winter heating is required.
- > Provide passive solar shading to north facing openings in regions where winter heating is required.



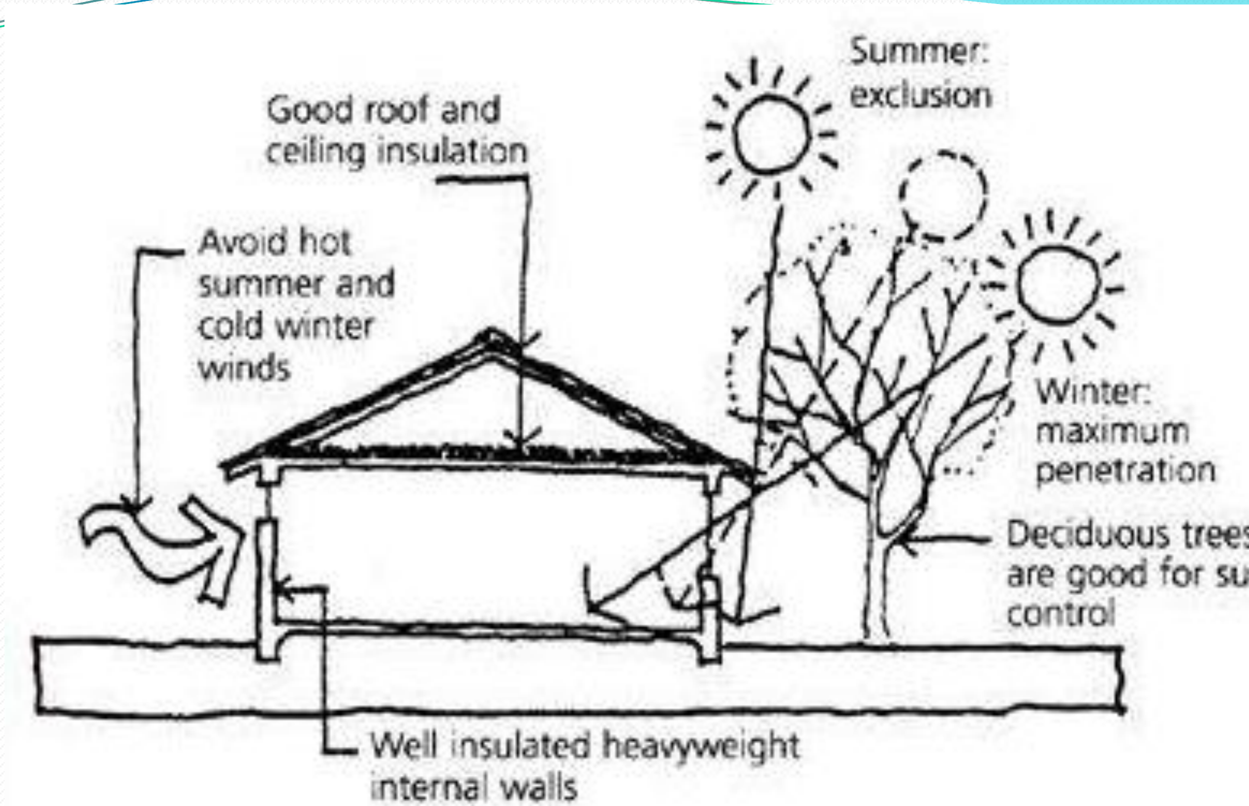
Warm humid and warm/mild temperate climates

> Provide passive solar shading to all north facing openings, using shade structures or correctly sized eaves.





WHAT IS PASSIVE SOLAR HEATING?



> Northerly orientation of daytime living areas.

> Appropriate areas of glass on northern facades.

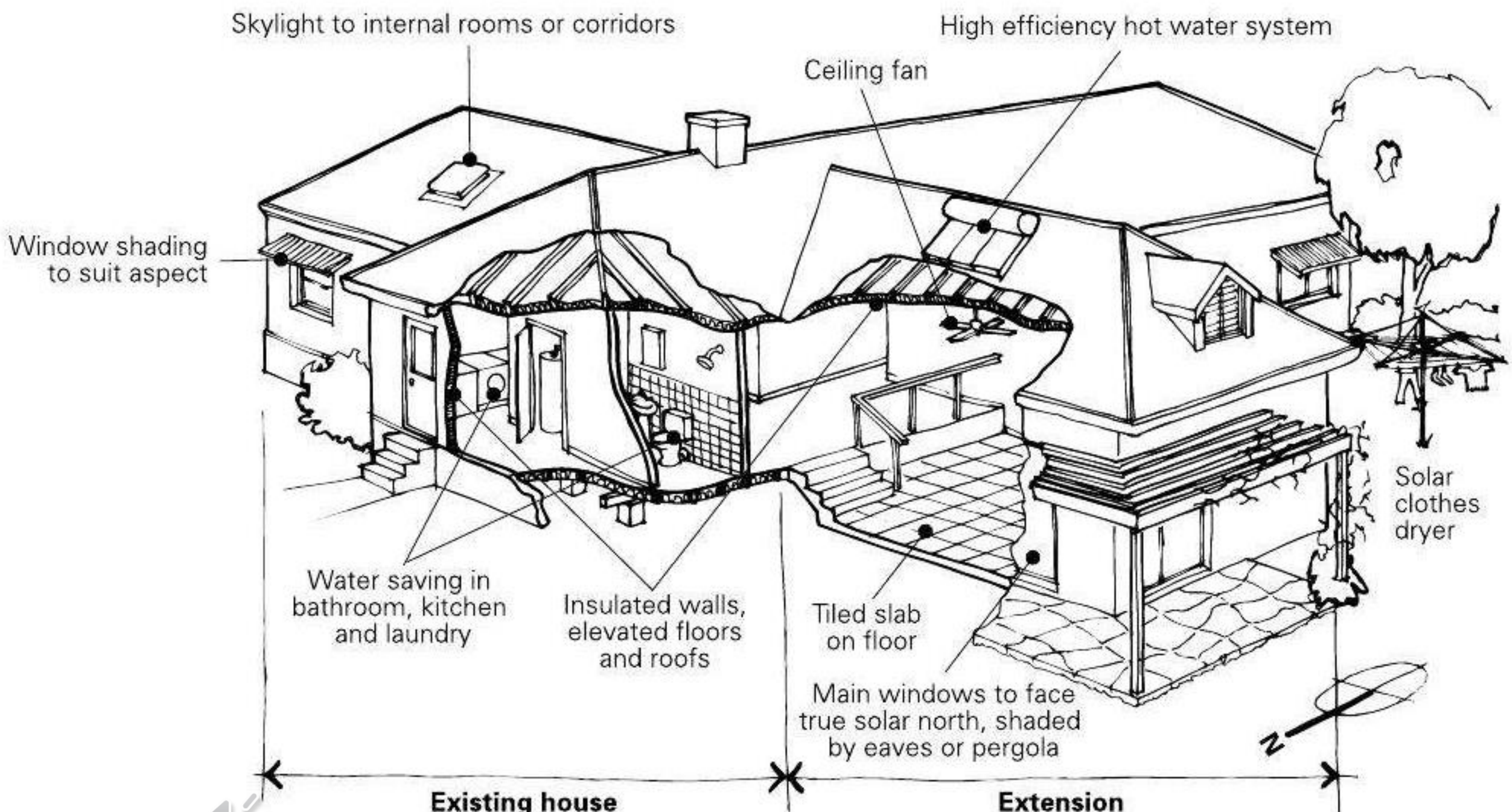
> Passive shading of glass.

> Thermal mass for storing heat.

> Insulation and draught sealing.

> Floor plan zoning based on heating needs.

> Advanced glazing solutions.


Skylight to internal rooms or corridors
High efficiency hot water system
Ceiling fan
Window shading
to suit aspect
Solar
clothes
dryer
Water saving in
bathroom, kitchen
and laundry
Insulated walls,
elevated floors
and roofs
Tiled slab
on floor
Main windows to face
true solar north, shaded
by eaves or pergola
N
Existing house
Extension

