1 Sun, energy and plants

Contents

1.1 Energy

1.1.1 Physical measures

The internationally accepted SI system of units defines energy and power according to Newton by distance, time and mass as follows. As long as a force ‘f’ causes an acceleration ‘a’, a distance ‘d’ is covered in a time interval ‘t’. Multiplying f by d produces the yielded energy f · d, expressed in joules. Energy per time interval t produces the performed power f · d / t expressed in watts (see *Fig. 2*).[1]

Velocity ‘v’ and acceleration ‘a’ suppose distance d and time interval t:

d (distance) **t (time)**	$\frac{d}{t}$ **= v (velocity)**	$\frac{d}{t^2}$ **= a (acceleration)**

Linear momentum ‘i’ and force ‘f’ suppose mass m, velocity v and acceleration a:

m (mass)	$\frac{d}{t}$ **m = i (momentum)**[2]	$\frac{d}{t^2}$ **m = ma = f (force)**[3]

	times distance = energy ‘e’	divided by time = power ‘p’
	$\frac{d^2}{t^2}$ **m = e (energy)**[4]	$\frac{d^2}{t^3}$ **m = e/t = p (power)**[5]

Energy is expressed in joules (J), power (energy per second) in watts (W)[6]

	$J=kg*m^2/sec^2$	W = J/sec

Old measures should be replaced as follows:

k= kilo(*10^3)	kWh = 3.6 MJ	kWh/year = 0.1142W
M= mega(*10^6)	kcal = 4.186 kJ	kcal/day = 0.0485W
G= giga(*10^9)	pk.h = 2.648 MJ	pk = hp = 735.5 W
T= tera(*10^{12})	ton TNT = 4.2 GJ	PJ/year = 31.7 MW
P= peta(*10^{15})[7]	MTOE = 41.87 PJ	J/sec = 1 W
E= exa(*10^{18})	kgfm = 9.81 J	
	BTU = 1.055 kJ	W (watt) could be read as watt*year/year.
	watt*sec = 1 J	

The equivalent of 1 m^3 natural gas (aeq)[8], roughly 1 litre petrol[9], occasionally counts 1 watt*year:

Occasionally:	m^3 aeq = 31.6 MJ and Wa = watt*year = 31.6 MJ	aeq/year = 1 W, or 1 W = 1 watt*year/year
	1 MJ = 0.0316888 Wa	‘a’ from latin ‘annum’ (year)
	1 GJ = 31.7 Wa	Wa is watt during a year
	1 TJ = 31.7 kWa	‘k’ (kilo) means 1 000x
	1 PJ = 31.7 MWa	‘M’ (mega) means 1 000 000x

Fig. 2 Dimensions of energy

A happy coincidence

A year counts 365.24 · 24 · 60 · 60 = 31 556 926 seconds or 31.6 Msec, since M means '·million'.
So, the **power** of 1 watt *during* a year: 1 watt·year = 31.6 MW·sec = 31.6 MJ =
1 Wa ('a' derived from latin 'annum', year), which is **energy**. [10]
Occasionally the equivalent of 1 m^3 natural gas ('aeq') or 1 litre petrol or 1 kg coal energy counts for approximately 31.6 MJ = 1 Wa energy as well.[11]

So: m^3 natural gas ('aeq') ≈ watt·year = Wa (energy)
and m^3 natural gas *per year* ≈ watt = W (power).

So, read 'Wa' and think '1 m^3 natural gas', '1 litre petrol' or '1 kg coal' (energy);
read 'W' and think '1 m^3 natural gas *per year*' (power);
read 'kW' and think '1000 m^3 natural gas *per year*' (power);
read 'kWh' and think '1000 m^3 natural gas per year *during an hour*' (again energy).

Easy calculating kilowatthours (kWh) and joules (J) by heart

Since there are 365.24 · 24 = 8 766 hours in a year: 1 Wa (watt·year) = 8 766 watt·hour (Wh) or 8.766 kilowatt·hour (kWh), because 'k' means '·thousand'.
Since there are 31 556 926 seconds in a year: 1 Wa = 1watt·year = 31 556 926 Ws (J) or 31 557 kJ, 31.557 MJ or 0.031557 GJ, because k = ·1 000, M = ·1 000 000 and G = ·1 000 000 000.[12]
This Wa measure is not only immediately interpretable as energy content of roughly 1 m^3 natural gas, 1 litre petrol or 1 kg coal, but via the average amount of hours per year (8 766) it is also easily transferable by heart into electrical measures as kWh and then via the number of seconds per hour (3 600) into the standard energy measure W·s=J (joule).
Moreover, in building design and management the year average is important and *per year* we may write this unit simply as W (watt). So, in this chapter for *power* we will use the usual standard W, known from lamps and other electric devices while for *energy* we will use Wa. If we know the average use of power, energy *costs* depend on the *duration* of use. So, we do not pay *power* (in watts, joules per second), but we pay *energy* (in joules, kilowatthours or wattyears): power x time.

Watts in everyday life

A quiet person uses approximately 100 W, that is *during* a year the equivalent of 100 m^3 natural gas. That power of 100 W is the same as the power of a candle or pilot light or the amount of solar energy/m^2 at our latitude[a]. That is a lucky coincidence as well. The power of solar light varies from 0 (at night) to 1000 W (at full sunlight in summer) around an average of approximately 100 W.
Burning a lamp of 100 W *during a year* takes 100 Wa as well, but electric light is more expensive than a candle.[13] Crude oil is measured in barrels of 159 litres. So, if one barrel costs € 80, a litre costs € 0.50. However, a litre petrol (1 Wa) from the petrol station after refining and taxes costs more than € 1. Natural gas requires less expensive refinary.
In the Netherlands 2008, 1 m^3 natural gas (1Wa) costs approximately *€ 0,70*[b]. However, an electric Wa costs approximately *€ 1.80*. That is more than 2 times as much. Why?

Conversion of fuel into a useful kind of energy

Electric energy is usually expressed in 'kWh_e' ('e' = electrical), heat energy in 'kWh_{th}' ('th' = thermal). A kWh_e electricity is more expensive than a kWh_{th} of heat by burning gas, petrol or coal, because a power station can convert only approximately 38% from the energy content of fossile fuels into electricity (efficiency η=0.38). The rest is necessarily produced as heat, mainly dumped in the environment 'cooling' the power station like any human at work also looses heat.[14] That heat content could be used for space heating, but the transport and distribution of heat is often too expensive. However, enterprises demanding both heat (Q) and work (W) at the same spot, could gain a profit by generating both locally (*cogeneration*, in Dutch 'warmte-kracht-koppeling' *WKK*).

Necessary heat loss

The necessary heat loss is described by two main laws of thermodynamics: no energy gets lost by conversion (first law of thermodynamics), but it always degrades (second law of thermodynamics).

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[a] It is slightly more, sometimes described as 1000 kWh/m^2 per year, which is 114 W/m^2. See *http://www.solaraccess.nl/content/page12.php*.

[b] Zie *http://consumenten.eneco.nl*

By any conversion only a part of the original energy can be utilised by *acculumation* and *direction* at one spot of application. The rest is *dispersed* as heat content Q (many particles moving in many directions), to concentrate a minor useful part W (work) on the spot where the work has to be done. The efficiency η of the conversion is W/(W+Q). In the case of electricity production it is $38kWh_e/100kWh$ or 38%. Once the work W is done, even the energy of that work is transformed into heat. However, according to the first law of thermodynamics both energy contents are not lost, they are degraded, dispersed, less useful. However it could still be useful for other purposes.
For example, the temperature of burning gas is ample 2000^oC, much too warm for space heating. If you would use the heat from burning fuels firstly for cooking, then for heating rooms demanding a high temperature and at last for heating rooms demaning a low temperature, the same heat content is used three times at the same cost in a 'cascade'. To organise that is a challenge of design.

Exergy

Theoretically any difference in temperature can be used to extract some work, but the efficiency of a small temperature difference ΔT is lower than that of a large temperature difference (see *Fig. 3*).

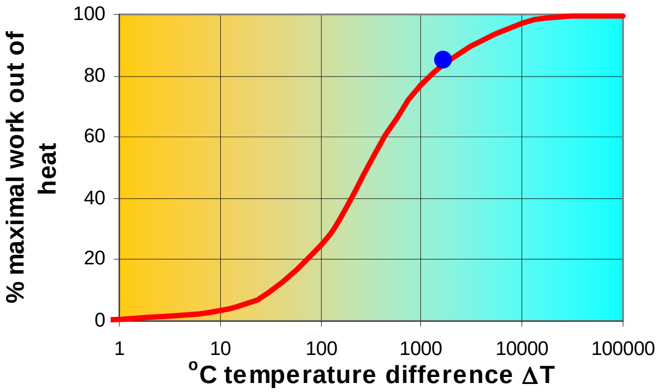

Fig. 3 The %maximum amount of work (W) retrievable from a temperature difference ΔT

The amount of work you can get out of heat (W/Q) per temperature difference available is called exergy. Apparently, chemical energy like fossile fuels do have a higher 'quality' than work; work has a higher quality than heat; high temperature heat has a higher quality than low temperature heat.
So, using high quality energy where low quality would be enough, leaves unused the opportunity to use the same energy several times in a cascade of uses.
The 'quality' of energy can be expressed in a single quantity. That quantity is called 'entropy'.

1.1.2 Entropy

The 'quality' of energy

The 'quality' of heat (Q) and work (W) is apparently different, though both are 'energy'.
In the same way high temperature (T) energy has a higher 'quality' than the same energy at low T. While converting fossile fuels into heat, the 'state' of energy changes. But how to describe that 'state' and its 'quality'? To introduce that 'state' in energy calculations the term 'entropy' S is invented by Clausius ca. 1855. In a preliminary approach one could think S = Q/T, but it concerns *change*, forcing us into differentials. It is often translated as 'disorder', but it is a special kind of disorder as Boltzmann showed in 1877. What we often perceive as 'order', a *regular* dispersion in space, is 'disorder' in thermodynamics. Let us try to understand that kind of thermodynamic disorder to avoid confusion of both kinds of 'order'.

'Disorder' in thermodynamics

In *Fig. 4* all possible distributions of n = {1,2,3,4} particles in two rooms are represented.
If you mark every individual particle by A, B, C, D, you can count the possible combinations producing the same distribution k over the rooms numbered as k = {0,1 …n}.

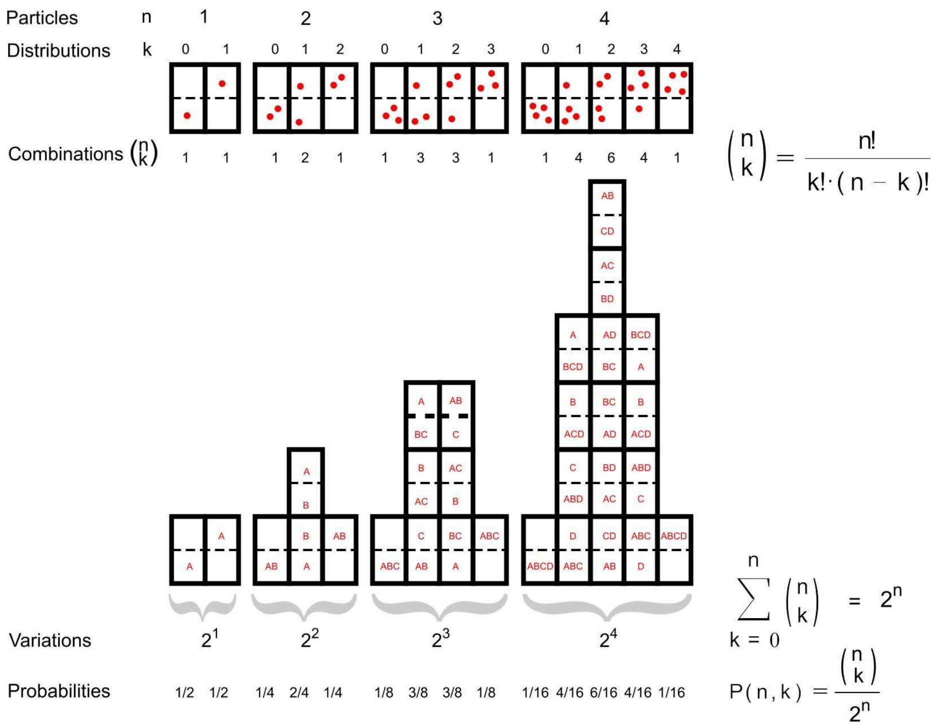

Fig. 4 k Distributions of n particles in two rooms

The numbers n and k determine the probability P(n,k) that this combination will occur[a].
Minimum and maximum values of k represent the extreme concentrations in one room or the other.

The more particles there are, the more combinations are possible and the more improbable will be the two extreme cases of accumulation in one room. For example, if there are 10 particles, the probability of total sprawl is 252 possible combinations from 1024 (25%), but the probability of total accumulation in one room is 1 case from 1024 (0.1% see *Fig. 5*, left).

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[a] Here is a tacid supposition, that the particles have an equal probability of entering and leaving a room without an selection at the doors between them like Maxwells Demon (remark of Van Bilsen 2007).

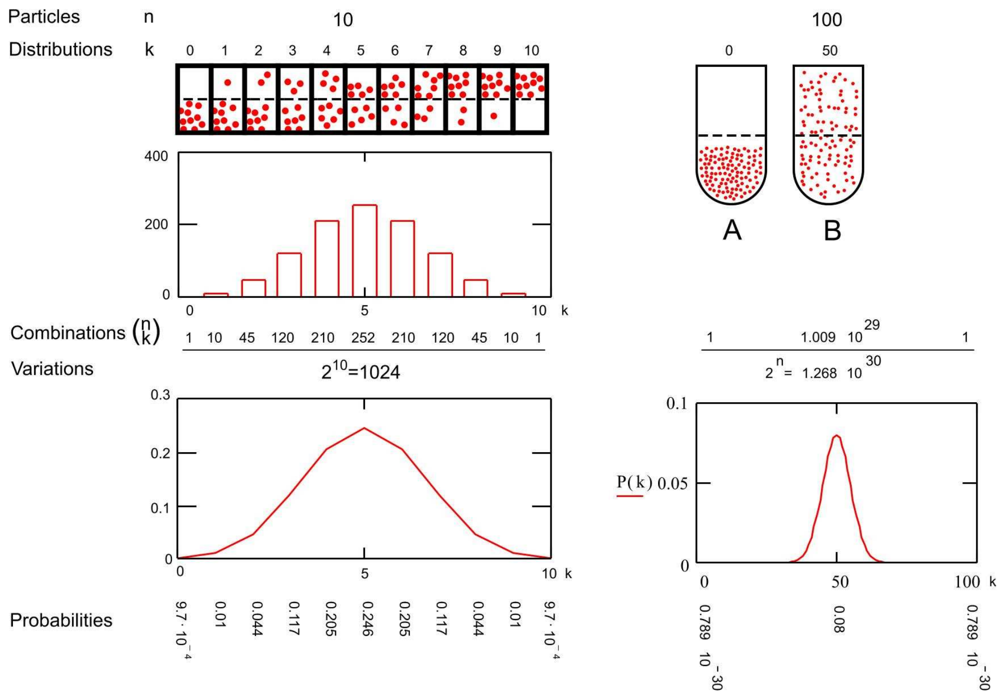

Fig. 5 The decreasing probability of concentration with a growing number of particles

Fig. 5 (A) shows the least probable distribution of 100 particles in a cylinder, but state B is very probable. These probabilities can be calculated as approximately $1/13 \cdot 10^{29}$ (A) and 1/13 (B). So, if anything changes it will most probably change from A into B instead of from B into A. That asymmetry of process is the core of thermodynamics.

From *Fig. 5* you also can learn that by an increasing number of particles most combinations accumulate around the middle of $k=0.5 \cdot n$. If you would calculate the possible combinations of 1000 particles the probability of sprawl (B) between k=495 and 505 (1% of n) would be practically 1 (100%). The graph would show a vertical line rather than a gaussian 'bell'.