Passive Cooling

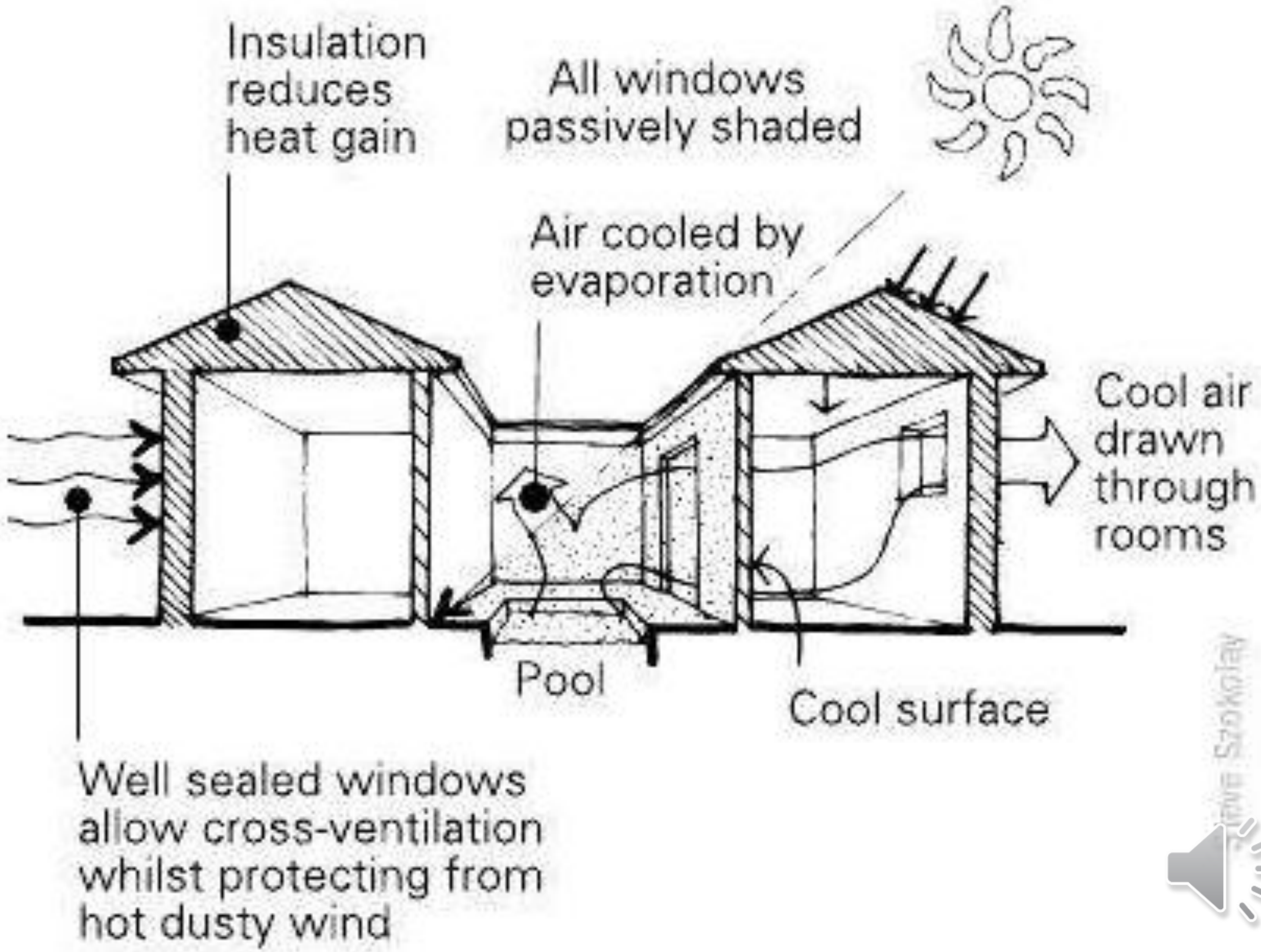
Passive cooling maximises the efficiency of the building envelope by minimising heat gain from the external environment and facilitating heat loss to the following natural sources of cooling:

> Air movement.

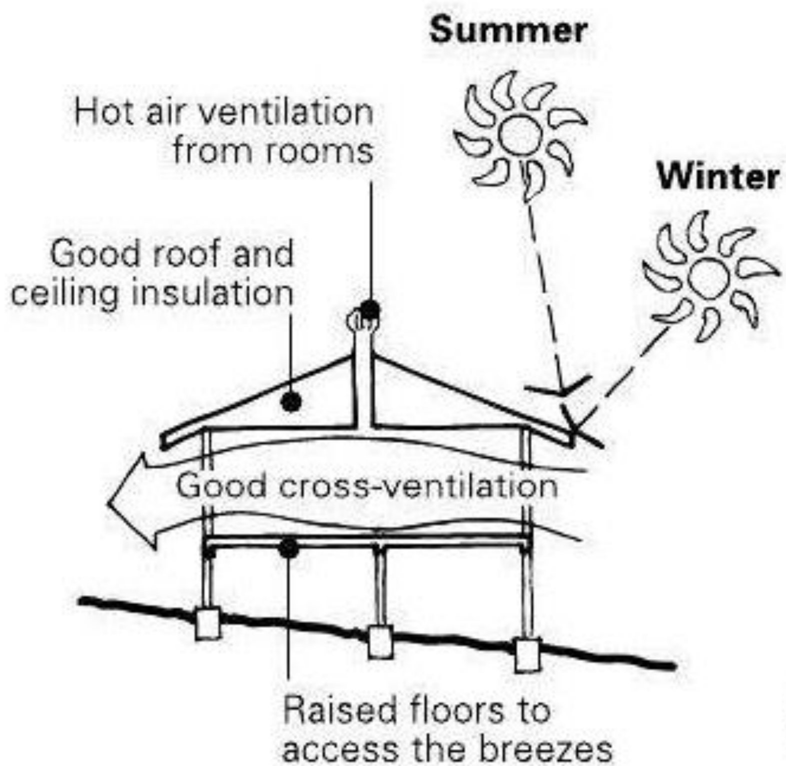
> Cooling breezes.

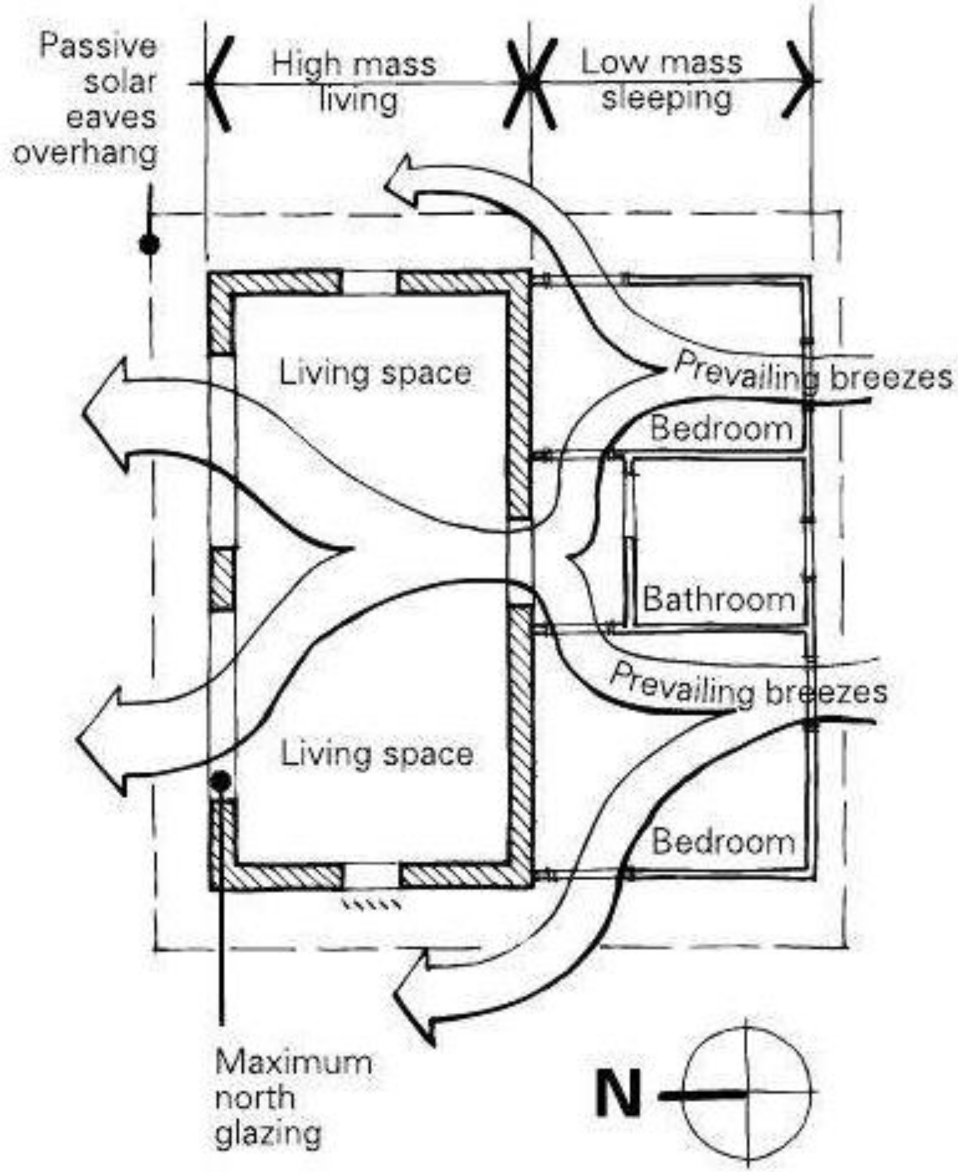
> Evaporation.