Difference of entropy

Suppose now the content of the cylinder is a mole of gas (that is approximately $6 \cdot 10^{23}$ particles, Avogadro's number n). Then the probability of state B approximates 1 (100%). The probability of state A is again $1/2^n$. That is nearly zero, because the number 2^n is extraordinary large: a 1 with more than 10^{23} zeros. An ordinary computer can not calculate all combinations of that number as done in *Fig. 4*. However, to determine the entropy of state A we need the natural logarithm (the exponent to 'e' or 2.718) of that probability: $\ln 1/2^n$ or $\ln(2^{-n})$. And $\ln(2^{-n})$ is easily written as $-n \cdot \ln(2)$. That will save a lot of calculation, because n will disappear in the definition of entropy by Boltzmann using that probability:

$$S = \text{moles} \cdot \frac{R}{n} \cdot \ln(\text{probability})$$

Fig. 6 The statistical definition of entropy by Boltzmann in 1877

In state A and B with $n = 6 \cdot 10^{23}$ particles, the number of moles is 1; n is Avogadro's number. R is a constant (gas constant) we will explain later.[a] So, entropy is related to probability by a constant! However, Boltzmann chose the logarithm of probability, because if you want to know the entropy of two sub systems (for example two moles), you would have to multiply the combination of each sub system. If you take the logarithm first, than you can simply add both[b].

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[a] R/n, the gas constant divided by Avogadro's number is mainly written as Boltzmann's constant k.

[b] Remark by Van Bilsen(2007).

In this case we can write the increase of entropy from stage A into B as S_B-S_A:

$$\Delta S = \frac{R}{n} \cdot \ln(1) - \frac{R}{n} \cdot \ln\left(\frac{1}{2^n}\right)$$

Fig. 7 The increase of entropy from accumulation in one room into sprawl in two rooms

The probability of state B is very near 1, and the logarithm of 1 is zero, so we can write:

$$\Delta S = -\frac{R}{n} \cdot \ln\left(\frac{1}{2^n}\right) = -\frac{R}{n} \cdot \ln\left(2^{-n}\right) = -\frac{R}{n} \cdot -n \cdot \ln(2) = R \cdot \ln(2)$$

Fig. 8 Simplifying the formula of Fig. 7

So, the entropy of stage B is R·ln(2). The natural logarithm of 2 is 0.693, but what is R?

R is the gas constant per mole of gas:

$$\frac{P_A \cdot V_A}{T_A} = \frac{P_B \cdot V_B}{T_B} = \frac{P \cdot V}{T} = 8.31472 \frac{\text{joule}}{K \cdot \text{mole}} = R$$

Fig. 9 Defining the gas constant R

In *Fig. 9* P is the pressure (force/m^2) and V is the volume (m^3). So, on balance P·V is ‘force times distance’: energy (expressed in newton·m: joule). T is the temperature in degrees of Kelvin (K).

In a mole of gas the proportion between that energy and temperature in normal conditions appears to be the same[a]: 8.31472 joule/K. That constant is named ‘gas constant’ R. So, that is also valid for both stage A and B. Now we could calculate the increase of entropy as R.ln(2) = 5.8 joule/K·mole. However, in thermodynamics the ‘probability’ of a state contains more than the distribution over two rooms. For example the reduced freedom of movements of particles in liquids and solids. That is why we limit ourselves here to complete freedom of movement (gas) to describe the states A and B. Moreover, gas plays a dominant role in energy conversion any engineer is occupied with.

Change of entropy

If a mole of gas expands from A to B, the heat content Q disperses over a doubled volume. So, the temperature tends to drop and the system immediately starts to adapt to the temperature of the environment. That causes an influx of extra heat energy ΔQ. So, in a slow process T could be considered as constant and the pressure will halve to keep also P·V constant at R·T (see *Fig. 10*).

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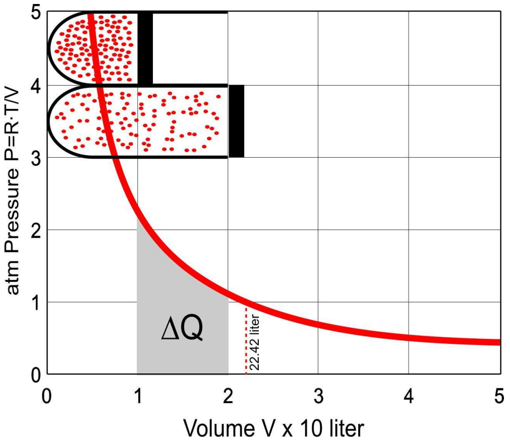
[a] the Boyle-Gay-Lussac law.



P·V = R·T (see *Fig. 9*), so P = R·T/V (see the graph left). If at any moment Q := P·V, any small change dQ equals P·dV and a larger change ΔQ from stage 1 into 2 is the sum of these small changes:

$$\Delta Q = \int_1^2 P\,dV = \int_1^2 \frac{R\cdot T}{V}\,dV = R\cdot T\cdot \ln(2)\ ^{a}$$

so, $\frac{\Delta Q}{T} = R\cdot \ln(2)$. Remember now Fig. 8: $R\cdot \ln(2) = \Delta S$

if $\Delta S = \frac{\Delta Q}{T}$, then also $dS = \frac{dQ}{T}$. So, $\boxed{S = \int \frac{1}{T}\,dQ}$

Fig. 10 Extending 1 mole of gas (22.42 liter at 1 atmosphere) from 10 to 20 liter keeping T at 0^{o}C or 273.26K.

The heat energy Q is equal to P·V, but if it increases P itself is dependent on V.
So, every infinitely little increase of V (dV) has to be multiplied by a smaller P. Summing these products P·dV between V = 1 and V = 2 is symbolised by the first ‘definite integral’ sign in *Fig. 10*. However, that formula can not be solved if we do not substitute P by R·T/V (see *Fig. 9*) in the next formula. In that case the mathematicians found out that definite integral is equal to R·T·ln(2).
Now we have a real quantity for ΔQ, because R·T·ln(2) = 1574 joule.

So, ΔQ/T = R·ln(2), and R·ln(2) reminds us of *Fig. 8*: it is ΔS, the change of entropy!
A few steps according to *Fig. 7* takes us back to the statistical definition of Boltzmann in *Fig. 6*, but now it is related to heat content Q and temperature T, the variables used in any engineering.
If ΔS = ΔQ/T, then also dS = dQ/T and now we can write the famous integral of Clausius:

$$S = \int \frac{1}{T}\,dQ$$

Fig. 11 The thermodynamic definition of entropy

This formula shows that an increasing heat content increases entropy, but a higher temperature decreases it. If we now keep the heat content the same (closed system) and increase volume, then accumulation, pressure and temperature decrease (Boyle-Gay Lussac, see *Fig. 9*), so entropy will increase.
So, accumulation (storage, difference between filled and empty) decreases entropy, increases order.

Design and the conception of order, specialists’ conceptions

The explanantion of entropy above is extended, because of two reasons.
Firstly, while defending a concept of order, arrangement in design, designers often refer to low entropy and that is not always correct. Perceptual order could refer to a regular dispersion of objects in space and just that means sprawl, entropy. In thermodynamics an irregular dispersion with local accumulations has a lower entropy (disorder) than complete sprawl. However, in fluids and solids rectangular or hexagonal patterns with low entropy appear, due to molecular forces. But in general, if the particles have freedom of movement, sprawl is much more probable than accumulation.
It reminds us of the avoidance of urban sprawl. Thermodynamically accumulation is possible, but very improbable. So, *if* thermodynamics has any lessons for designers: sprawl is not the task of design, if there is freedom of movement, than it very probably happens without intention.

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[a] A little math: $\int_1^2 \frac{1}{V}\,dV = \ln(2) = 0.693$; $\int_1^3 \frac{1}{V}\,dV = \ln(3) = 1.099$; $\int_2^3 \frac{1}{V}\,dV = \ln(3) - \ln(2) = 0.405$

Secondly, energy and entropy are basic concepts in any engineering. To understand specialists in their reasoning and to be able to criticise them demands some insight by designers. The impact of the industrial revolution, the accumulation of population in cities can not be understood without understanding the manipulation of sprawl on another level of scale as has happened in the development of the internal-combustion engine. The internal-combustion engine is extensively used in industry and traffic. So, I would like to proceed with some explanation of that engine, the main application of sunlight stored in fossile fuels in human society.

Forced concentration

The (change of) force by which a piston is pushed out of a cylinder is equal to the proportion of (change of) energy and entropy *Fig. 12*. In a cylinder engine, alternating states of dispersion are used to convert imported disordered energy (heat) partly into directed movement. It is only possible by exporting part of the heat in an even more dispersed form (cooling).

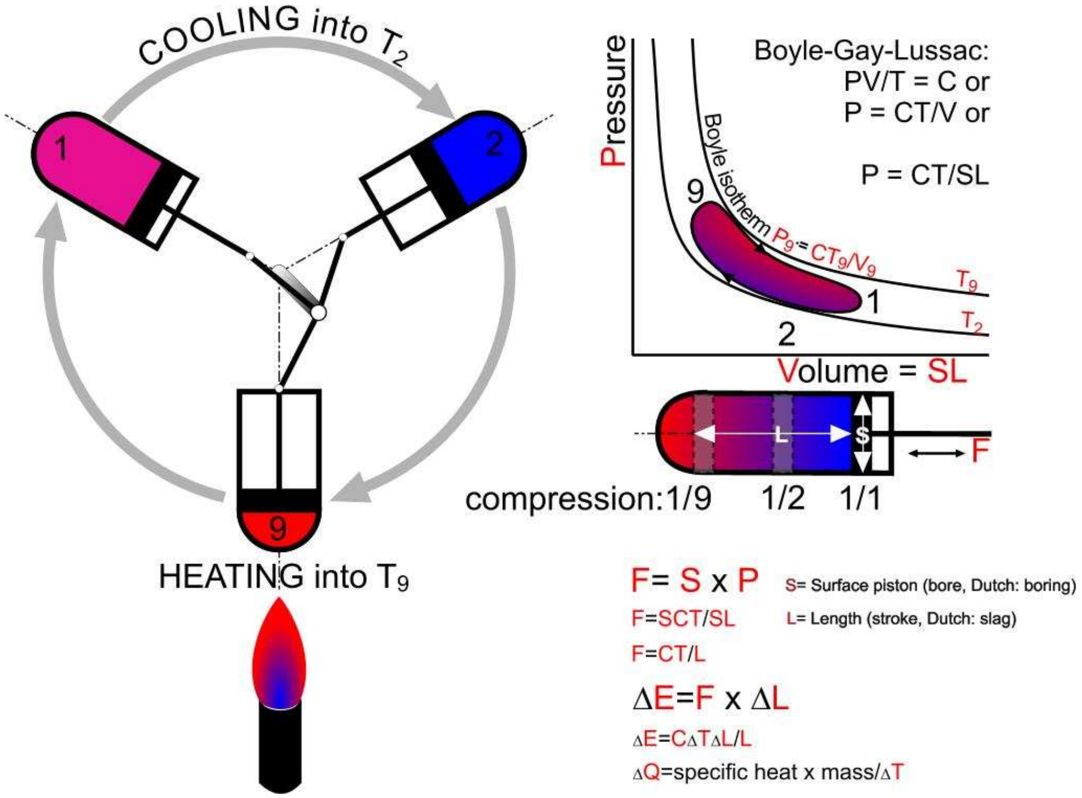

Fig. 12 Carnot-engine

The necessary event of cooling makes an efficiency of 100% impossible and increases entropy in a larger environmental system. The reverse, adding rotating energy to this engine the principle that can be used for heating (heat pump) and cooling (refrigerator).

1.1.3 Energetic efficiency

The proportion of the applicable part from total energy content of a primary source is the efficiency of the conversion.[15] In *Fig. 13* some conversion efficiencies are represented.

Device or process	chemical->thermic	thermic->mechanisal	mechanical->electric	electric->mechanical	electric->radiation	electric->chemical	chemical->electric	radiation->electric	thermic->electric	efficiency
										100%
electric dynamo			■							
electric motor				■						
										90%
steam boiler	■									
HR-boiler	■									
										80%
c.v.-boiler	■									
electric battery						■	■			
										70%
fuel cell							■			
										60%
										50%
steam turbine		■								
										40%
electric power station	■	■	■							
gas turbine	■	■								
										30%
car engine	■	■								
neon lamp					■					20%
solar cell								■		
										10%
thermocouple									■	
										0%

Fig. 13 Energy conversion efficiencies[a]

Producing electric power

An electric power station converts primary fuel (mostly coal) into electricity with approximately 38% efficiency. *Fig. 13* shows that such a power station combines 3 conversions with respecitive efficiencies of 90, 45 and 95%. Multiplication of these efficiencies produces 38% indeed.[16] The step from chemical into electrical power could also be made directly by a fuel cell (*brandstofcel*)[b], but the profit of a higher efficiency (60%) does not yet counterbalance the costs.

The table shows the solar cell as well. The efficiency is between 10 and 20% (theoretical maximum 30%). Assuming 100W sunlight per m^2 Earth's surface average per year in The Netherlands (40 000 km^2 land surface) we can yield at least $10W/m^2$.

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[a] Gool e.a. (1986)

[b] Zie *http://mediatheek.thinkquest.nl/~lla091/fuelcell_nl.html*

Domestic use of solar energy

The average Dutch household uses approximately 375 wattyear/year or 375W electricity.
In a first approach a household would need 37.5 m2 solar cells. However, a washing machine needs also in periods without sunshine now and then 5000W. So, for an autonomous system solar electricity has to be accumulated in batteries. According to *Fig. 13* such batteries have 70% efficiency for charging and discharging or 0.7 x 0.7 = 50% for total use. The needed surface for solar cells doubles in a second approach to at least 75 m^2 (37.5 m^2 / (0.7 x 0.7)).

Changing into alternating current

However, most domestic devices do not work on direct current (D.C.) from solar cells or batteries, but on alternating current (A.C.). The efficiency of conversion into alternating current may increase the needed surface of solar cells into 100 m^2 or 1000 W installed power. Suppose solar cells cost € 3,- per installed W, the investment to harvest your own electricity will be € 3 000,-. In the tropics it will be approximately a half.

Peak loads

Suppose, electricity from the grid amounts about *€ 0.70* per Wa. So, an average use of approximately 375 W electricity approximately amounts to € 250 per year. In this example the solar energy earn to repay time exclusive interest is already approximately 3000/250 per year = 12 year. Concerning peak loads it is better to cover only a part of the needed domestic electricity by solar energy and deliver back the rest to the electricity grid avoiding efficiency losses by charging and discharging batteries. It decreases the earn to repay time.

The costs of solar cells compared to fossile fuel

The costs of solar cells decreased since 1972 a factor of approximately 100. Their efficiency and the costs of fossile fuels will increase. To pass the economic efficiency of fossile fuels as well the price of solar cells has to come down relatively little (*Fig. 14*). 'Solar power cost about $4 a watt in the early 2000s, but silicon shortages, which began in 2005, have pushed up prices to more than $4.80 per watt, according to Solarbuzz … In a recent presentation, Bradford said that prices for solar panels could drop by as much as 50 percent from 2006 to 2010.'[a]

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[a] *http://www.technologyreview.com/Biztech/20702/?a=f*

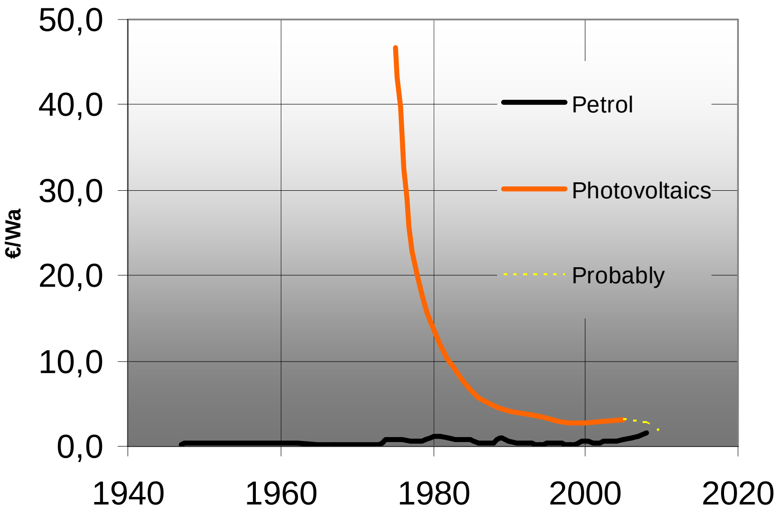

Fig. 14 Decreasing costs of solar cells and petrol[a]*, possibly developing according to* [a]*.*

The efficiency of solar cells compared to plants

The efficiency of solar cells is rather high compared with the performance of nature. Plants convert approximately 0.5 % of sunlight in temporary biomass (sometimes 2%, but overall 0.02%), from which ony a little part is converted for a longer time in fossile fuels. Biomass production on land delivers maximally 1 W/m^2 being an ecological disaster by necessary homogeneity of species. In a first approach a human of 100 W would need minimally 100 m^2 land surface to stay alive. However, by all efficiency losses and more ecologically responsible farming one could better depart from 5 000 m^2 (half a hectare).

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[a] *http://www.wtrg.com/prices.htm* and Maycock cited by Brown, Kane et al. (1993)

1.1.4 Global energy

Available solar power

There is more than 6 000 times as much solar power available as mankind and other organisms use. The Earth after all has a radius of 6Mm (6 378 km at the equator, 6 357 km at the poles) and therefore a profile with approximately 128 Mm^2 (π x 6 378 km x 6 378 km = 127 796 483 000 000 m^2) capturing sunlight. The solar constant outside atmosphere measures 1 353 W/m^2, on the Earth's surface reduced to approximately 47% by premature reflection (-30%) or conversion in heat by watercycle (-21%) or wind (-2%). The remainder (636 W x 127 796 483 000 000 m^2 of profile surface unequally distributed over the spherical surface) is available for profitable retardation by life or man. However, 99.98% is directly converted into heat and radiated back to the universe as useless infrared light. Only a small part (-0.02%) is converted by other organisms in carbohydrates and since about a billion years a very small part of that is stored more than a year as fossile fuel.

		Earth	The Netherlands	
radius	Mm	6		
profile	Mm^2 [a]	128		
spherical surface	Mm^2	510	0,10	0,02%
solar constant	TW/Mm^2	1353	832,99	61,57%[b]
solar influx	TW	172259	33,83	0,02%
from which available				
sun 47% or 100W/m2	TW	80962	10,00[c]	0,01%
wind 2%	TW	3445	0,68	0,02%
fotosynthesis 0,02%	TW	34	0,01	0,02%

Fig. 15 Globally and nationally received solar power

The human use of energy

The actual energy use is negligible compared to the available solar energy (*Fig. 15* and *Fig. 16*).

		Earth	The Netherlands	
coal	TW	3	0,02	0,45%
oil	TW	4	0,03	0,77%
gas	TW	2	0,05	2,14%
electricity	TW	2	included in fossile	
traditional biomass	TW	1		
total	TW	13[d]	0,10	0,73%

Fig. 16 Gobal and national energy use[e]

Biological storage

The biological process of storage produced an atmosphere livable for much more organisms than the palaeozoic pioneers. Without life on earth the temperature would be 290°C average instead of 13°C. Instead of nitrogen (78%) and oxigen (21%) there would be a warm blanket of 98% carbon dioxide (now within a century increasing from 0.03% into 0.04%). By fastly oxidating the stored carbon into atmospheric CO_2 we bring the climate of Mars and heat death closer, unless increased growth of algas in the oceans keep up with us.

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[a] $Mm^2 = (1\ 000\ 000\ m)^2$
[b] Cosine of latitude.
[c] Here 100W/m^2 is assumed. See also http://www.solaraccess.nl/content/page12.php
[d] rounding off difference
[e] Dutch figures are more recent than global ones.

Wind and biomass

Concerning *Fig. 14*, *Fig. 15* and *Fig. 16* making a plea for using wind or biomass is strange. Calculations of an ecological footprint based on surfaces of biomass necessary to cover our energy use have ecologically dangerous suppositions. Large surfaces of monocultures for energy supply like production forests (efficiency 1%) or special crops (efficiency 2%) are ecological disasters.
Without concerning further efficiency losses Dutch ecological footprint of 0.10 TW (*Fig. 16*) covered by biomass would amount 10 times the surface of The Netherlands yielding 0.01 TW (*Fig. 15*). However, covered by wind or solar energy it would amout 1/7 or 1/100. However, efficiency losses change these facors substantially (see 1.1.5).

How much fossil fuel is left

To compare energy stocks of fossile fuels with powers (fluxes) expressed in terawatt in *Fig. 15* and *Fig. 16*, *Fig. 17* expresses them in power available when burned up in one year (a = annum).

		Earth	The Netherlands	
coal	TWa	1137	0,65	0,06%
oil	TWa	169	0,03	0,02%
gas	TWa	133	1,60	1,20%
total	TWa	1439	2,28	0,16%

Fig. 17 Energy stock

By this estimated energy stock the world community can keep up its energy use 110 years.[17] However, the ecological consequence is ongoing extinction of species that can not keep pace with climate change. Forests can not move into the direction of the poles in time because they need thousands of years to settle while others 'jump from the earth' flying for heat.

Fission of uranium

Fig. 16 shows an actual global energy use of 13 TWa. One TWa is 1 000 GWa. One GWa_e can also be generated in a nuclear power station. Instead of 2 000 000 000 kg coal, that requires 800 kg enriched uranium (U) only[a]. Dependent on the density in the rock, substantial extraction marks can be left in the landscape. Storage and transport of the raw material with uranium has to be protected against possible misuse.

The conversion ino electricity occurs best in a fast breeder reactor. Older fission cycles with and without retracing of plutonium (Pu) use so much more uranium that the stocks will not be sufficient until 2050. The fast breeder reactor recycles the used uranium with a little surplus of plutonium (see *Fig. 18*). However, that requires higher temperatures than without recycling.

With non-braked 'fast' neutrons from the core of the reactor in the 'casing' or 'mantle' of fissionable material non-fissionable heavy uranium (U238) is converted in fissionable plutonium (Pu239), suitable for fuel in the same reactor.

Uranium stocks

Because the uranium stocks are estimated to be approximately 5 000 000 000kg, approximately 6 million GWa electricity could be extracted (plus approximately two times as much rest heat). If you estimate the world electricty use to be 1000 Gw_e per year, then that use can be sustained some 6 000 years with fast breeder reactors. Supposing an all-electric society and a world energy use of 10 000 GWa, then the uranium stocks are enough for 600 year.

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[a] AER (1979) Kolen en uraan ('s-Gravenhage) Staatsuitgeverij

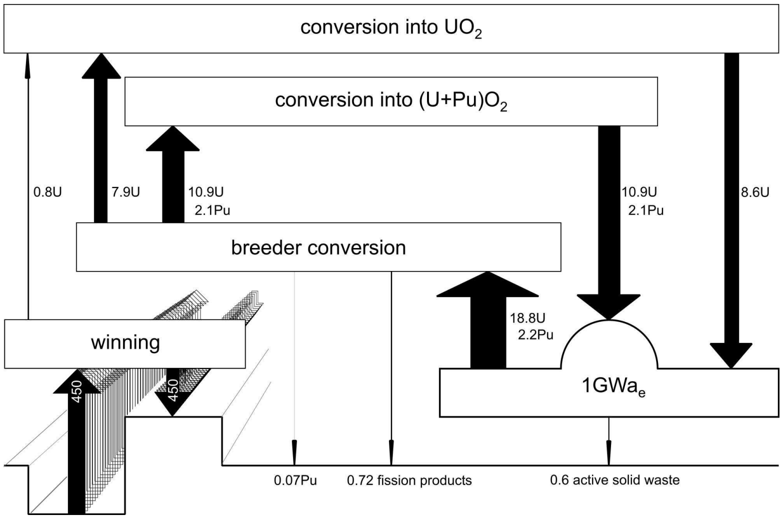

Fig. 18 Nuclear fuel cycle of a fast breeder reactor in 1000kg, producing 1 GWa$_e$[a]

Impacts of radio activity on the human body

The released radio-active material radiates different kinds of ionizing particles. Dependent on their energy (expressed in electronvolt, eV) they can penetrate until different depths in the soft body tissues where they can cause damage (see *Fig. 19*).

in millimetres	charged particles		non-charged particles		
	alfa	proton	beta	neutron	gamma
on 1 MeV	0.005	0.025	5	25	100
on 10 MeV	0.2	1.4	50	ca 100	310

Fig. 19 Halving depth of ionizing radiation in body tissue[b]

In the air similar distances apply. That means that approaching radio active waste until some metres does not have to be dangereous. The real danger starts by dispersion of radio-active particles in the air, water, soil and food. Through that dispersion the sources of radiation can enter the body and cause damage on a short distance of vulnerable organs.

The damage is determined by the quantity of the particles of *Fig. 19*, but also by the composition of the intake and the time they remain in the body (biological halving time). The composition determines the radio active halving time and the energy of different particles. The damage is different for sex cells, lungs, bone forming tissue and/or red bone marrow.

Objections against nuclear enery conversion

Against nuclear energy social and political objections are raised concerning:[18]

1. possible misuse of plutonium (proliferation of nuclear weapons)
2. risks in different parts of the cycle
3. the long lasting dangers of dispersion of radio-active waste.

Possible misuse

In *Fig. 18* some moments exist where ample 2 000kg of plutonium have to be transported into the next production phase. At these moments the plutonium can be stolen. If in the breeder conversion plant 12

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[a] after AER 1979 Kolen en uraan blz. 116
[b] Hermans & Hoff 1982, blz. 46

kg PuO_2 is stolen, then 10 kg pure metal can be produced, the ‘critical mass’ for an nuclear bomb. However, it is not easy to produce a nuclear bomb from this material without very large investments.[19]

Risks during operation

In different parts of the cycle risky moments occur. Though the formation of a ‘critical mass’ where enough neutrons are confined to cause a spontaneous explosion is very improbable, non-nuclear causes like a failing coolingsystem or ‘natrium burning’ can get a ‘nuclear tail’ if they cause a concentration of fissionable material. Both can be caused by terrorist attacks or war.

Liquid natrium is used as cooling medium in breeder reactors because water would brake the necessary fast neutrons. Natrium reacts violently with water and air (eventually with the fission material as well). So, the cooling system sould not have any leakage. If the cooling system fails, then the fisson material can melt forming a critical mass somewhere. A breeder reactor can contain 5 000 000 kg of natrium and by its breeding mantle a relatively large amount of fission material.

Waste

The danger of dispersion of radio-active material does not only occur by accidents. Radio active waste has to be isolated from the biosphere for centuries to prevent entering the food chains. For any GWa electricity produced the wastes are approximately:

1 000 kg of fission products
10 000 kg of highly active solid waste (in Dutch: HAVA)
20 000 kg of medium active solid waste (MAVA)
300 000 kg of low active solid waste (LAVA)
2 GWa of heat

Besides that, once in the 20 years dismantling of the plant has to be taken into account. Many components will have become radio active, so they have to be stored or reused for new plants.

Dispersion of radio-active material

If concentration of these wastes on a few places could be guaranteed for many centuries, this relatively small stream of waste would be no problem. The distance of impact of these radiations is so small, that you can live safely in the neigbourhood of wastes from many centuries.
However, you cannot guarantee concentration for centuries. Even salt domes can be affected by geological or climatic proceses. Blocks of concrete can leake, storage places can be blown up by terrorist or military operations.

Dispersion through the air, water, soil, the food chain or the human body is dangerous and impredictable. Comparison with other environmental risks is difficult. If you take the accepted maximum concentrations in the air as a starting point, you can calculate how much of air you need to reach an acceptible concentration of the dispersed wastes. To make a volume like that imaginable, you can express it as the radius of an imaginagy air dome reaching the accepted concentration by complete dispersion. In that case very roughly calculated recent nuclear waste of 1 GWa requires 50km radius. One year old waste requires 40km, 10 years old waste 15km and 100 years old waste 7km. However, from calculations like this you cannot conclude that you are safe at any distance. In reality dust is not dispersed in the form of a dome, but depending on the wind in an elongated area remaining above the standards over very long distances.

Fission and fusion

If you would have a box with free neutrons and protons at your disposal, you could put together atoms of increasing atomic weight. However, you would have to press very hard to overcome the repelling forces between the nuclear particles. Once you would have forced them together the attracting forces with a shorther reach would take over the effort and press the particles together in such a way that they have to loose mass producing energy[a]. Until 56 particles (iron, Fe56) you would make energy profit. Adding more particles increases the average distance between the particles mobilising the repelling forces again. If you would like to build furter than iron, then you would have to *add* energy.

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[a] A billion watt during a year with 31 560 000 seconds (GWa) is $3.156*10^{16}$ joule and the speed of light c = 299 792 458 m/sec. So, according to the famous Einstein formula $E=mc^2$, if E = 1 GWa, then the loss of mass is 0.351 kg.

However, that also means that heavier atoms like uranium can produce fission energy as discussed above.

Bond energy

The added or released energy are called bond energy. The amount of available bond energy is dependent from the number of particles in the atomic nucleus (zie *Fig. 20*). For example, if you split the nuclei of 1000 kg of uranium (U235) or even better plutonium (Pu239) into strontium (Sr96) and cesium (Cs137), *Fig. 20* shows that you can yield several GWa's. However, it is also clear that if you put together 1000 kg of the hydrogen isotopes deuterium (D2) and tritium (T3) into helium (He4), approximately ten times more GWa can be released.

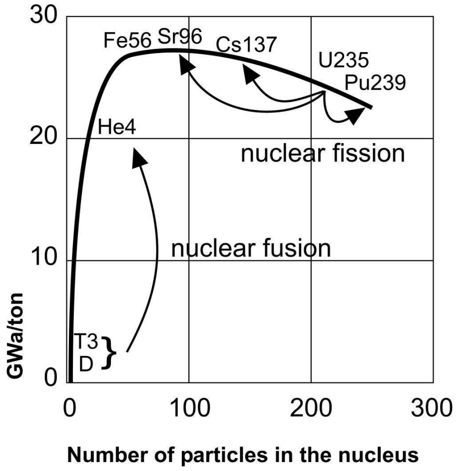

Fig. 20 Bond energy of nuclei as a function of the number of particles[a]

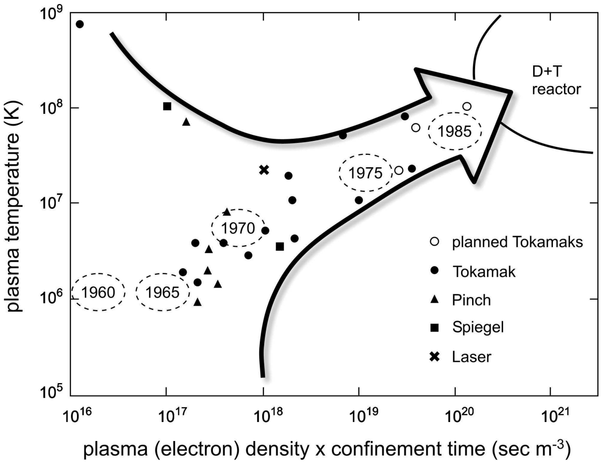

Fig. 21 Progress of nuclear fusion as expected in 1982[b]

Nuclear fusion, the Sun on Earth

This 'putting together' is called nuclear fusion. That is more difficult than it seems, because you could overcome the repelling forces only on 100 000 000 degrees kelvin if in the same time you could keep the hydrogen together in sufficient density long enough (criterion of Lawson). The Sun does so by its mass, isolated by vacuum, delivering its energy by radiation only. On Earth until now, that only has succeeded in experiments with hydrogen bombs, each ignited with a limited fission of uranium. Since long, the temperature under controlled laboratory circumstances is no problem anymore. Already in 1960 higher temperatures have been reached. The real problem is, to reach the Lawson-criterion together with these high temperatures. In that respect impressive progress is made at the end of the 20th century recapitulated in the "Lawson-diagram" of *Fig. 21*.