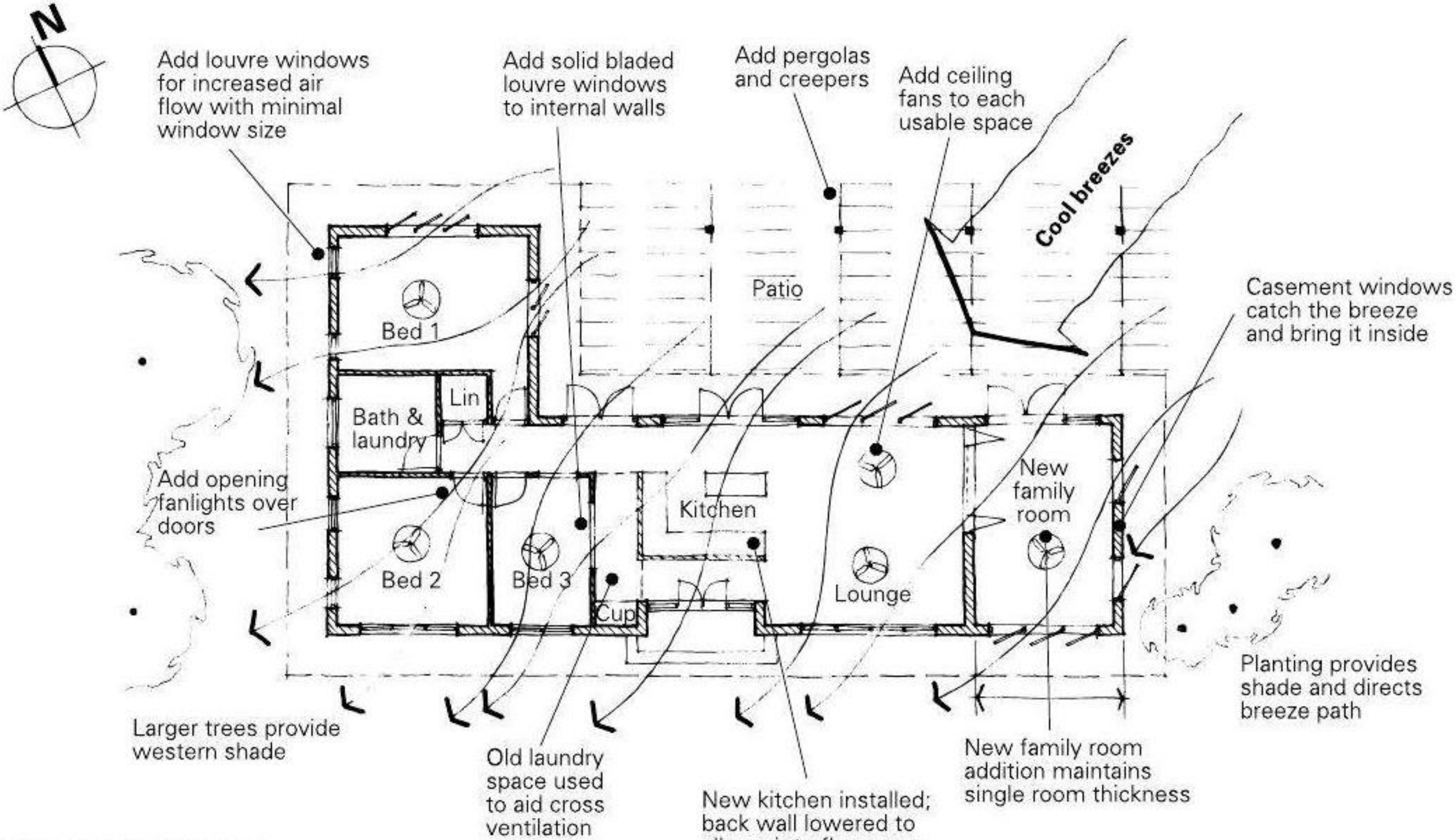
> Earth coupling.



Courtyard design with evaporative cooling pond.


Summer
Hot air ventilation from rooms
Winter
Good roof and ceiling insulation
Good cross-ventilation
Raised floors to access the breezes


Passive solar eaves overhang
High mass living
Low mass sleeping
Living space
Prevailing breezes
Bedroom
Bathroom
Prevailing breezes
Living space
Bedroom
Maximum north glazing
N



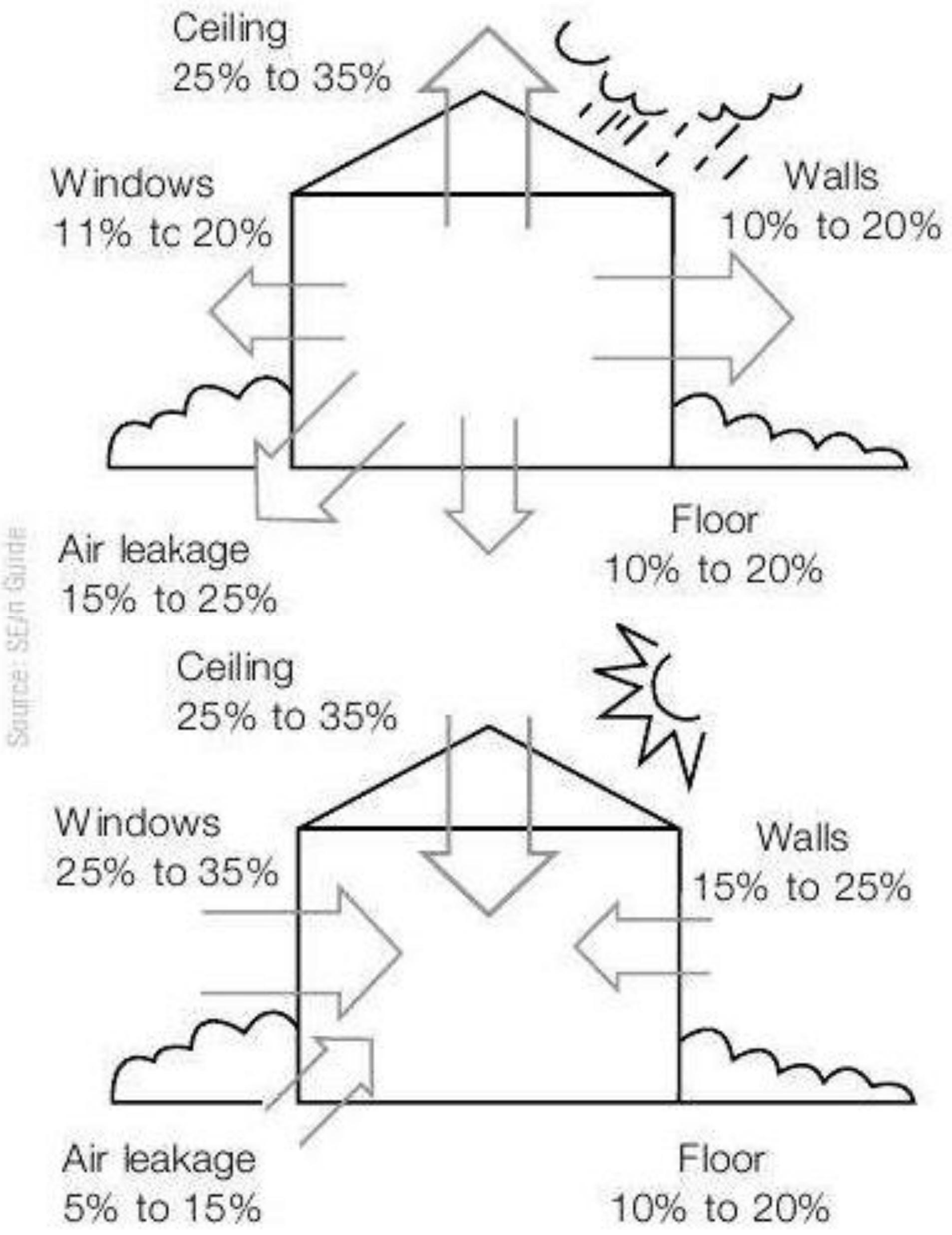
Renovation ideas for a tropical house.

Insulation

Insulation acts as a barrier to heat flow and is essential to keep your home warm in winter and cool in summer. A well insulated and well designed home will provide year-round comfort, cutting cooling and heating bills by up to half. This, in turn, will reduce greenhouse gas emissions.

Check the information supplied on the product, including the R-value, the price per square metre and whether it must be installed professionally or can be DIY – some types of insulation require the use of masks and protective clothing. Ensure that it suits your particular application and will fit within the space available. Ask if performance guarantees or test certificates are available.

- **Up R-values** describe resistance to heat flow upwards (sometimes known as 'winter' R-values).
- **Down R-values** describe resistance to heat flow downwards (sometimes known as 'summer' R-values).



Typical heat gains and losses in a temperate climate.

WHERE TO INSTALL INSULATION

Roofs and ceilings work in conjunction when it comes to insulation.

> Install insulation under the roofing material to reduce radiant heat gain.