Thermonuclear power conversion

In 1982 it seemed probable that the first thermonuclear reactor (a converter based on fusion) could deliver electricity before the end of the century. But that fell short year after year. Immense budgets were and still are spent to reach that phase. However, after reaching fusion in controlled circumstances many technical problems have to be solved, but in the end thermonuclear reactors will play an important role in energy supply. In the initial phase of this technology lithium (to be bred from the very volatile and radio active heavy isotope of hydrogen tritium) will be necessary (D+T reactor). However, exclusive use of abundantly available and harmless deuterium will be possible at last.

The stock of deuterium

One of 7000 hydrogen nuclei is a deuterium nucleus. If you estimate the total amount of water on Earth at one billion km^3, the stock of deuterium is 30 000 Pg (1Pg is 1000 000 000 000 kg). This amount is practically spoken inexhaustible. The end product is non radio active inert helium. The radio

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[a] *Lysen 1980 eindeloze energie p42*
[b] *Braams in Hermans en Hoff 1982 p.273*

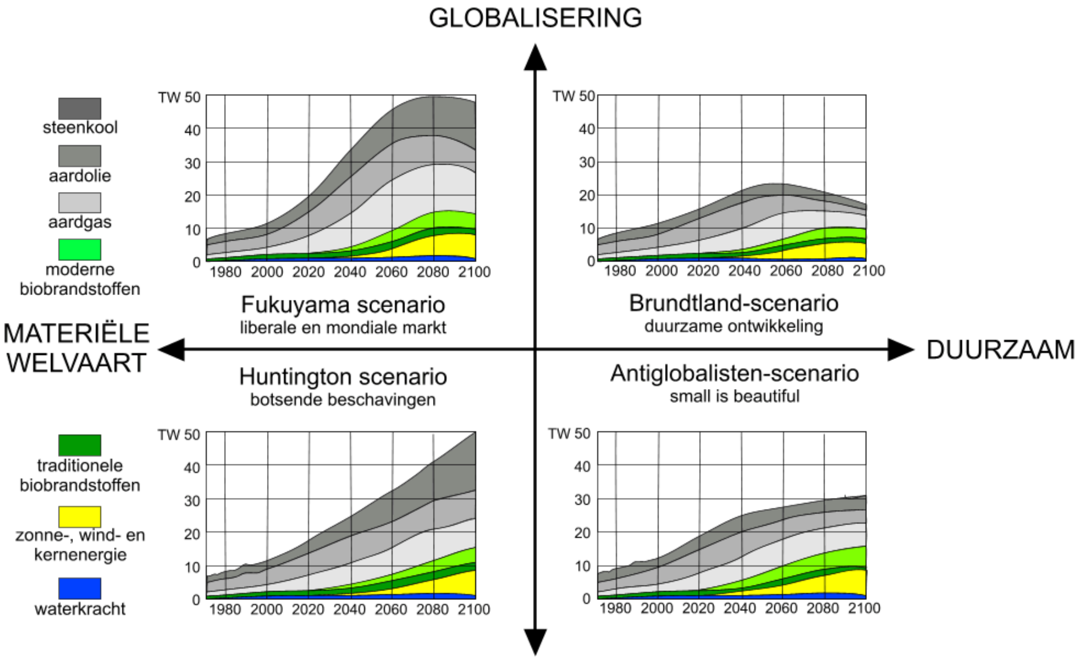
active waste of a thermonuclear reactor merely consists of the activated reactor wall after dismantlement. At average that will be approximately 100 000 000 kg construction material. In the right composition it will loose its radio activity in 10 years. Instead of storing it, you can better use it to construct a new plant immediately. Connected to that, thermonuclear plants can be built best in units of 1.5 GW_e regularly renewed by robots. So, we would need approximately 9000 plants to meet our current global needs or 7 for the Dutch.

Risks of thermonuclear power

The risks of fission power plants like for example the proliferation of plutonium, a "melting down" with dispersion of radio active material are not present in thermonuclear processes based on deuterium. Any attack will stop the process by a fall-down of temperature. However, the use of the extremely volatile radio active tritium in the initial phase is very dagerous. Plutonium is not a necessary by-product as in any fission cycle, but you can use a fusion reactor to breed plutonium if you really want to do so. Perhaps it is possible to make existing radio active wastes from earlier fission harmless in the periphery of the ‘fusion sun’.[20]

Energy scenarios

For the contribution of different kinds of energy supply scenarios are made (*Fig. 22*).



IPCC TARGETS- EN IMAGEMODEL (RIVM)

Fig. 22 Energy scenarios[a]

The small contribution solar energy (even combined with nuclear power) and the great confidence in fossile fuels and biomass are remarkable.

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[a] *After RIVM (2000)*

1.1.5 National energy

Use

According to CBS (2009) Dutch energy use (see *Fig. 23*) approaches 100 GW (0,1 TW)[a] from which approximately 10% finally electric: 10Gw$_e$ (0.01TW$_e$)[b].[21]

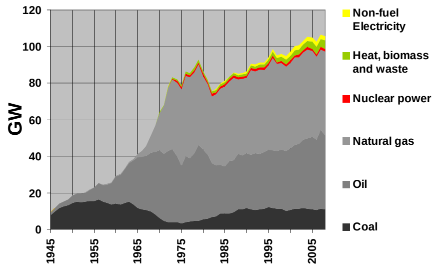

Fig. 23 Development of Dutch energy use 1945-2008 ..

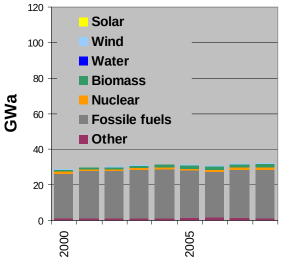

Fig. 24 .. of which used by power stations 2000-2008

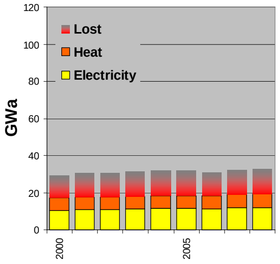

Fig. 25 .. of which used as electricity, heat and lost

Sun and wind energy

An ecological footprint of 1/7 of our surface on the basis of nearly 7 times as much wind as we need looks favourable, but how efficiently can wind be harvested? How useful is the power of 680 GW blowing over The Netherlands? The technical efficiency of wind turbines is maximally 40%, practically 20%. The energy from wind principally cannot be harvested fully because the wind then would stand still behind the turbine. At least 60% of the energy is necessary to remove the air behind the turbine fast enough. Technical efficiency alone (R1) increases the windbased footprint of 1/7 into more than ½. But there are other efficiencies (see *Fig. 26*) together reducing the available wind energy from 680 GW available into maximally 20 GW useful.

The Netherlands full of windturbines only can afford 1/5 of the energy demand

Putting the Dutch coast from Vlaanderen to Dollard full with a screen of turbines and behind it a second one and so on until Zuid Limburg, these screens could not be filled by more than 80% with circular rotors (R2). In the surface of the screen some space has to be left open between the rotors to avoid nonproductive turbulence of counteracting rotors (R3). In a landscape of increasing roughness by wind turbines the wind will choose a higher route. So, in proportion to the height the screens need some distance to eachother (R4). The higher the wind turbine, the higher the yield, but we will not harvest wind on heights where costs outrun profits too much (R5). Decreasing height could be compensated partly by increasing horizontal density (R6) though local objections difficult to be estimated here can force to decrease horizontal density (R7).

R1 technical efficiency	0,20	R5 vertical limits	0,30
R2 filling reduction	0,80	R6 horizontal compensation	2,50
R3 side distance	0,25	R7 horizontal limits	P.M.
R4 foreland distance	0,85	PRODUCT TOTAL	0,03

Fig. 26 Reductions on theoretical wind potential.

By these efficiency reductions the ecological footprint on basis of wind appears not to be 1/7, but at least 5. For an ecological footprint on the basis of solar energy there are only technical and horizontal limits. A comparable ecological footprint then is 1/10. In both cases efficiency losses should be added caused by storage, conversion and transport, but these are equal for both within an all-electric society.

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[a] http://statline.cbs.nl/StatWeb/publication/default.aspx?DM=SLNL&PA=37281&D1=6-7%2c16-18%2c25&D2=1%2c4%2c7-10&D3=0-52%2c57%2c62%2c67%2c72%2c77%2c82%2c87%2c92%2c97%2cl&HDR=G2&STB=G1%2cT&VW=D

[b] TW$_e$ is the electrical part. To convert 1 PJ/year (10^{15} joule per year) as usual in CBS figures into MW (10^6 joule per second) one should multiply by 31,7 (amongst others dividing by the number of seconds per year: $10^{15}/(10^6*365*24*60*60)$).

Sun, wind or biomass?

The ecological footprint based on biomass depends on location-bound soil characteristics and efficiency losses for instance by conversion into electricity. A total efficiency of 1% applied in the comparance of *Fig. 27* is optimistic.[22]

			W/m^2
rounded off total Dutch energy use	100	GW	1.00
rounded off Dutch electricity use	10	GW	0.10
SUN			
The Nederlands receives	10000	GW	100
after reduction by 0.1	1000	GW	10
required surface	10%		
BIOMASS			
The Nederlands receives	10000	GW	100
after reduction by 0.01	100	GW	1
required surface	100%		
WIND			W/m2
over The Nederlands blows at least	680	GW	6.80
after reduction by 0.03	17	GW	0.17
required surface	577%		

Fig. 27 Comparing the yield of sun, biomass and wind

Costs

What are the costs? In *Fig. 28* for wind, sun and biomass the required surface is represented only. The environmental costs are not yet stable. Environmental costs of new technologies are in the beginning always higher than later on. For coal, uranium and heavy hydrogen the environmental costs are calculated, the required surface is negligible.[a]

	total		**per inh.**	
Current Dutch energy use	**96**	**GW**	**5993**	**W**
yielded by				
solar cells	10	x 1000 km2	0,06	ha
wind	564	x 1000 km2	3,53	ha
biomass	96	x 1000 km2	0,60	ha
surface of The Nederlands inclusive Continental Plat	100	x 1000 km2	0,63	ha
Actual use electric	**10**	**GW**	**652**	**W**
remaining heat	26	GW	1630	W
yielded by				
coal	20864	mln kg coal	1304	kg coal
waste	62592	mln kg CO2	3912	kg CO2
waste	835	mln kg SO2	52	kg SO2
waste	209	mln kg NOx	13	kg NOx
waste	1043	mln kg as	65	kg as
uranium	0.01	mln kg uranium	0,001	kg uranium
waste	3.45	mln kg radio-active	0,216	kg radio-active
heavy hydrogen (fusion)	0.01	mln kg h.hydrogen	0,001	kg h.hydrogen
waste	0.01	mln kg helium	0,001	kg helium

Fig. 28 Environmental costs of energy use

The environmental costs of oil and gas are less than those of coal, but concerning CO_2-production comparable: the total production is approximately 30kg per person per day! That makes clear we have to avoid the use of fossile fuels.

The contribution of alternative sources

The contribution of non fossile fuels is increased substantially (*Fig. 29*), but it is not yet 1 from the yearly used 100 GW. The growth of 0,5% into 0,8% is mainly due to the use of waste including biomass unused otherwise.

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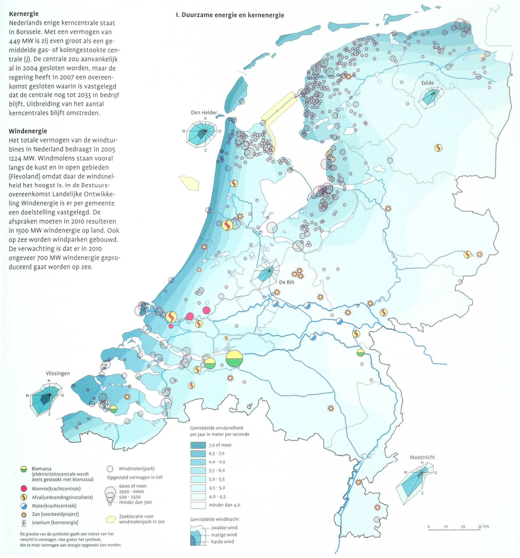
[a] Jong, Moens et al. (1996)



Kernergie
Nederlands enige kerncentrale staat in Borssele. Met een vermogen van 449 MW is zij even groot als een gemiddelde gas- of kolengestookte centrale (J). De centrale zou aanvankelijk al in 2004 gesloten worden, maar de regering heeft in 2007 een overeenkomst gesloten waarin is vastgelegd dat de centrale nog tot 2033 in bedrijf blijft. Uitbreiding van het aantal kerncentrales blijft omstreden.

Windenergie
Het totale vermogen van de windturbines in Nederland bedraagt in 2005 1224 MW. Windmolens staan vooral langs de kust en in open gebieden (Flevoland) omdat daar de windsnelheid het hoogst is. In de Bestuursovereenkomst Landelijke Ontwikkeling Windenergie is er per gemeente een doelstelling vastgelegd. De afspraken moeten in 2010 resulteren in 1500 MW windenergie op land. Ook op zee worden windparken gebouwd. De verwachting is dat er in 2010 ongeveer 700 MW windenergie geproduceerd gaat worden op zee.

De grootte van de symbolen geeft een indruk van het verschil in vermogen. Hoe groter het symbool, des te meer vermogen aan energie opgewekt kan worden.

Fig. 29 Sustainable energy sources and nuclear power in the Netherlands 2007[a]

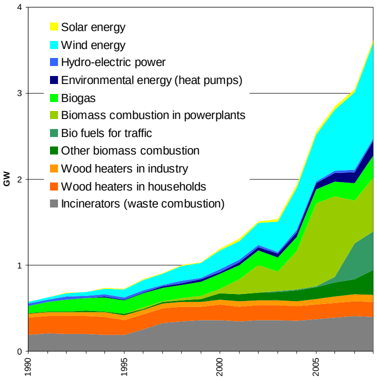


Fig. 30 GW sustainable energy sources between 1990 en 2008[a]

The growth of the contribution of wind, heat pumps and sun (*Fig. 30*) is impressive on itself, but responsible for approximately 0.1% of total energy use.

Stagnating decrease of solar cell costs

Why does solar energy develop so slowly while so much energy can be gained? Solar cells are 100 times as cheap as 40 years ago. The stagnating decrease in price of *Fig. 14* would be due to increasing silicium prices and efficiency improvements in peripheral equipment. Just before passing the economic efficiency of fossile fuels these barriers loom up. The oil industry has collected solar patents and studies that question, in the mean time developing the technology to exploit the still large stocks in oil sands (an ecological disaster). Scenarios still depart from a small contribution of solar energy in 2030. The development of the steam engine lasted 40 years. Are the technological barriers now larger? Any way, the consequences are larger than those of the industrial revolution. Many people will loose their jobs or investments, but use of energy, depletion of resources and mobility would no longer be environmental problems. Only basic ecological problems remain: from the 1.5 mln known species 100 000 are lost, 80% of the human population is not healthy.