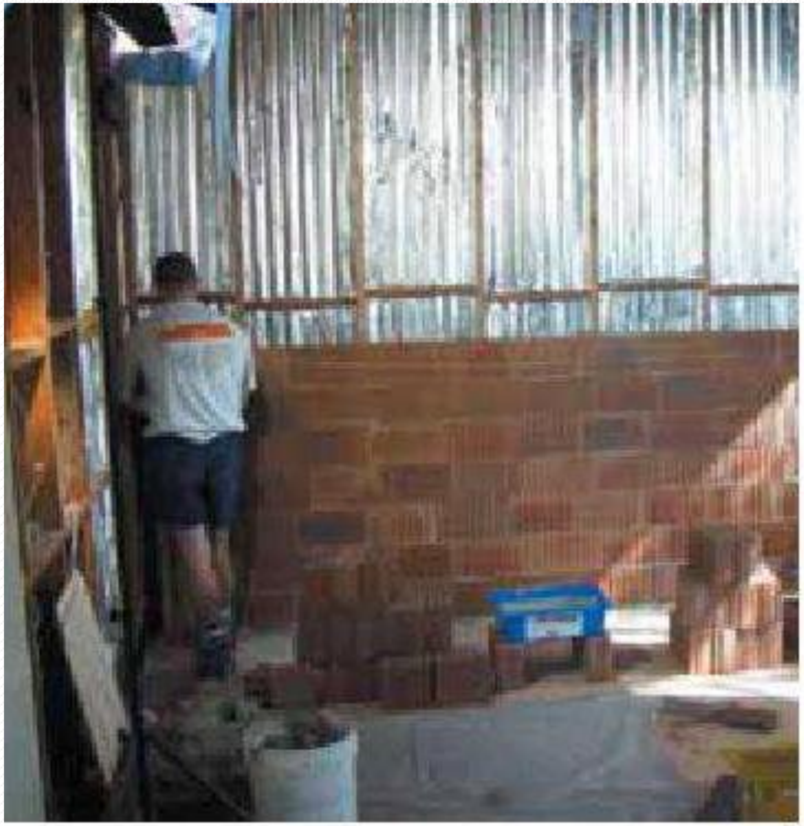
> Install insulation in the ceiling to reduce heat gain and loss. In most cases ceiling insulation is installed between the joists.

[See: 4.8 Insulation Installation]

Walls

Most walls will benefit from added insulation, and it is possible to add insulation to most construction types used in Australia. Autoclaved aerated concrete (AAC) already has a reasonable degree of insulation built into the blocks themselves, and straw bale is an extremely highly insulated system.

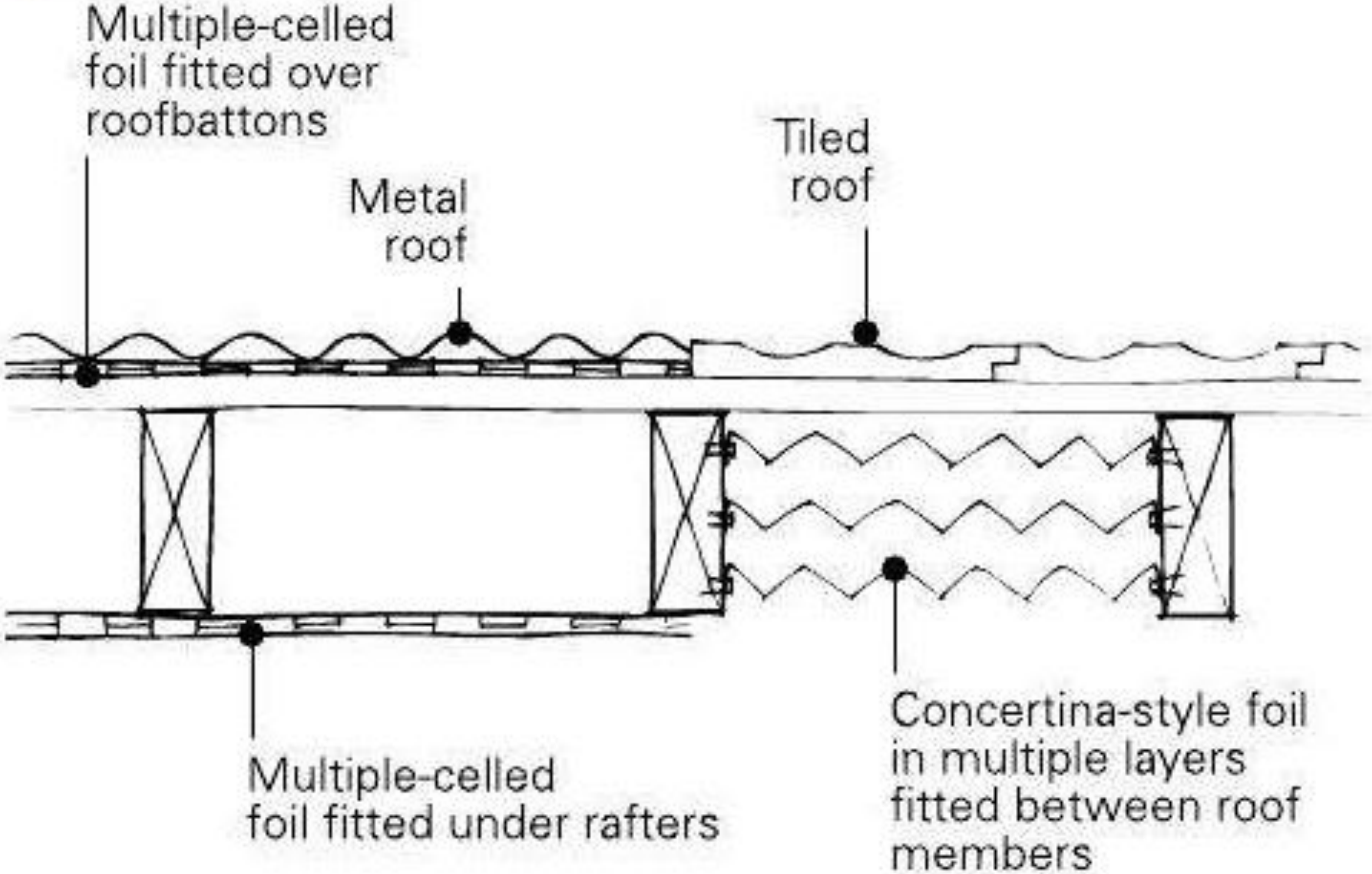
Brick veneer, reverse brick veneer and timber framed walls



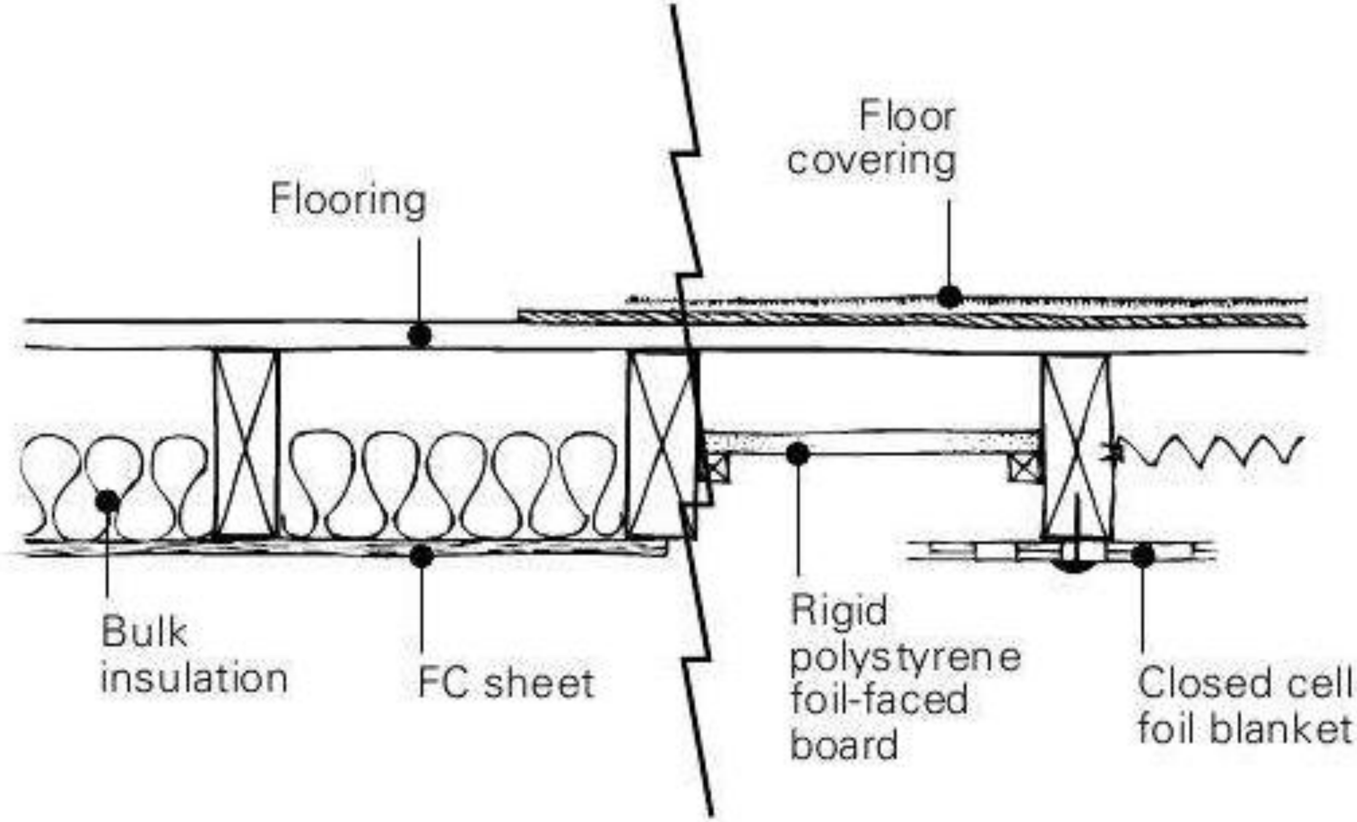
Cavity Brick Walls

Cavity brick walls have high thermal mass, but without insulation are usually too cold in winter, and often too hot in summer if exposed to prolonged heat wave conditions. If the cavity is insulated, the internal thermal mass (ie. the internal brick skin) is protected from external temperature changes, and becomes highly effective at regulating temperatures within the home.