Power supply

The capacity of electric power stations in The Netherlands is approximately 15 GW_e (15 000 MW_e), from which at average 10 GW_e is used (the rest is necessary to receive peak loads). These plants produce in the same time approximately 15 GW_{th}. From that heat only a part is used by cogeneration.[b] Electric power stations can not be switched off immediately. Temporary overproduction is sold cheaper at night or into foreign countries (for example to pump up water in storage reservoirs). Approximately 2% is generated by nuclear power, 1% sustainable, the rest by fossile fuels (see *Fig. 24*).

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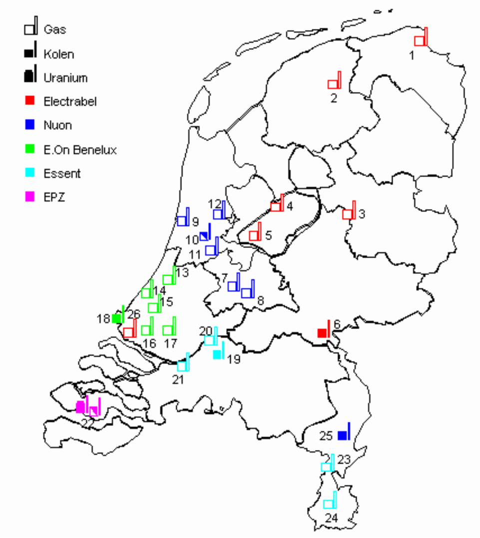
[a] Bosatlas(2007)Bosatlas van Nederland(Groningen)Wolters-Noordhoff

[b] http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=7516&D1=0&D2=0-2,5,14-15,26-30,34,37,42&D3=a&HDR=G2,T&STB=G1&VW=T



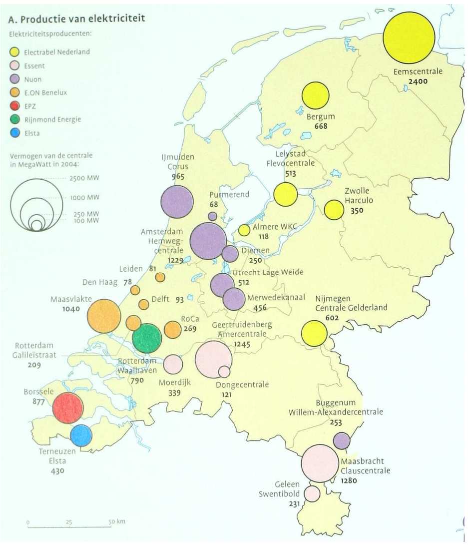


Fig. 31 Power stations in The Netherlands[a] *Fig. 32 MW capacity per power station of Fig. 31*[b]

The use of electricity takes up only a small part of our total consumption of primary energy sources. The Dutch energy balance as a whole is represented in the flow diagram[c] of *Fig. 33*.

Comment [T.M.1]: Pagina: 29
Op basis van de energiestatistieken van het CBS voor 2000 is dit Sankey diagram gemaakt, dat de herkomst en bestemming van energiestromen in Nederland aangeeft. De verschillende energiedragers (aardgas, ruwe olie, olieproducten, kolen, kernenergie, duurzaam, elektriciteit, warmte en afval) zijn alle in PJ's, maar in verschillende kleuren weergegeven. Herkomst van energiedragers is winning dan wel import, of een conversie vanuit andere energiedragers (raffinaderijen, elektriciteitscentrales en WKK). Energieverliezen bij conversie zijn ook in het Sankey diagram verwerkt. Dat is vooral goed te zien bij elektriciteitscentrales: de ingaande stroom gas, kolen, kernergie en afval is groter dan de uitgaande stroom elektriciteit. Bestemming van energiedragers is export of het verbruikssaldo van één van de eindverbruikerssectoren (diensten, huishoudens, landbouw, industrie of transport). De dikte van de lijnen wordt bepaald door de omvang van de energiestromen. Hiermee is in één oogopslag te zien wat de onderliggende verhoudingen zijn. Opvallend is de omvangrijke doorvoer van olie en olieproducten. Ook is het belang van de raffinaderijensector in Nederland te zien. De daar geproduceerde olieproducten worden slechts beperkt in eigen land gebruikt, ze zijn vooral voor de export bestemd. In het binnenlands verbruik speelt aardgas een belangrijke rol.

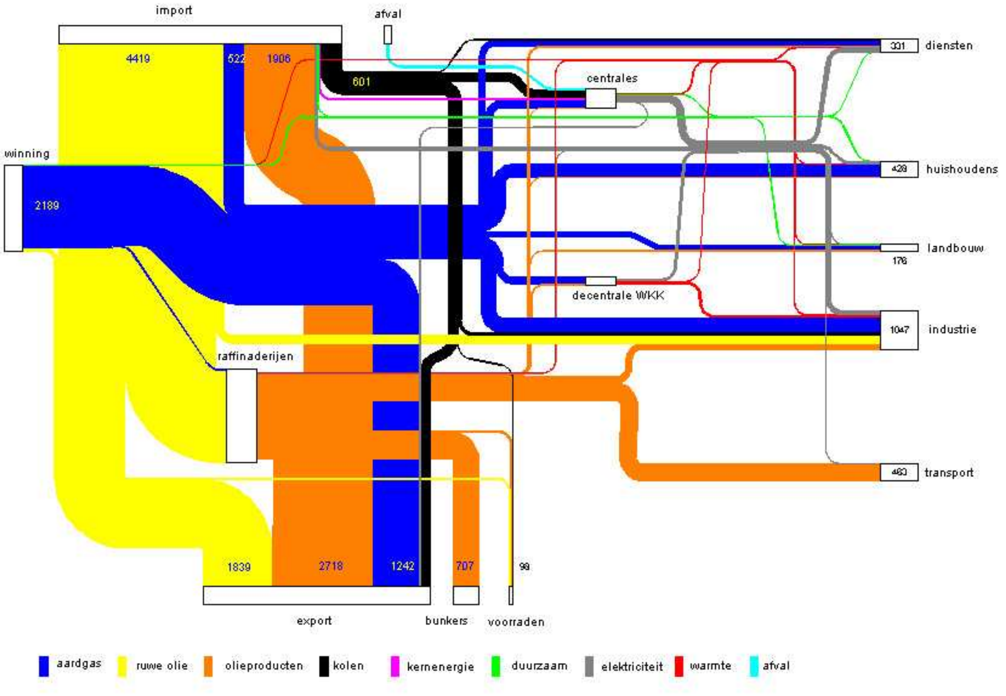


Fig. 33 Energy flows through The Netherlands, 2000 (x PJ equalling 31.7 MWa)[d]

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[a] http://www.energie.nl/
[b] Bosatlas(2007)Bosatlas van Nederland(Groningen)Wolters-Noordhoff
[c] http://www.sdraw.com/
[d] http://www.energie.nl/

A summary like *Fig. 33* is made every year[a]. Adding “winning” (extraction) and import while subtracting export, “bunkers” (stocks) and “verliezen en verschillen” (losses and differences), one has left “verbruikerssaldo” (balance of use). Subtracting from that balance of use what power companies need themselves, one has left the quantity customers can use. Losses on the way to the customer have to be subtracted to find what really lands to the customer, the ‘finaal gebruik’ (final use).[23]

Energy slaves

Calculating back these figures per inhabitant, expressing them into the individual human power during a year (100 Wa), one gets a figure like the number of ‘energy slaves’ people have to their disposal. The balance of use comes down to about 60 energy slaves per Dutch (wo)man. Power companies need 11 of them to produce the rest. So, 46 remain for final use. From these 46 energy slaves industry takes 19, transport 8 and 19 are needed for offices and dwellings. From these 19 natural gas delivers 13, oil 3 and electricity 3 as well.

In 1982 the average inhabitant had 11 energy slaves in his own home, 10 of them needed for heating. At that time there were 2.8 inhabitants per dwelling. So, at average approximately 3000 m3 natural gas per year was needed for heating a house.

1.1.6 Local energy storage

The importance of storage for alternative sources

Sustainable energy sources fluctuate per season or per 24 hour. That is why their supply does not stay in line with demand. Therefore, energy storage is of overriding importance for succes of these sources, but also for mobile applications like cars.[24]

Different kinds of storage

In *Fig. 34* some kinds of storage are summed up with their use of space and efficiency. If you lift up 1000 kg water ($1m^3$) 1 meter against Earth’s gravity ($9.81\ m/sec^2$), you need 1000 kgf or 9810 newton during 1 m and 9810 newton·meter is 9810 joule or 0.0003109 watt during a year (Wa, see *Fig. 2*, page 12). Now you have got potential energy you can partly gain back as electricity any time you want by letting the water flow down via a water turbine and a dynamo. The efficiency is approximately 30%. So, you can gain back maximally some $0.000095\ Wa/m^3$ electricity. If you have a basin of $1km^2$ where you can change the waterlevel 1m you can deliver 95 W_e[b] during a year, 190 W_e during half a year or 34722 W_e (0.00003472 GW_e) during a day. To deliver 1 GW_e you need 1/ 0.00003472 km^2 = 28800 km^2 (see *Fig. 34*). That is nearly three-quarter of the Netherlands! A larger fall (of 10m for example) improves both storage and efficiency of the turbine by increased speed of falling water.

---

[a] See *http://statline.cbs.nl/StatWeb/start.asp?LA=nl&lp=Search/Search*

[b] 1 GW_e means "1 000 000 000 watt electric", the heat part is lost in efficiency reduction.

	Storage[25]	Efficiency		Surface for 1 GW_e during	
	gross	(max.)	net	24 hours	half a year
	Wa/m3	%	Wa/m3	km^2	km^2
Potential energy					
water (fall = 1 m)	0,0003	x30%	=0,0001	28800	5259600
water (fall = 10 m)	0,003	x75%	=0,002	1152	210384
water (100 m)	0,03	x90%	=0,03	96	17532
50 atm. pressed air	1,3	x50%	=0,6	4	789
Kinetic energy					
fly weel	32	x85%	=26,9	0,10	18,56
Chemical energy					
natural gas	1	x80%	=0,8	3,42	625,00
lead battery	8	x80%	=6,3	0,43	78,89
hydrogen (liquid)	274	x40%	=109,5	0,03	4,57
petrol	1109	x40%	=443,6	0,01	1,13
Heat					
water (70°C)	6	x40%	=2,5	1,08	197,24
rock (500°C)	32	x40%	=12,7	0,22	39,45
rock salts(850°C)	95	x40%	=38,0	0,07	13,15

Fig. 34 Storage capacity (for conversion into electricity) from some systems[a]

Land use

From the row ‘50 atm. pressed air’ on, the last column of *Fig. 34* simply departs from a surface with a built height of 1m needed to deliver 1 GWe (1 000 MWe) during 24 hours or half a year continuously. By doubling the height of course you can halve the needed surface. Space for turbines and dynamos is not yet included. Fossile fuel like petrol still stores energy most efficiently.

However, in normal storage circumstances this surface is estimated too large for two reasons. Firstly energy production by some differentiation of sources never falls out completely. So you can partly avoid storage. Secondly, the average time difference between production and consumption is smaller than half a year or 24 hours. So, you need a smaller capacity. However, you have to tune the capacity to peak loads and calculate a margin dependent on the risks of non-delivery you want to take. These impacts can be calculated as separate reductions of the required storage

The actual Dutch energy use amounts nearly 100 GW, partly converted into electricity. So, you do not need 100x the given surface per GW to cover this use from stock. After all, in the total figure losses of conversion from fuel into electricity are already calculated in, and these are calculated in *Fig. 34* as well.

---

[a] After Lysen (1980) and Hermans and Hoff (1982)

1.2 Sun, light and shadow

1.2.1 Looking from the universe (α, β and latitude λ)

The different axes of the Earth's rotation and orbit $\alpha=23,46^o$

The earth orbits around the sun in 365.25 days[a] at a distance of 147 to 152 million km. The radius of the earth is only maximally 6 378 km. So, the sunlight reaches any spot on earth by practically parallel rays. The surface covering that practically circular orbit is called the ecliptic surface. The polar axis of the Earth has always an angle $\alpha = 23,46^o$ with any perpendicular on that ecliptic surface.

The angle β between polar axis and sunrays varies around 90^o at average

On December 22nd (Fig. 35) the angle β between polar axis and the line from Sun into Earth within the ecliptic surface equals $90^o + \alpha$. On March 21st $\beta = 90^o$, on June 21st $\beta = 90^o - \alpha$ and on September 23rd again $\beta = 90^o$. Arrows a in Fig. 35 show the only latitudes where sunrays hit the Earth's surface perpendicular at December 22nd and June 21st. So, the sunlight reaches the earth perpendicular only between plus or minus $23,46^o$ latitude from the equator (tropics). Anywhere else they hit the Earth's surface slanting. At December 22nd the sunlight (sunray b in Fig. 35) does not even reach the northpole inside the arctic circle at $90^o – 23,46^o = 66,54^o$ latitude (arctic night).

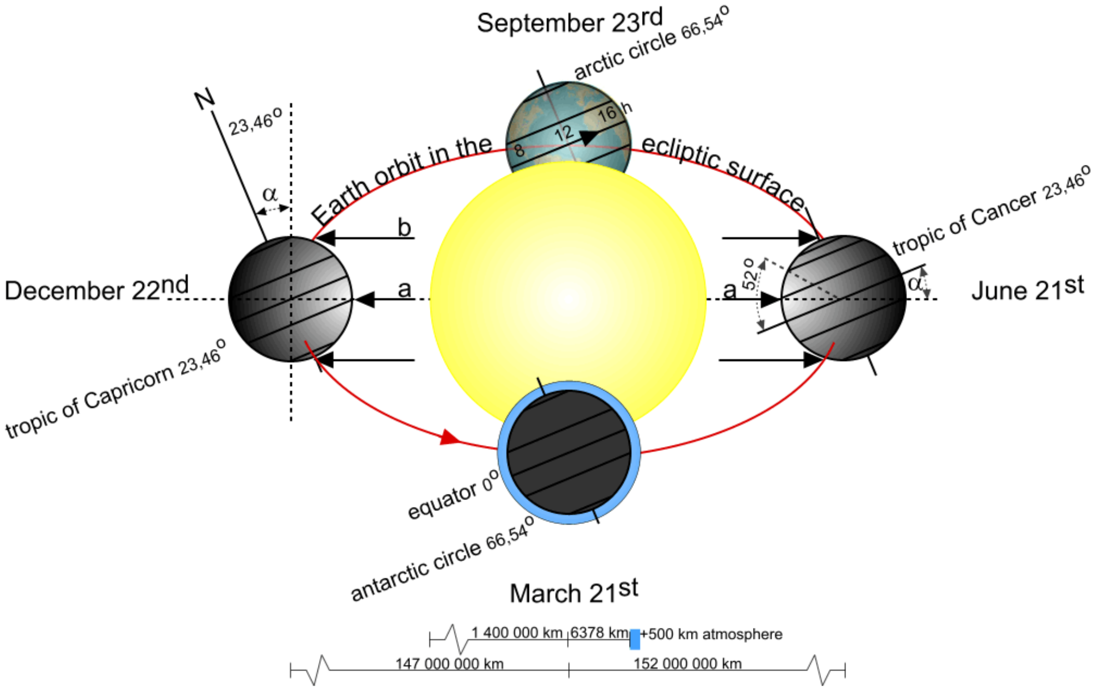

Fig. 35 *The orbit of the earth around the sun*

Sunlight reaching the earth's surface

The sunlight reaching the earth's atmosphere has a capacity of 1353 W/m^2 (solar constant). Some 500 km atmosphere reduces it by approximately 50%. So, any m^2 of sunrays reaching the surface of the Earth distributes say 677 W over its slanting projection on the earth's surface. Let us restrict ourselves

---

[a] These days are 'sun-days'. However, the Earth turns around its axis in 23 hours, 56 minutes and 4 seconds ('star days'). Related to the sun that period is completed into 24 hours by travelling around the sun approximately 1^o per day. So, if we look at distant stars they turn around us in 366.25 days ('star-year'). That is slower than the sun. That is why we see the sun and its other planets travelling against the background of distant stars passing the same 12 constellations in the ecliptic surface called Zodiac in a year: Ram, Bull, Twins, Crab, Lion, Virgin, Scales, Scorpion, Archer, Sea-goat, Water-bearer, Fishes.

in the next section to the two moments per year the sunrays are perpendicular to the Earth's axis of rotation (β = 90° on March 21st and on September 23rd).

Culmination γ, the maximum angle of sunrays to the local Earth's SN surface

In Fig. 36 (left) the solar capacity of $1m^2$ (677W) is distributed that way over the larger surface SN (South-North). That 1 m^2 capacity, divided by hypotenuse surface SN, equals $\sin(\gamma) = \cos(\lambda)$.
So, $1m^2$ Earth's surface in P (maximally turned to the Sun at solar noon) receives $\cos(\lambda) \times 677W$.

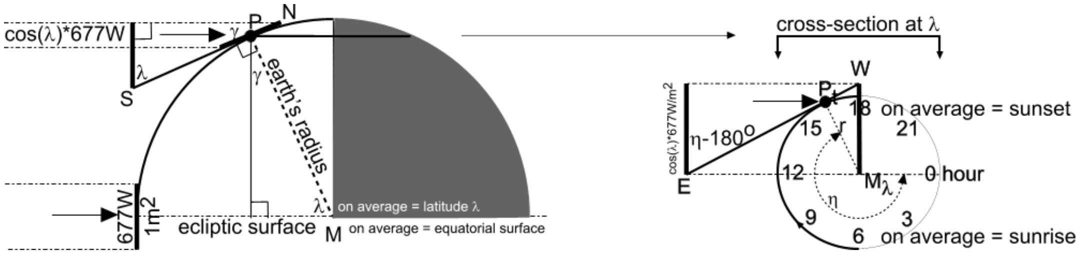

Fig. 36 *The maximally received solar capacity at latitude λ;daily fluctuations with the hour angle η.*

Hour angle η reducing solar capacity turning away from noon

However, by rotation of the Earth noon-point P travels around our latitude in 24 hours. At any other point of the cross-section the maximum capacity $\cos(\lambda) \times 677W$ at noon is reduced again by turning away from the sun (see Fig. 36 right). At solar midnight our location is turned away as much as possible from the sun (hour angle $\eta = 0^o$). At noon our location is exposed to the sun as much as possible (hour angle $\eta = 180^o$). So, at 6 o'clock solar time the hour angle is 90°, at 18 o'clock 270°. Between these hours the maximum capacity $\cos(\lambda) \times 677W$ at noon is reduced again by $\cos(\eta\text{-}180)$ according to the hour of the day.

The average solar capacity given latitude λ

The University of Technology in Delft is positioned around 52° latitude, a global parallel crossing the building for Electrotechnical and Civil Engineering on its campus. The cosine of 52° is 0.616. So, there the year average solar capacity *at noon* is 417 W per square meter earth surface. Averaged again per 24 hours it is $417/\pi = 133$ W (not concerning Dutch weather conditions). This value is reached only as daily average on March 21st or September 23rd. At other dates it varies symmetrically around that average.

Average sunlight per day

On March 21st or September 23rd it happens 24 hours on the whole latitude λ circle because these days polar axis is perpendicular to the sunrays. That circle with radius r of latitude λ ('parallel'), seen from the Sun is a straight line with **2r** length. On both days the Sun continuously delivers $\cos(\lambda)\cdot 677W$ distributed over any m^2 of that line. In 24 hours that capacity is distributed over a larger circular surface length **2πr** of the whole latitude circle. So, the 24hour average is that capacity divided by π. We do not yet have to calculate more cosinuses for every hour (Fig. 36 right) to conclude that 24hour average. And March 21st or September 23rd offer useful averages for the whole year as well.

1.2.2 Looking from the Sun (declination δ)

The day period between sunrise and sunset varies and throughout the year the sunlight reaches the earth's surface at noon by a varying maximum angle γ ('culmination' related to the Earth' surface, not to be confused by declination δ related to its polar axis, see Fig. 38). After all, seen from the sun the earth nods 'yes' (Fig. 37). Bending to left and right does not matter for locally received sunrays.

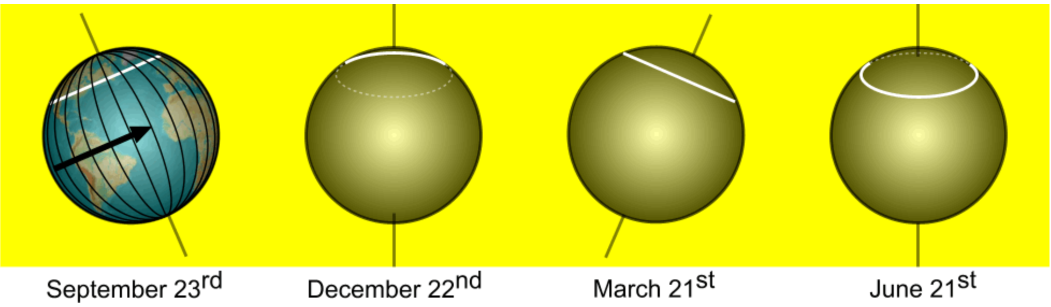

Fig. 37 *The yearly nodding earth with a parallel λ=52^o seen from the sun*

December 22nd the earth is maximally canted $\alpha = 23.46^o$ backwards related to the sunrays. At noon we receive: $677 \cdot \cos(52^o + \boldsymbol{\alpha}) = 170$ W/m^2. Canting forward on June 21st we have to subtract α: $677 \cdot \cos(52^o - \boldsymbol{\alpha}) = 595$ W/m^2. Inbetween we need a variable 'declination' $\{\delta \mid +23.46^o \le \delta \le -23.46^o\}$ instead of α. In Fig. 38 declination δ is positive in June, so now we can write $677 \cdot \cos(\lambda - \delta)$ W/m^2 for any day at noon at any latitude. From Fig. 38 we can derive visually: $\gamma + \lambda - \delta = 90^o$ or $\lambda - \delta = 90^o - \gamma$.

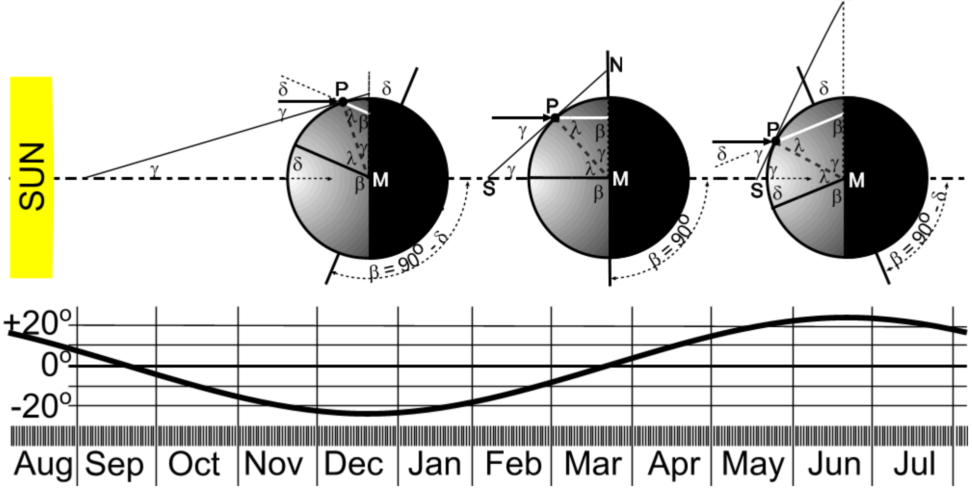

Fig. 38 *Declination δ*

Declination δ could be read from Fig. 38 or calculated according to Voorden (1979) by $\delta = 23.44 \sin(360^o \times (284 + \text{Day}) / 365)$. As 'Day' we fill in the number of days from January 1st, for instance:

Mar21 = 31 + 28.25 + 21 = 80.25
Jun21 = 31 + 28.25 + 31 + 30 + 31 + 21 = 172.25
Sep21 = 31 + 28.25 + 31 + 30 + 31 + 30 + 31 + 31 + 21 = 264.25
Dec22 = 31 + 28.25 + 31 + 30 + 31 + 30 + 31 + 31 + 21 + 31 + 30 + 22 = 356.25

1.2.3 Looking back from Earth (azimuth and sunheight)

The turning earth

But how is that capacity distributed per hour? The earth turns 360^o in 24 hours ousting the Old World by the New Word all the time. That is 15^o per hour, drawn in Fig. 37 (left) by 12 visible meridians of 15^o.

The distribution on a constant latitude λ is not only affected by a declination δ varying day by day but also by the hour angle η visibly varying every minute. From Fig. 39 we derive the hour angle of sunset and sunrise: $\cos(\eta_{sunset}) = h \times \cot(\beta) / r \times \cos(\lambda)$, while $h = r \cdot \sin(\lambda)$.

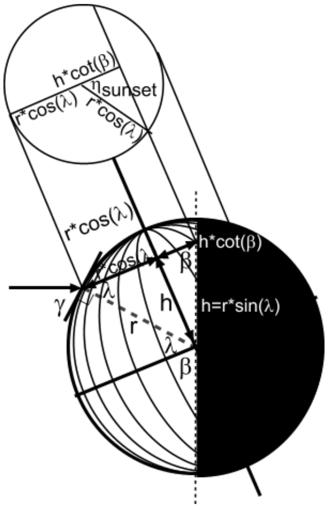

Fig. 39 *Sunset and sunheight at noon varying with β and hour angle η on one parallel circle.*

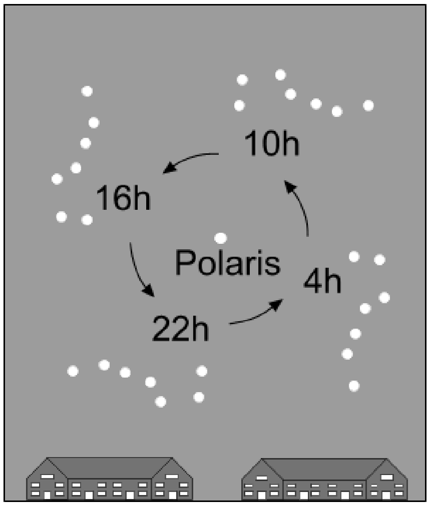

Fig. 40 *Looking back to the universe in the Autumn.*

Within that formula, r plays no rôle and $\cot(\beta) = \tan(90^o - \beta) = \tan(\delta)$, see Fig. 38.
So, we can write:

$$\text{sunrise} = \text{acos}(\sin(\lambda) \times \tan(\delta) / \cos(\lambda)) / 15^o \text{ and sunset} = 24 \text{ hour} - \text{sunrise}.$$

The turning sky

Now we can move our field of vision down to earth looking back to the universe as Copernicus saw it, reconstructing the preceding model from what he saw. Then we see any star moving daily in perfect circles around, the Pole Star (Polaris) practically standing still. So, we see the Great Bear and some 'circumpolar' constellations througout the year turning around Polaris (Fig. 40). Other constellations disappear daily behind the horizon, be it seasonly at an other moment of the day and therefore in some seasons by day not visible behind the brightness of the Sun. Polaris is a star 1600 times more powerful than the Sun, but on a distance of 300 light years. Occasionally it stands in our polar axis apparently standing still that way, moving too little (1 degree) to take into account.

The sun against the background of stellar constellations

The Sun makes its daily circles shifting approximately 1 degree per day (the year circle of 360^o is called eclipse) against a more stable remote background of 12 constellations (the Zodiac[a]), according to its yearly wave seen by a nodding Earth.

Turning ourselves 360^o we see a lamp on our desk describing a circle around us as well. Bowing our head backward 23.46^o while turning around we see the lamp low in our field of vision. When we stay turning around and in the same time walk around the lamp keeping our head in the same polar direction (slowly nodding forward until we are half way and than again backward) we experience how

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[a] Aries (The Ram), Taurus (The Bull), Gemini (The Twins), Cancer (The Crab), Leo (The Lion), Virgo (The Virgin), Libra (The Scales), Scorpius (The Scorpion), Sagittarius (The Archer), Capricornus (The Sea-goat), Aquarius (The Water-bearer), Pisces (The Fishes).

we see the sun during the year starting from December 22st. When we had a third eye in our mouth we would have a complementary view from the southern hemisphere as well.

Sun bows in a sky dome

Such circles we can draw as sun bows in a sky dome using β as deviation from the polar axis (Fig. 41).

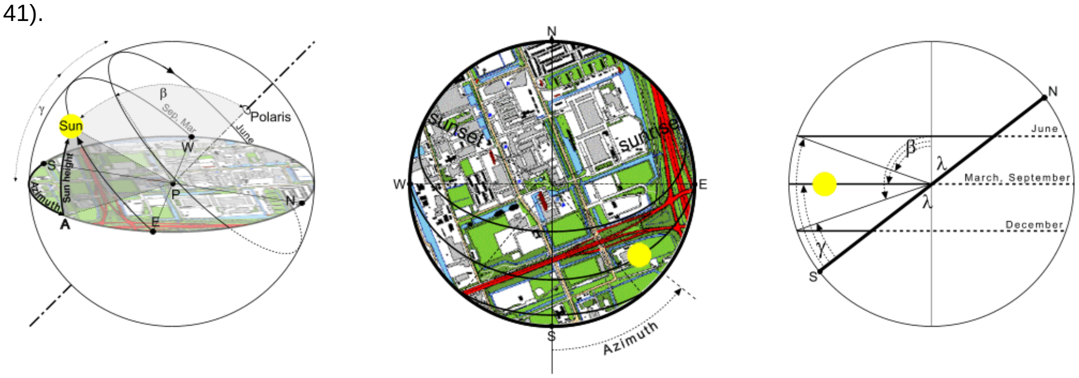
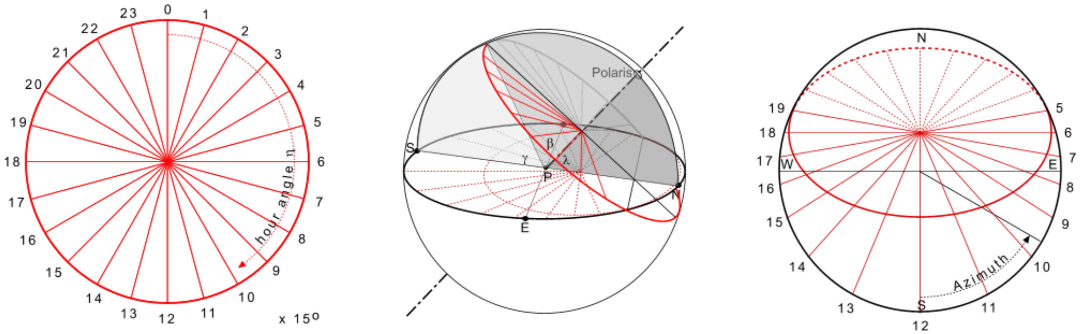


Fig. 41 *Sun bows 3D in a sky dome, map and cross section.*

Projecting the sun bow on the earth's surface

The circular parallel sun bow divided in hours has to be projected as an ellipse on the Earth's surface (see Fig. 42). The hours in the Azimuth angle then decrease in the direction of sunrise and sunset.