Roof


Multiple-celled
foil fitted over
roofbattons
Metal
roof
Tiled
roof
Multiple-celled
foil fitted under rafters
Concertina-style foil
in multiple layers
fitted between roof
members

Floor

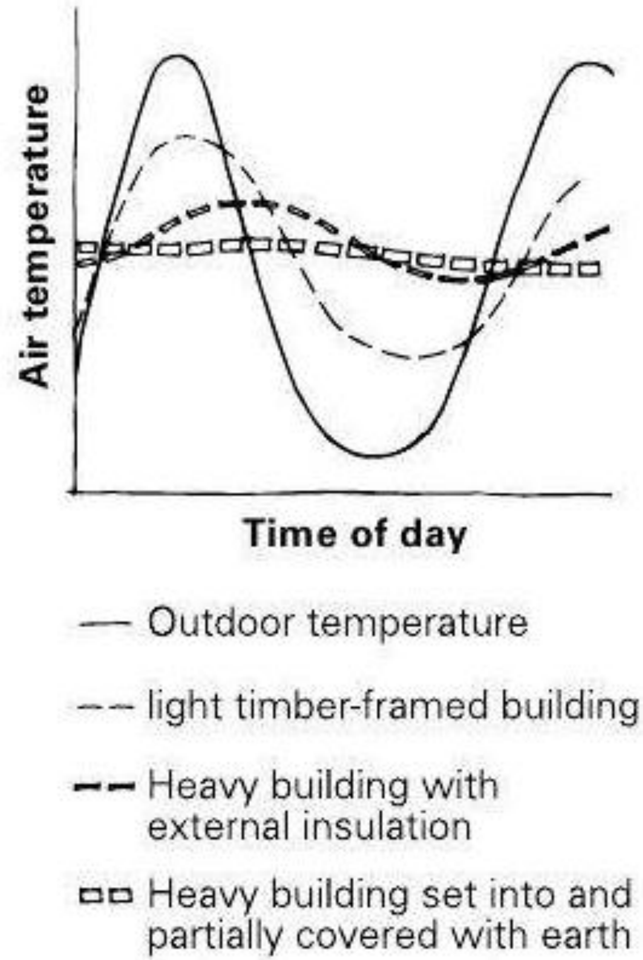


Exposed subfloor (Pole home).

Enclosed or ventilated subfloor (brick, brick veneer, timber frame).

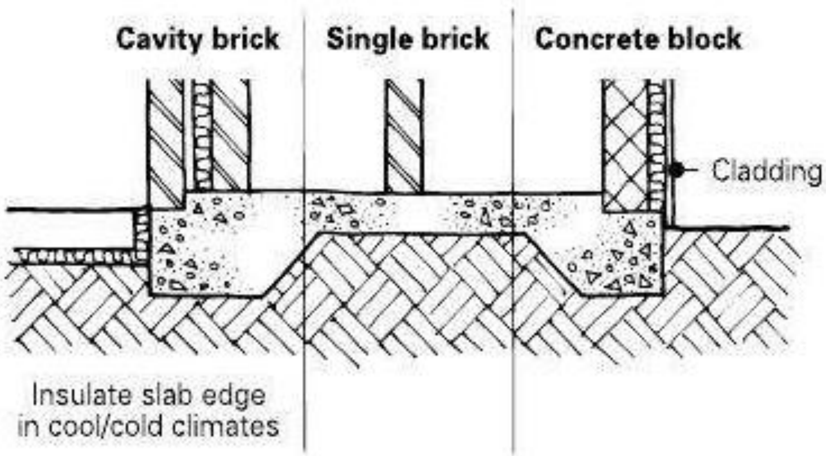
Thermal Mass

Thermal mass is the ability of a material to absorb heat energy. A lot of heat energy is required to change the temperature of high density materials like concrete, bricks and tiles. They are therefore said to have high thermal mass. Lightweight materials, such as, timber have low thermal mass. Appropriate use of thermal mass throughout your home can make a big difference to comfort and heating and cooling bills. This fact sheet shows you how.