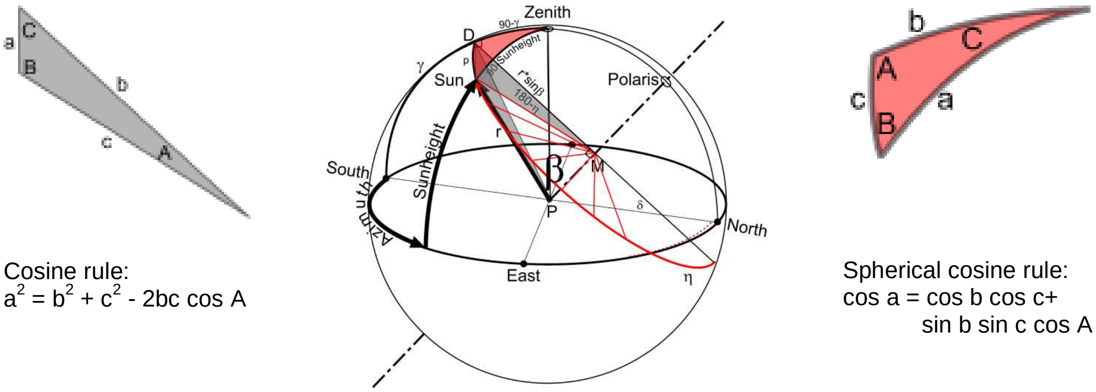


The hour angle η in the parallel surface projected on the Earth's surface.

Fig. 42 *The hour angle transformed into Azimuth.*

Some formulas

To transform the hours of the parallel surface into hours on the Earth's surface we can observe two triangles perpendicular to the surface SouthZenithNorth (see Fig. 43) the first with two equal sides SunM and MD (r sin β), the second with two equal sides SunP and PD (r) as well, and a common third side. The first triangle has an angle SunMD=180^o-η. So, we can use the cosine rule two times to calculate the square of the third side SunD in both triangles and angle SunPD = arc p. Spherical cosine rules applied on the spherical triangle SunZenithD produce Sunheight and Azimuth as angles.



Cosine rule:
$a^2 = b^2 + c^2 - 2bc \cos A$

Spherical cosine rule:
$\cos a = \cos b \cos c + \sin b \sin c \cos A$

Fig. 43 *Two isosceles triangles and a spherical one*

However, Voorden (1979) in his Appendix A and C (see Enclosure 2) derives by more difficult transformation rules the usual and easier formulas:

Declination = 23.44^o x sin(360^o x (284+Day)/365))

Sunheight=
asin(sin(Latitude) sin(Declination(Day)) – cos(Latitude) cos(Declination(Day) cos(Hour x 15^o)

Azimuth= asin(cos(Declination(Day) sin(Hour x 15^o))/cos(Sunheight(Latitude, Day, Hour))

1.2.4 Appointments about time on Earth

On a meridian 1° East of us (68 km on our latitude) local solar time is already 4 minutes later. If we used the solar time of our own location we could only make appointments with persons living on the same meridian. So, we agreed to make zones East from Greenwich of ± 7.5° around multiples of 15° (1026 km on our latitude), using the solar time of that meridian. However, between the weekends closest to April 1st an November 1st we save daylight in the evening by using summertime. By adding an hour around April 1st in the summer, 21.00h seems 22.00h on our watch and it is unexpectedly light in the evening. So, to find the solar time from our watch we have to subtract one hour in the summer and the number of degrees of longitude x 4 minutes West of the agreed meridian. In the Netherlands we use the solar time of 15° East of Greenwich (time zone 1), but live between 3° and 8°.

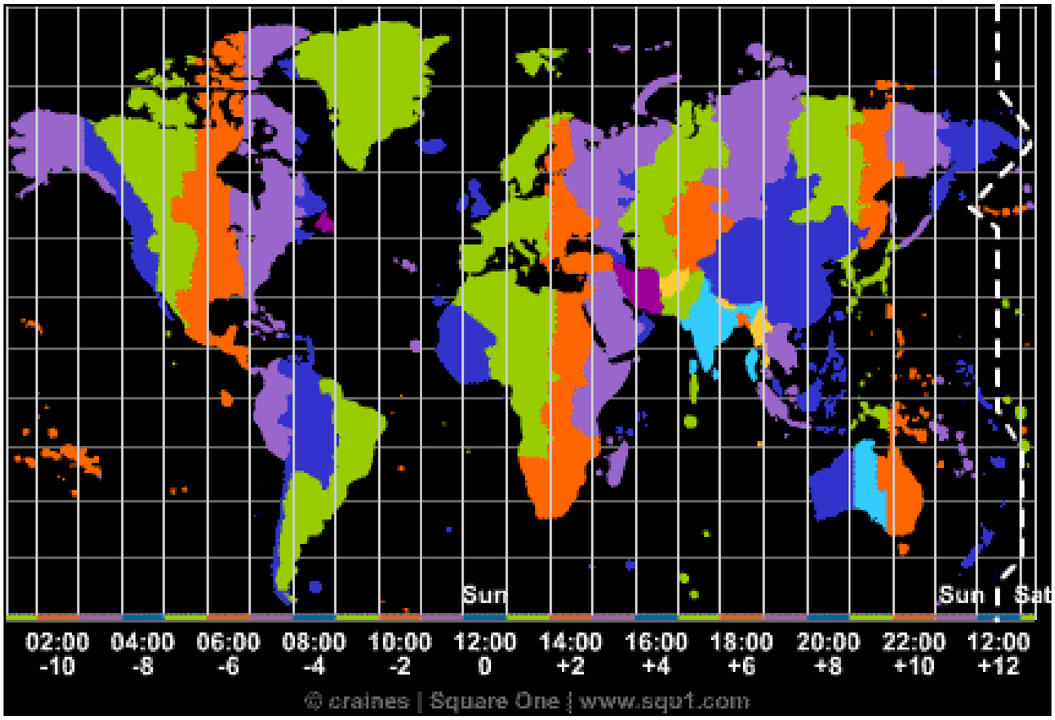


Fig. 44 Time zones[a]

So, on the Faculty of Architecture in Delft (4° 22.5' easter longitude = 4.38°) in winter we have to subtract 15 x 4 minutes from our watch time and add 4.38 x 4 minutes (-10.62° x 4 minutes = -48.48 minutes) to find an approximate solar time. In summertime we have to subtract an extra hour.

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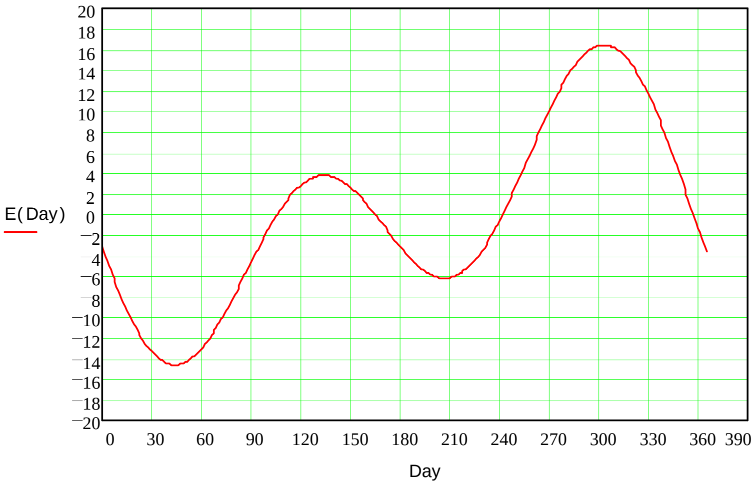
[a] *http://www.squ1.com*

Slowing down traveling around the sun

In addition to these corrections we have to add or subtract some minutes (time equalization E) amongst others due to differences in travel speed (29.3 km/s in summer, 30.3 km/s in winter) around the Sun according to *Fig. 45*.



$$\mathrm{Day} := 0 \,..\, 365$$

$$E(\mathrm{Day}) := 9.87 \cdot \sin\left[\frac{4 \cdot \pi}{364} \cdot (\mathrm{Day} - 81)\right] - 7.53 \cdot \cos\left[\frac{2 \cdot \pi}{364} \cdot (\mathrm{Day} - 81)\right] - 1.5 \cdot \sin\left[\frac{2 \cdot \pi}{364} \cdot (\mathrm{Day} - 81)\right]$$

Fig. 45 Time equalization per day of the year

So, instead of the Hour we read on our watch (WHour with minutes decimally added) in the formulas for Sunheight and Azimuth we should fill in Sun Hour (SHour) from:

SHour(WHour,Timezone,Longitude,Summertime,Day) = WHour - Timezone + Longitude/15^o – Summertime + E(Day)/60

As Timezone we fill in 1, 2, 3 and so on with a maximum of 23. As Summertime we fill in daylight saving yes=1, no=0 and E(Day) we read or calculate from *Fig. 45*.
Finally, atmospheric refraction of 34’ and sun radius of 16’ (together nearly 1^o) shows us sunrise nearly 4 minutes earlier and sunset 4 minutes later, but by day this effect approaches to zero at noon.

1.2.5 Calculating sunlight periods

Putting the formulas we found in an Excel Sheet (download *http://team.bk.tudelft.nl*, publications 2007 Sun.xls), we can check them by observing shadows.

Input									
Date		Time		Latitude		Longitude			
Date	Days	Hour	Minute	Degrees	Minute	Degrees	Minute	Timezone	Summertime
18-apr-03	108,25	**11**	**45**	**52**	**0**	**4**	**30**	**1**	**yes**

Fig. 46 Data needed for solar calcuations

We need date, time, geographical coordinates, the time zone and wether or not we have to take summer time into account. The Sheet brings them into a decimal form and adds a time correction to calculate the hour angle in radians. Excel needs radians to calculate sine, cosine and tangent.

Calculated	**hour**	**h**	**m**	**deg**		**rad**
Watch time	11,75	11	45			
TimeCorrection	-1,69	-2,00	19			
Sunhour	10,06	10	4			
Hour angle				151		2,63
Timezone	1					
Summertime	1					
Latitude				52,00		0,91
Longitude				4,50		0,08

Fig. 47 Restating data in dimensions needed

The sheet then calculates the declination of the day and at what time on our watch we can expect sunrise, culmination and sunset neglecting atmospheric influence from –4 to + 4 minutes. Finally the sheet calculates Azimuth and Sunheight. Azimuth is calculated from South, but a compass gives the number of degrees from North (180 – Azimuth).

Calculated	**hour**	**h**	**m**	**deg**	**rad**
Declination				10,6	0,18
Watch Sunrise	6,77	6	46		
Watch Culmination	13,69	13	41		
Watch Sunset	20,61	20	37		
Azimuth				40	0,70
On Compass	(180 - Azimuth)			140	
Sunheight				42	0,74
Prediction					
Height	10,00				
Shadow	10,97				

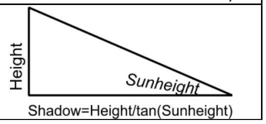


Fig. 48 Solar calculations

The height of an object on the Earth's surface given, the sheet calculates the length of its shadow.

Measuring sunheight

Now we can check these results by putting a pencil in the sun. Measure its height, the length of its shadow and Azimuth as the angle of its shadow with a North-South line (using a map or reliable compass, not disrupted by iron in the neighbourhood!) (*Fig. 49*).

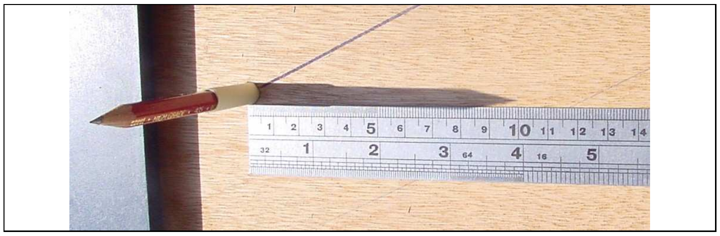


Fig. 49 Fast indoor check of shadow.

Outdoors you can measure angles copying, folding and cutting the paper instrument of *Fig. 50* to get the sunheight and the height of buildings. To measure height of buildings you need a mirror or mirroring piece of glass. Measuring Azimuth you need a compass or map as well.

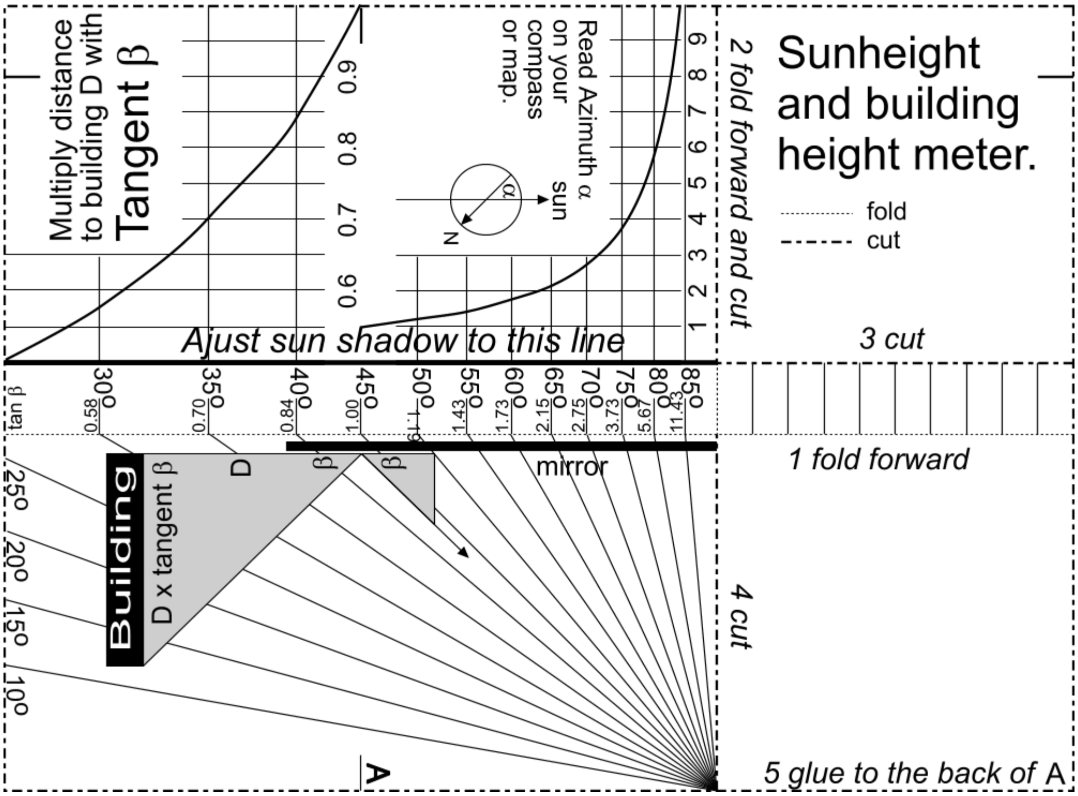


Fig. 50 Cut and fold this paper instrument

Using the paper instrument

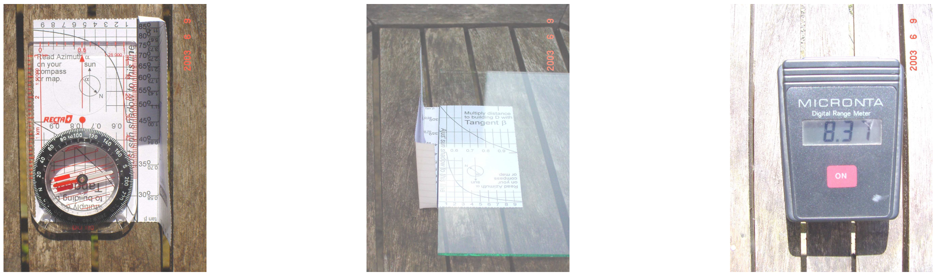


Fig. 51 Measuring Azimuth, sunheight and building height outdoors

Fig. 51 shows a compass directed to the sun by adjustment to the shadow line of a vertical object. It indicates 106° from North, which is 74° from South (azimuth). Sunheight appears to be 39° on the paper instrument. Turning the instrument 180° partly covered by a piece of glass we read an angle of 40° (tangent 0.84) to the upper edge of the mirrored building. According to our distance meter that building is at 8.37m distance. However, when we measure it by tape measure it appears to be 10.30m, occasionally just like the shadow . So, we do not trust the electronic divice. It apparently has measured the tree closer by. The height of the building must be 10.30 x 0.84 = 8.65m above the table surface from which we took the measurement (35cm above ground level). So, the building should be 9m high. That could be right, because the building has 2 storeys (3 layers).

Check your measurement by calculation

Now we can fill in the measurements (Fig. 52) and check its prediction.

date	09-06-03	dd-mm-yy
Watch time	10.15	hour.minute
Building height	9	metres
Shadow	10.30	metres
Azimuth	74	degrees
Sun height	39	degrees
Building height and Shadow would indicate (calculated):		
Azimuth	74	1.29
	degrees	radians
Sunheight	41	0.79

Fig. 52 Checking shadows[a]

The sun height may be measured a quarter earlier. Then it was calculated as 39° indeed. The shadow was predicted to be 10.27m elsewhere in the sheet So, the measurement agrees with the calculation rather well.

1.2.6 Shadow

Around your house

Fig. 53 shows a plot division of 19 dwellings taking shadow into account (download *http://team.bk.tudelft.nl* publications 2003 standaardverkaveling.exe). All of them have the same plot area of 120m^2, but the Southern dwellings have narrow and deep plots to make front gardens possible and make the back gardens accessible for sunlight at some distance of the buiding. However, the Northern dwellings with South gardens have shorter and wider plots and parking lots instead of front gardens and public green. Eastern and western buiding blocks have no sun in the street in the morning or evening but at noon they have. But at the back they have a different character. Western

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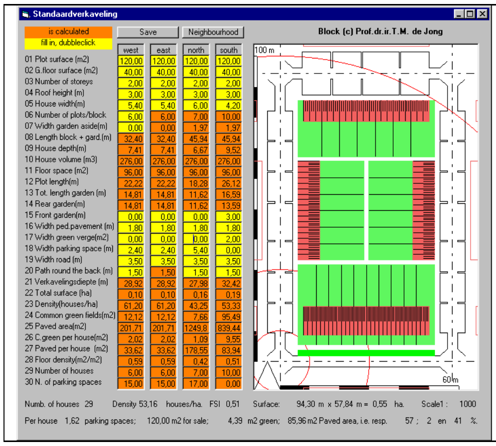
[a] sun.*xls*, downloadable from *http://team.bk.tudelft.nl/* > Publications 2008

blocks do have sun in the garden and living room in the morning, Eastern blocks in the evening. Having breakfast or dinner in the sun attract (or create) people with different life styles.



Standaardverkaveling

is calculated
fill in, dubbleclick

Block (c) Prof.dr.ir.T.M. de Jong

	west	east	north	south
01 Plot surface (m2)	120,00	120,00	120,00	120,00
02 G.floor surface (m2)	40,00	40,00	40,00	40,00
03 Number of storeys	2,00	2,00	2,00	2,00
04 Roof height (m)	3,00	3,00	3,00	3,00
05 House width(m)	5,40	5,40	6,00	4,20
06 Number of plots/block	6,00	6,00	7,00	10,00
07 Width garden aside(m)	0,00	0,00	1,97	1,97
08 Length block + gard.(m)	32,40	32,40	45,94	45,94
09 House depth(m)	7,41	7,41	6,67	9,52
10 House volume (m3)	276,00	276,00	276,00	276,00
11 Floor space (m2)	96,00	96,00	96,00	96,00
12 Plot length(m)	22,22	22,22	18,28	26,12
13 Tot. length garden (m)	14,81	14,81	11,62	16,59
14 Rear garden(m)	14,81	14,81	11,62	13,59
15 Front garden(m)	0,00	0,00	0,00	3,00
16 Width ped.pavement (m)	1,80	1,80	1,80	1,80
17 Width green verge(m2)	0,00	0,00	0,00	2,00
18 Width parking space (m)	2,40	2,40	5,40	0,00
19 Width road (m)	3,50	3,50	3,50	3,50
20 Path round the back (m)	1,50	1,50	1,50	1,50
21 Verkavelingsdiepte (m)	28,92	28,92	27,98	32,42
22 Total surface (ha)	0,10	0,10	0,16	0,19
23 Density(houses/ha)	61,20	61,20	43,25	53,33
24 Common green fields(m2)	12,12	12,12	7,66	95,49
25 Paved area(m2)	201,71	201,71	1249,8	839,44
26 C.green per house(m2)	2,02	2,02	1,09	9,55
27 Paved per house (m2)	33,62	33,62	178,55	83,94
28 Floor density(m2/m2)	0,59	0,59	0,42	0,51
29 Number of houses	6,00	6,00	7,00	10,00
30 N. of parking spaces	15,00	15,00	17,00	0,00

Numb. of houses 29 Density 53,16 houses/ha. FSI 0,51 Surface: 94,30 m x 57,84 m = 0,55 ha. Scale1 : 1000

Per house 1,62 parking spaces; 120,00 m2 for sale; 4,39 m2 green; 85,96 m2 Paved area, i.e. resp. 57 ; 2 en 41 %.

Fig. 53 Plot division taking shadow into account[a]

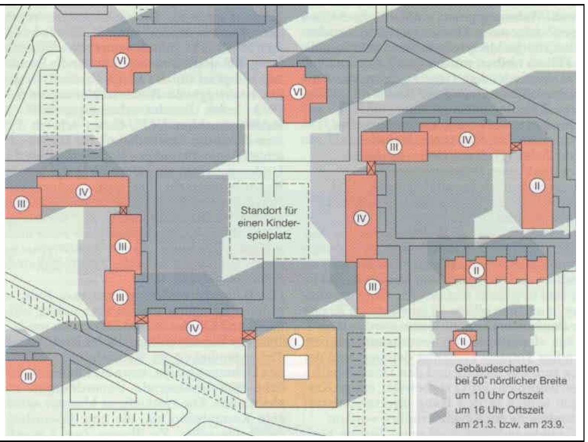


Fig. 54 Avoiding shadow by neigbours according to German regulations[b]

The value of dwellings can decrease when neigbours are not limited in building on their plots by regulation removing sun from other gardens. So, many urban plans regulate building on private plots.

In the garden

Fig. 55 shows the length of shadows on June 2nd from an object of 10m height for every hour. Try other dates.[c]

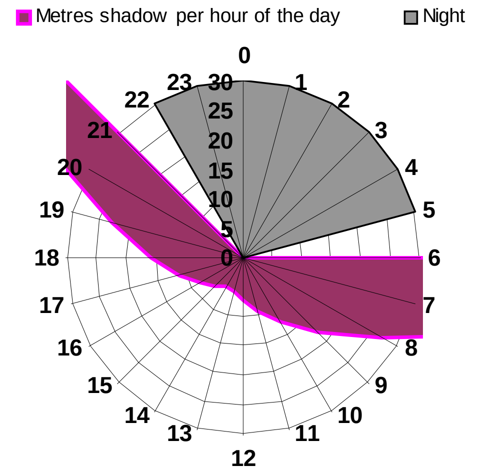


Fig. 55 *Shadows throughout the day June 2nd*[d]

Fig. 56 *A garden on June 2nd at 12 o'clock*

At noon - 13h40min. - shadows are smallest. Turning the figure with that point North we got some idea (not precise, see Fig. 42!) of the shadows to be expected throughout the day. The figure is symmetrical around that point and the centre. It does not seem so because the graph rounds off on full hours, sunrise is at 5h31min., sunset at 21h50min. and noon inbetween. So, we can put the figure on

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[a] Jong (2001)
[b] Hotzan (1994)
[c] Download sun.*xls*, from *http://team.bk.tudelft.nl/* > Publications 2008
[d] sun.*xls*, downloadable from *http://team.bk.tudelft.nl/* > Publications 2008

a map of same scale with that orientaton and shift it on a line with given height to get som idea of the shadow caused by a building block, a line of trees and so on. East~ and westward shadows are symmetrical.[26]

Diversity of life

From an urbanistic point of view shadow is important for climate and lightning of outdoor space, gardens and public spaces. Fig. 56 shows a South garden with two small trees at the southern border (above) throwing shadow. The Northern part has sunlight all day and ants clearly undermine the pavement there. There is a substantial damage on pavements by ants in towns. However, the continuously shadowed Southern part of the garden is more moisty and the pavement is filled by rough moss. At the Eastern and Western part of the circle inbetween the tiles (20x20cm) grass and flatter kinds of moss find their optimum.

North and South parts

In the sunny Northern side sun loving plants like grape (Fig. 57 left) find their optimum, in the Southern shadowed borders you find shadow loving plants like ferns (Fig. 57 middle).

grapes ferns cars

Fig. 57 *Full sun to grow grapes, filtered shadow for ferns and full shadow for parking cars*

On the other side of the building (Fig. 57 right) there is full shadow all day with high trees catching light in their crowns only and slow growing compact shrubby vegetation in a little front garden. Such fully shadowed spaces are suitable for parking lots. “Keep pavements in the shadow” may be a sound rule.

The roof of public space

Trees filter sunlight by small openings projecting images of the sun on the ground as Minnaert noted in the first article of his marvellous book in three volumes on physics of the open air. You can see it best when an eclipse of the sun is projected thousendfold on the ground (Fig. 58). Most solar images are connected to vague spots and sometimes the openings in the foliage are too large to get clear images. Leaves of a tree are composed differently into a so called leaf mozaic (Fig. 59).

Fig. 58 *Eclipse of the sun August 11th 1999*

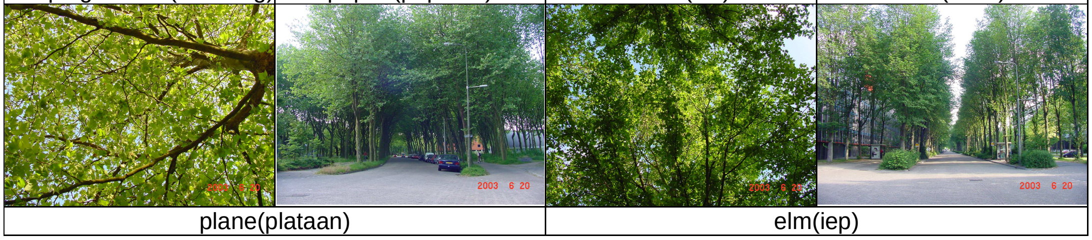
Fig. 59 *Leaf mozaic*

That roof of public space is worth more attention. People love the clairobscur of filtered light with local possibilities of choice for full sun and full shadow meeting their moods. It challenges their eyes more than one of the extremes continuously. Urban designers should be aware of the importance of light and its diversity in cities. None of them ever makes a shadow plan, though any painter knows that shadow makes the picture. The same goes for artificial city light in the evening and at night. Dry engineers calculate the minimum required amount of light for safety to disperse streetlamps as equally (economically) as possible over public space.

Fight for light

Nature's diversity is primarily based on competition for light. Some plants grow as high as possible to outrun neighbours. Others are satisfied by less light growing slower, using more years to reproduce. By very closed foliage some trees do not leave any light to plants on the ground like spruces and beeches. They are the trees of dark forests. Trees of light forests are not stingy with light for plants growing below, like birches. They need helpers there to get the right minerals from soil. So, trees are different in light permeability (Fig. 60).

weeping willow (treurwilg) poplar(populier) alder(els) lime(linde)



plane(plataan) elm(iep)

Fig. 60 *Light permeability of trees*

Light

How do we measure such differences? The power of visible radiation (the part of radiation we call 'light') produced by a 1/60 cm^2 black body with the temperature of melting platina (2047^{o}K) under specified pressure in a specified angle ('sr', 8% of a sphere, see *Fig. 61*) is 1 candela (cd).[27] That equals 1/683 watt/sr. It is a measure characterising the power of a source of light in its point of departure, not its dispersed impact elsewhere, at any distance or surface. To quantify *that* amount of light we need an other unit, the lux. To calculate the number of lux you receive at your desk, you have to take the distance to the source into account, because that determines the dispersion of light power per m^2 of your desk. If you want 1 lux covering 1m^2, you need a power of 1 candela at 1m distance and that is called 1 lumen. The surface increases with the square of the distance, so at 2 m distance you need 4 lumen and 14 candela (produced by a light bulb of less than 0.1 watt). To be able to read you need much more.

The Sun produces $2 \cdot 10^{28}$ candela, but the amount of light reaching the Earth is small. To calculate that amount we have to divide the number of candelas of the Sun by some angle covered by the Earth to get the number of lumens at that distance. What we subsequently receive per m^2 is lux (lumen/m^2). The Earth receives $7 \cdot 10^{17}$ lumen. Devided by its cross (see Fig. 35) section that would be approximately 5000 lux. That is too much to read a book.

Now, let us take a closer look.

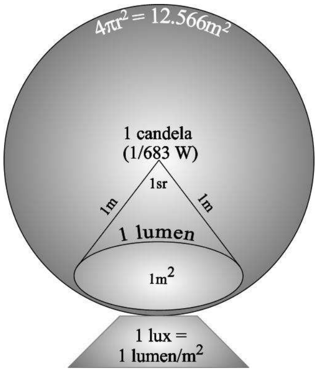
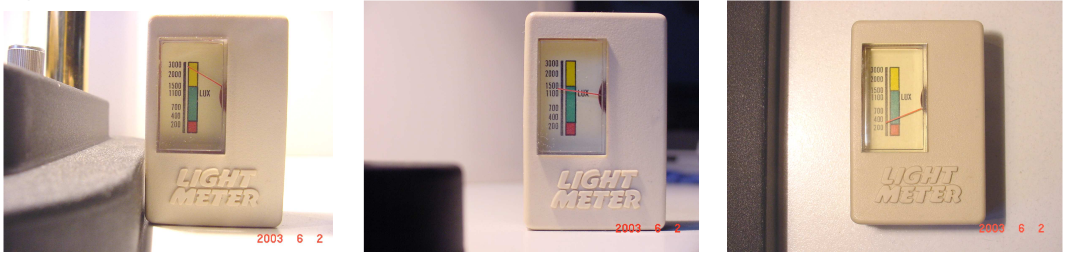


Fig. 61 Candela, lumen, lux

An angle covering 1 spherical m^2 at 1m distance (radius) around the source[a] is called a 'spherical radius' ('sr', ample 8% of a sphere, a rotated angle of 65.541^{o}). A candela (cd) produces per sr a power of 1 lumen (lm), at 0.5 sr 0.5 lm, dispersing that power according to the distance to source. So, cd = lm/sr and lm = cd·sr.[28]

But how much power actually reaches your book? The lightning power of 1 lm *per m*^{2} on a specific location is 1 lux (lx). So, lx = cd·sr /m^2.[29] And you need 300 – 1500 lux to read a book. Lux is something we can measure easily by a lux meter. Fig. 62 shows how shifting the lux meter 10cm can decrease lightning power from 2500 to 1100 lux.

Light on your desk



directly under the lamp at a small distance 90^{o} turned laying flat

Fig. 62 *Impacts of distance to source and direction of surface on local lightning power*

Turning the lux meter 90^{o} (Fig. 62) diminishes the available power/m^2 further to 300 lux. So, distance to source and orientation of surface to light in the neighbourhood of the source (here approximately 30cm) make much difference. On larger distance the impact is less dramatic. Besides to this, the colour differences between the photographs show the differences a camera can not compensate like our eyes do by perception with brains near by.

To calculate which lamp you need at a given distance to read a book, you can avoid candelas if you know the lumen/watt efficiency of a lamp. A light bulb has 12 lm/W, low voltage halogen 20, a LED nowadays reaches 150. If you need 300 lux, that is 300 lm/m^2 at 1m, but lumens are dispersered over a larger surface by the square of the distance to the source, so you should divide the available lumens by the square of the distance. So, at 2m you need 1200 lm. That is a light bulb of 100W, a low voltage halogen of 60W or LEDs totalling 8W.

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[a] Or in 100 spherical m^2 at 10m distance (radius). Surface or distance do not matter, only their proportion called 'spherical radius' or 'sr' matters