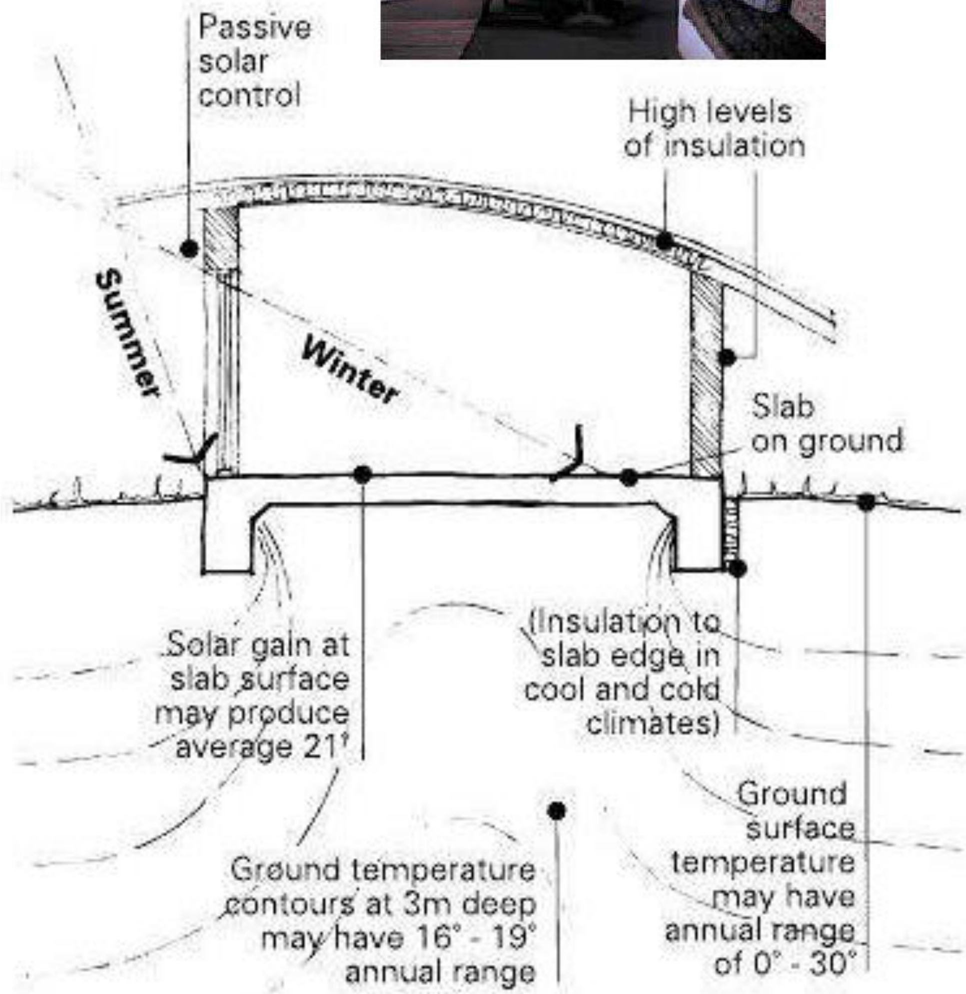


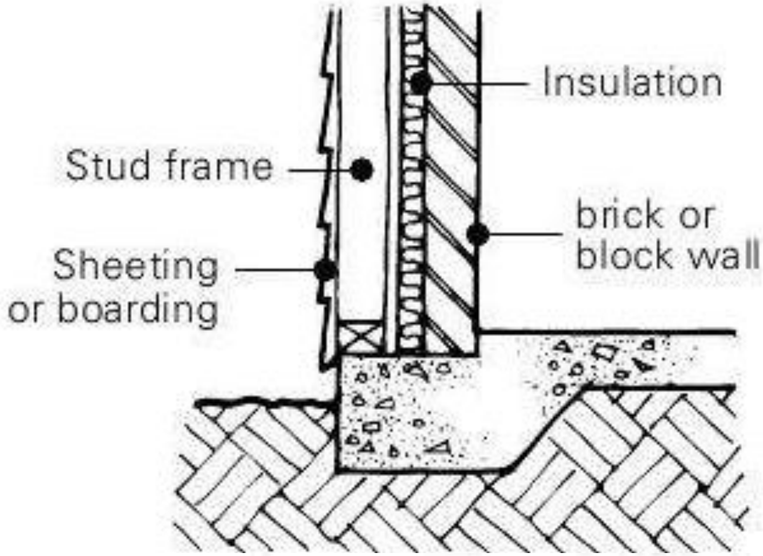
TYPICAL APPLICATIONS

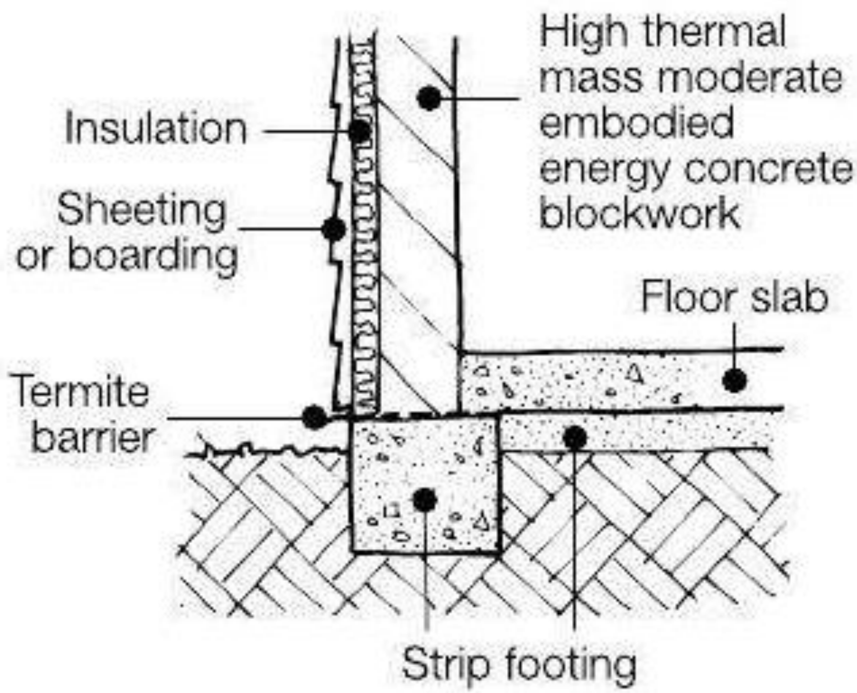
In rooms with good winter solar access it is useful to connect the thermal mass to the earth. The most common example is slab on ground construction. A less commor example is earth-sheltered housing.



Examples of high mass construction.




Insulation
Stud frame
brick or
block wall
Sheeting
or boarding


High thermal
mass moderate
embodied
energy concrete
blockwork
Insulation
Sheeting
or boarding
Floor slab
Termite
barrier
Strip footing

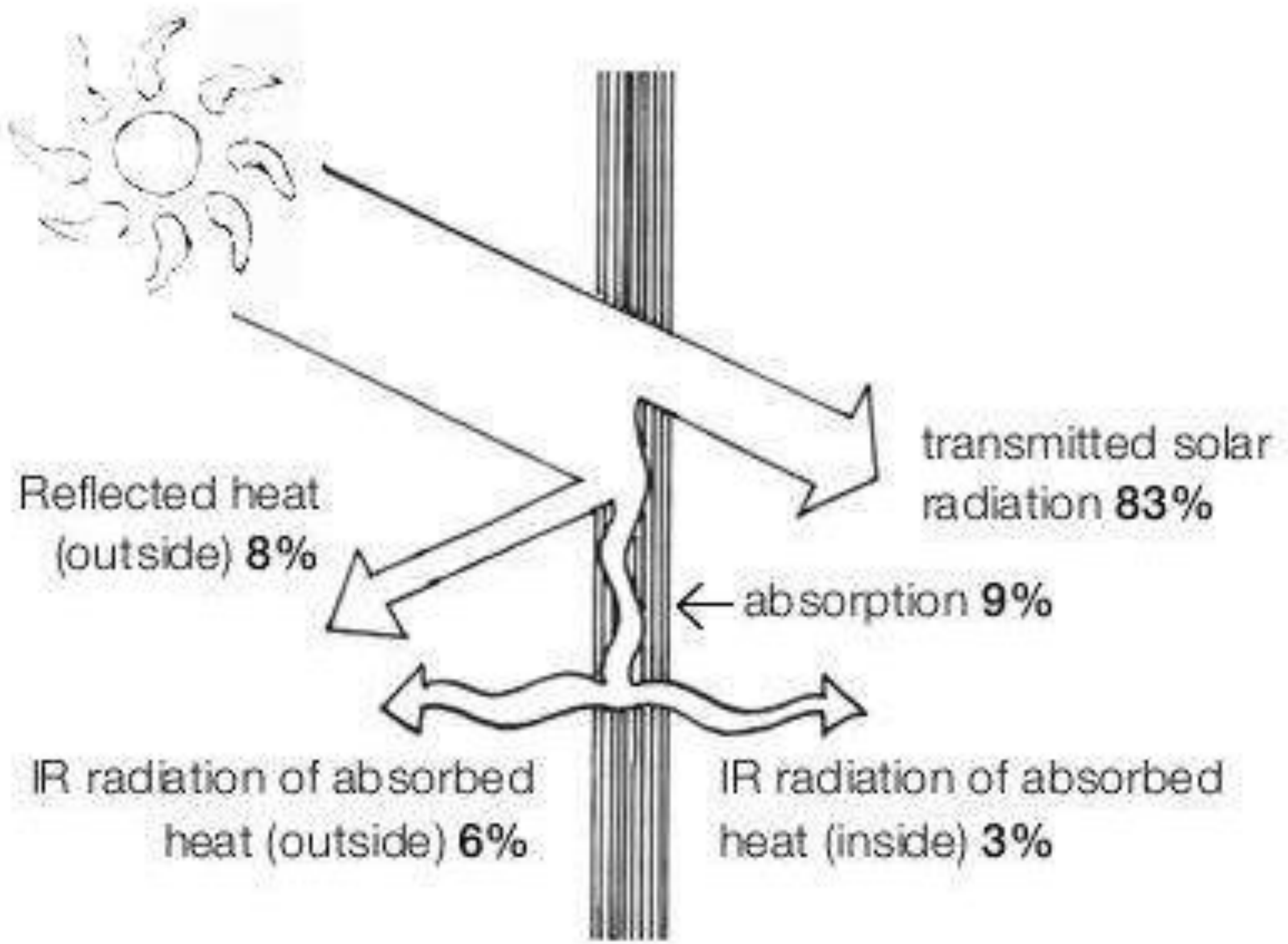
Glazing

Glazing has a major impact on the energy efficiency of the building envelope. Poorly designed windows, skylights and glazed surfaces can make your home too hot or too cold. If designed correctly, they'll help maintain year-round comfort, reducing or eliminating the need for artificial heating and cooling.

Glazing is a key element of your home's design providing, light, ventilation, noise control and security.

THERMAL COMFORT

Careful choice of glazing system provides major improvements in thermal comfort for people close to windows – especially large windows. Our sense of comfort is not just determined by air temperature. The temperature of surrounding surfaces has a great impact. The objective should be to achieve an inside glass surface temperature as close as possible to the desired room air temperature. This means glass that is neither cold in winter or hot in summer.


transmitted solar radiation 83%
Reflected heat (outside) 8%
absorption 9%
IR radiation of absorbed heat (outside) 6%
IR radiation of absorbed heat (inside) 3%

How much power does a regular car-user consume? Once we know the conversion rates, it's simple arithmetic:

$$\frac{\text{energy used}}{\text{per day}} = \frac{\text{distance travelled per day}}{\text{distance per unit of fuel}} \times \text{energy per unit of fuel.}$$

For the **distance travelled per day**, let's use 50 km (30 miles).

For the **distance per unit of fuel**, also known as the **economy** of the car, let's use 33 miles per UK gallon (taken from an advertisement for a family car):

$$33\,\text{miles per imperial gallon} \simeq 12\,\text{km per litre.}$$

$$8\,\text{kWh per kg} \times 0.8\,\text{kg per litre} \simeq 7\,\text{kWh per litre.}$$

Rather than willfully perpetuate an inaccurate estimate, let's switch to the actual value, for petrol, of 10 kWh per litre.

$$\begin{aligned}\text{energy per day} &= \frac{\text{distance travelled per day}}{\text{distance per unit of fuel}} \times \text{energy per unit of fuel} \\ &= \frac{50\,\text{km/day}}{12\,\text{km/litre}} \times 10\,\text{kWh/litre} \\ &\simeq 40\,\text{kWh/day.}\end{aligned}$$

calorific values	
petrol	10 kWh per litre
diesel	11 kWh per litre

A Boeing 747-400 with 240 000 litres of fuel carries 416 passengers about 8 800 miles (14 200 km). And fuel's calorific value is 10 kWh per litre. (We learned that in Chapter 3.) So the energy cost of one full-distance round-trip on such a plane, if divided equally among the passengers, is

$$\frac{2 \times 240\,000\,\text{litre}}{416\,\text{passengers}} \times 10\,\text{kWh/litre} \simeq 12\,000\,\text{kWh per passenger.}$$

If you make one such trip per year, then your average energy consumption per day is

$$\frac{12\,000\,\text{kWh}}{365\,\text{days}} \simeq 33\,\text{kWh/day.}$$

1. In *short-distance travel* with lots of starting and stopping, the energy mainly goes into speeding up the vehicle and its contents. Key strategies for consuming less in this sort of transportation are therefore to *weigh less*, and to *go further between stops*. Regenerative braking, which captures energy when slowing down, may help too. In addition, it helps to *move slower*, and to *move less*.

2. In *long-distance travel* at steady speed, by train or automobile, most of the energy goes into making air swirl around, because you only have to accelerate the vehicle once. The key strategies for consuming less in this sort of transportation are therefore to *move slower*, and to *move less*, and to *use long, thin vehicles*.

3. In all forms of travel, there's an energy-conversion chain, which takes energy in some sort of fuel and uses some of it to push the vehicle forwards. Inevitably this energy chain has inefficiencies.

A widely quoted statistic says something along the lines of "only *1 percent* of the energy used by a car goes into moving the driver" – the implication being that, surely, by being a bit smarter, we could make cars *100* times more efficient? The answer is yes, almost, but only by applying the principles of vehicle design and vehicle use, listed above, to *extreme* degrees.

One illustration of extreme vehicle design is an eco-car, which has small frontal area and low weight, and – if any records are to be broken – is carefully driven at a low and steady speed. The *Team Crocodile* eco-car (figure 20.2) does 2184 miles per gallon (1.3 kWh per 100 km) at a speed of 15 mph (24 km/h). Weighing 50 kg and shorter in height than a traffic cone, it comfortably accommodates one teenage driver.

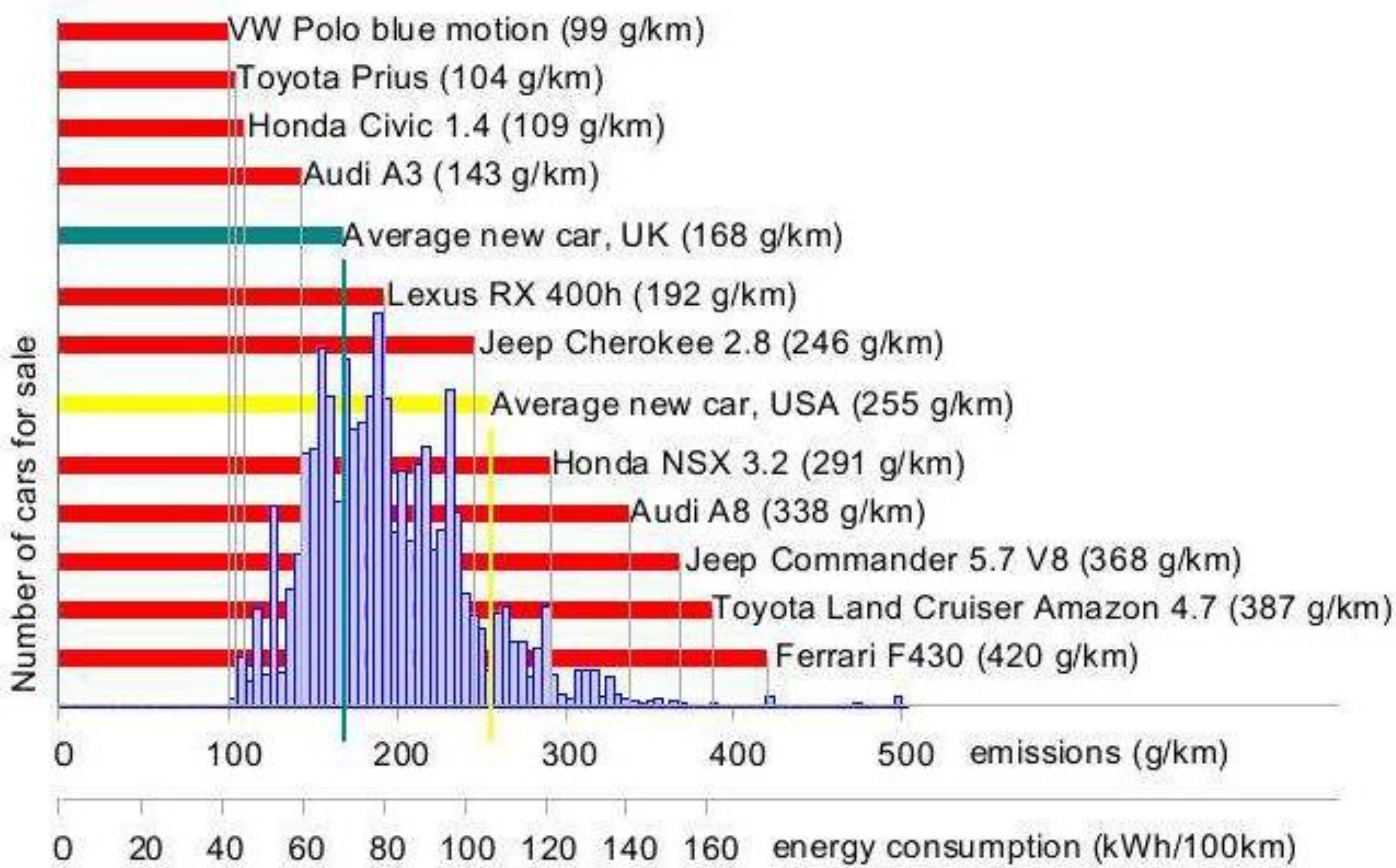
Figure 20.3 shows a multi-passenger vehicle that is at least 25 times more energy-efficient than a standard petrol car: a bicycle. The bicycle's

Figure 20.4 shows another possible replacement for the petrol car: a train, with an energy-cost, if full, of 1.6 kWh per 100 passenger-km. In contrast to the eco-car and the bicycle, trains manage to achieve outstanding efficiency without travelling slowly, and without having a low weight per person. Trains make up for their high speed and heavy frame by exploiting the principle of small frontal area per person. Whereas a cyclist

Figure 20.4. This 8-carriage train, at its maximum speed of 100 mph (161 km/h), consumes 1.6 kWh per 100 passenger-km, if full.

	Energy consumption (kWh per 100 p-km)
Car	68
Bus	19
Rail	6
Air	51
Sea	57

Table 20.8. Overall transport efficiencies of transport modes in Japan (1999).


VW Polo blue motion (99 g/km)
Toyota Prius (104 g/km)
Honda Civic 1.4 (109 g/km)
Audi A3 (143 g/km)
Average new car, UK (168 g/km)
Lexus RX 400h (192 g/km)
Jeep Cherokee 2.8 (246 g/km)
Average new car, USA (255 g/km)
Honda NSX 3.2 (291 g/km)
Audi A8 (338 g/km)
Jeep Commander 5.7 V8 (368 g/km)
Toyota Land Cruiser Amazon 4.7 (387 g/km)
Ferrari F430 (420 g/km)
Number of cars for sale
0 100 200 300 400 500 emissions (g/km)
0 20 40 60 80 100 120 140 160 energy consumption (kWh/100km)

Bikes

My favourite suggestion is the provision of excellent cycle facilities, along with appropriate legislation (lower speed-limits, and collision regulations that favour cyclists, for example). Figure 20.12 shows a roundabout in Enschede, Netherlands. There are two circles: the one for cars lies inside the one for bikes, with a comfortable car's length separating the two. The priority rules are the same as those of a British roundabout, except that cars exiting the central circle must give way to circulating cyclists (just as British cars give way to pedestrians on zebra crossings). Where excellent cycling facilities are provided, people will use them, as evidenced by the infinite number of cycles sitting outside the Enschede railway station (figure 20.13).

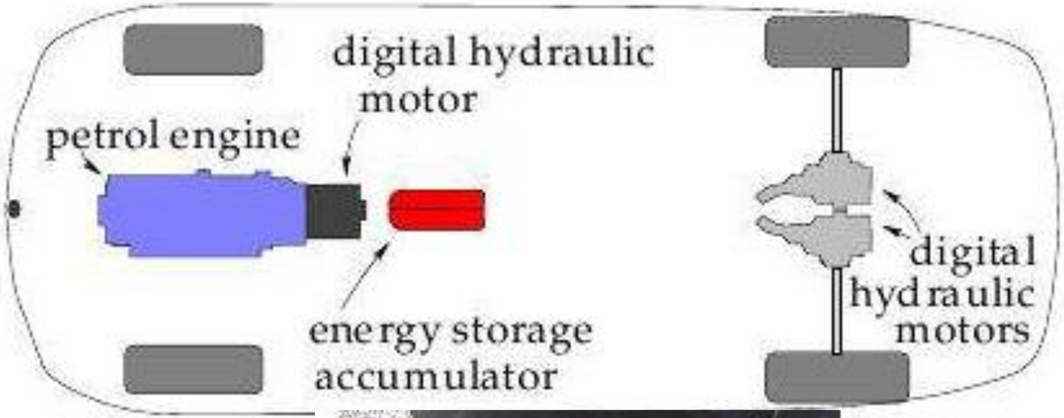


Figure 20.17. A BMW 530i modified by Artemis Intelligent Power to use digital hydraulics. Lower left: A 6-litre accumulator (the red canister), capable of storing about 0.05 kWh of energy in compressed nitrogen.

Lower right: Two 200 kW hydraulic motors, one for each rear wheel, which both accelerate and decelerate the car. The car is still powered by its standard 190 kW petrol engine, but thanks to the digital hydraulic transmission and regenerative braking, it uses 30% less fuel.

Regenerative braking

There are four ways to capture energy as a vehicle slows down.

1. An electric generator coupled to the wheels can charge up an electric battery or supercapacitor.
2. Hydraulic motors driven by the wheels can make compressed air, stored in a small canister.
3. Energy can be stored in a flywheel.
4. Braking energy can be stored as gravitational energy by driving the vehicle up a ramp whenever you want to slow down. This gravitational energy storage option is rather inflexible, since there must be a ramp in the right place. It's an option that's most useful for trains, and it is illustrated by the London Underground's Victoria line, which has hump-back stations. Each station is at the top of a hill in the track. Arriving trains are automatically slowed down by the hill, and departing trains are accelerated as they go down the far side of the hill. The hump-back-station design provides an energy saving of 5% and makes the trains run 9% faster.

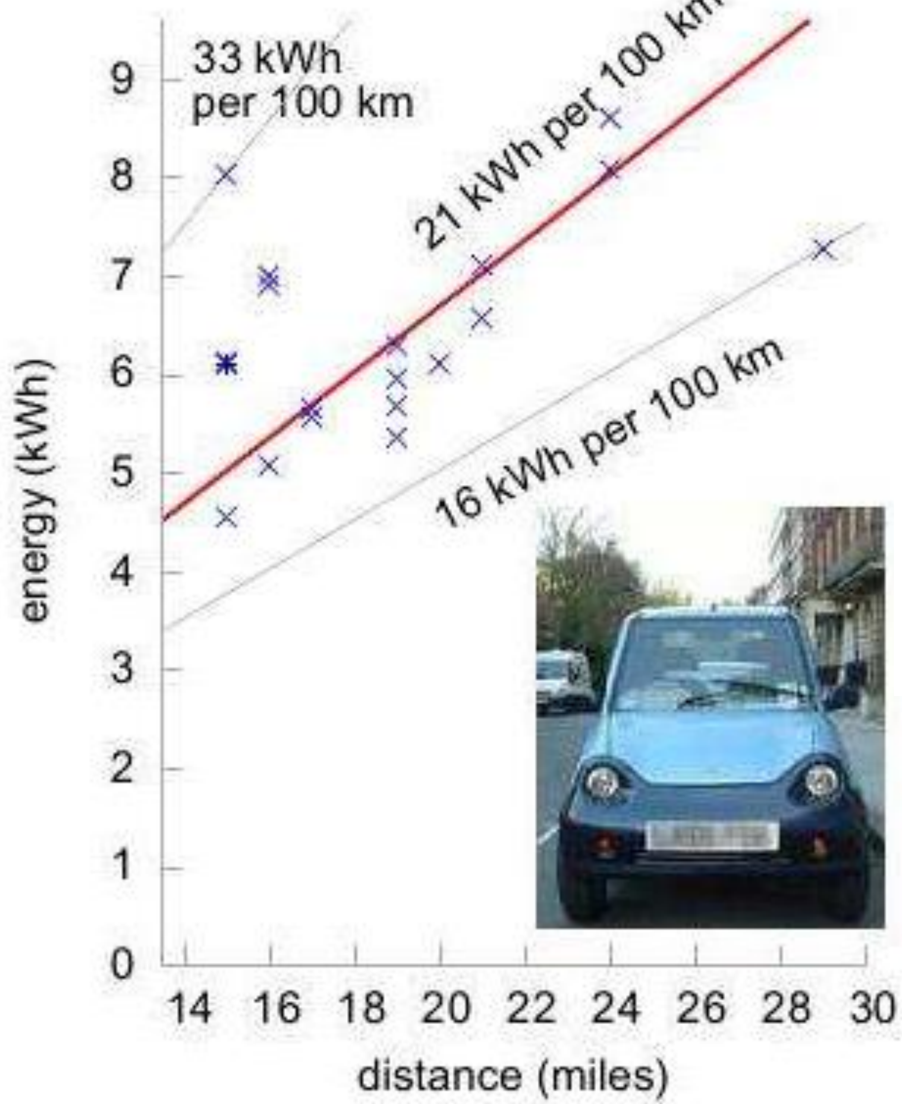


Figure 20.21. Electricity required to recharge a G-Wiz versus distance driven. Measurements were made at the socket.

International shipping is a surprisingly efficient user of fossil fuels; so getting road transport off fossil fuels is a higher priority than getting ships off fossil fuels. But fossil fuels are a finite resource, and eventually ships must be powered by something else. Biofuels *may* work out. Another option will be nuclear power. The first nuclear-powered ship for carrying cargo and passengers was the NS Savannah, launched in 1962 as part of President Dwight D. Eisenhower's *Atoms for Peace* initiative (figure 20.31). Powered by one 74-MW nuclear reactor driving a 15-MW motor, the Savannah had a service speed of 21 knots (39 km/h) and could carry 60 passengers and 14 000 t of cargo. That's a cargo transport cost of 0.14 kWh per ton-km. She could travel 500 000 km without refuelling. There are already many nuclear-powered ships, both military and civilian. Russia has ten nuclear-powered ice-breakers, for example, of which seven are still active. Figure 20.32 shows the nuclear ice-breaker Yamal, which has two 171-MW reactors, and motors that can deliver 55 MW.

Magnetic levitation is one of many technologies that gets hyped up when people are discussing energy issues. In energy-consumption terms, the comparison with other fast trains is actually not as flattering as the hype suggests. The Transrapid site compares the Transrapid with the InterCityExpress (ICE), a high-speed electric train.

Fast trains compared at 200 km/h (125mph)	
Transrapid	2.2 kWh per 100 seat-km
ICE	2.9 kWh per 100 seat-km

The main reasons why maglev is slightly better than the ICE are: the magnetic propulsion motor has high efficiency; the train itself has low mass, because most of the propulsion system is in the track, rather than the train; and more passengers are inside the train because space is not needed for motors. Oh, and perhaps because the data are from the maglev company's website, so are bound to make the maglev look better!

Phase R: Making **raw materials**. This phase involves digging minerals out of the ground, melting them, purifying them, and modifying them into manufacturers' lego: plastics, glasses, metals, and ceramics, for example. The energy costs of this phase include the transportation costs of trundling the raw materials to their next destination.

Phase P: Production. In this phase, the raw materials are processed into a manufactured product. The factory where the hair-dryer's coils are wound, its graceful lines moulded, and its components carefully snapped together, uses heat and light. The energy costs of this phase include packaging and more transportation.

Phase U: Use. Hair-dryers and cruise-ships both guzzle energy when they're used as intended.

Phase D: Disposal. This phase includes the energy cost of putting the stuff back in a hole in the ground (landfill), or of turning the stuff back into raw materials (recycling); and of cleaning up all the pollution associated with the stuff.

We can thus roughly estimate the energy footprint of our imports simply from the weight of their manufactured materials, if we exclude things like ores and wood. Given the crudity of the data with which we are working, we will surely slip up and inadvertently include some things made of wood and glass, but hopefully such slips will be balanced by our underestimation of the energy content of most of the metals and plastics and more complex goods, many of which have an embodied energy of not 10 but 30 kWh per kg, or even more.

Material	Embodied energy (MJ/kg)	Embodied energy (kWh/kg)
kiln-dried sawn softwood	3.4	0.94
kiln-dried sawn hardwood	2.0	0.56
air dried sawn hardwood	0.5	0.14
hardboard	24.2	6.7
particleboard	8.0	2.2
MDF	11.3	3.1
plywood	10.4	2.9
glue-laminated timber	11	3.0
laminated veneer lumber	11	3.0
straw	0.24	0.07

	Embodied energy (kWh/m^2)
Walls	
timber frame, timber weatherboard, plasterboard lining	52
timber frame, clay brick veneer, plasterboard lining	156
timber frame, aluminium weatherboard, plasterboard lining	112
steel frame, clay brick veneer, plasterboard lining	168
double clay brick, plasterboard lined	252
cement stabilised rammed earth	104
Floors	
elevated timber floor	81
110 mm concrete slab on ground	179
200 mm precast concrete T beam/infill	179
Roofs	
timber frame, concrete tile, plasterboard ceiling	70
timber frame, terracotta tile, plasterboard ceiling	75
timber frame, steel sheet, plasterboard ceiling	92

	Area (m^2)	×	energy density (kWh/m^2)		energy (kWh)
Floors	100	×	81	=	8100
Roof	75	×	75	=	5600
External walls	75	×	252	=	19 000
Internal walls	75	×	125	=	9400
Total					42 000

2.3.3 Transport Electrification and Mode Shift to Public Transport

The ZCA2020 Sector Report: Transport will include detailed costings of:

• replacement of the present petroleum-fuelled fleet with electric vehicles, comprising 'plug-in, battery swap' models and plug-in hybrid-electric vehicles, using liquid biofuels to extend the driving range;

• the design of future personal transport vehicles, fostering and encouraging development and roll-out of a range of lower cost zero-emission electric vehicles;

• a general shift from private cars and trucks to electric passenger trains, passenger trams, freight trains and cargo trams;

• additional energy savings from reductions in average cycling infrastructure will encourage the use of bicycles in urban areas.

These figures are based on a switch to efficient, electric light & heavy rail of

- 50% of urban passenger-kilometres
- 25% of non-urban passenger-kilometres
- 50% of urban freight tonne-kilometres
- 80% of non-urban freight tonne-kilometres

- all domestic passenger and freight air and shipping