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

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 1 GJ = 31.7 Wa 1 TJ = 31.7 kWa 1 PJ = 31.7 MWa	'a' from latin 'annum' (year) Wa is watt during a year 'k' (kilo) means 1 000x '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).

[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^{o}C, 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*).

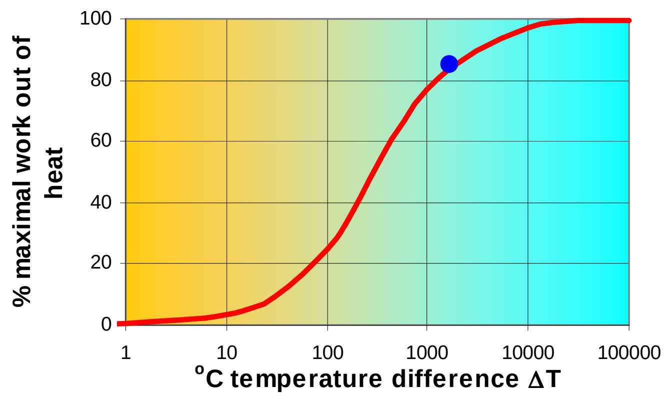


Fig. 3 The %maximum amount of work (W) retrievable from a temperature difference ΔT

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}.

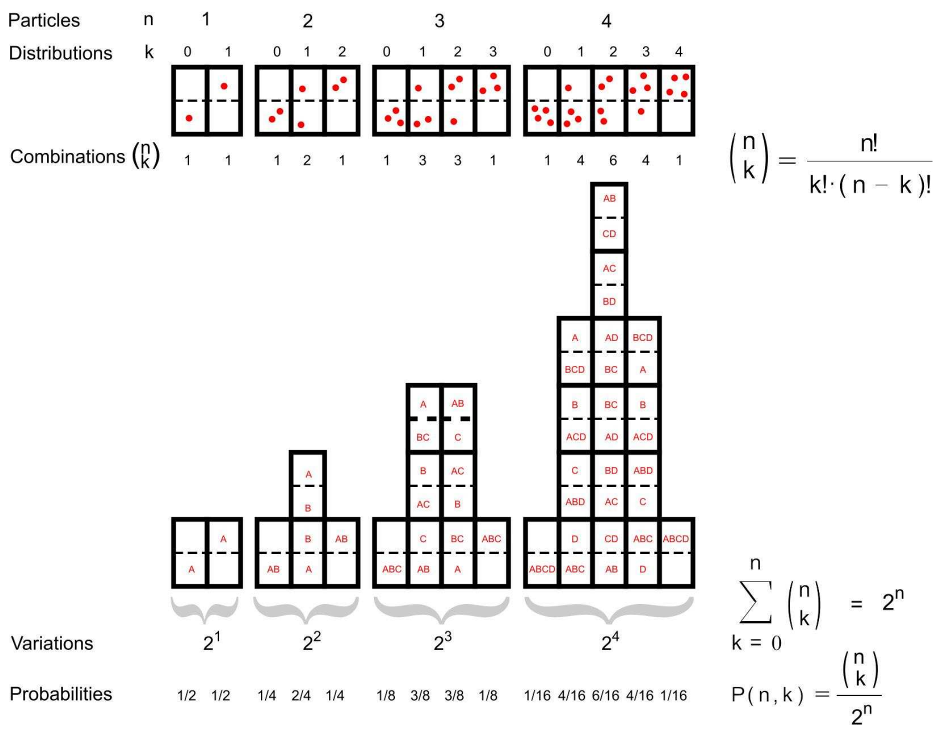


Fig. 4 k Distributions of n particles in two rooms

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).

[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).

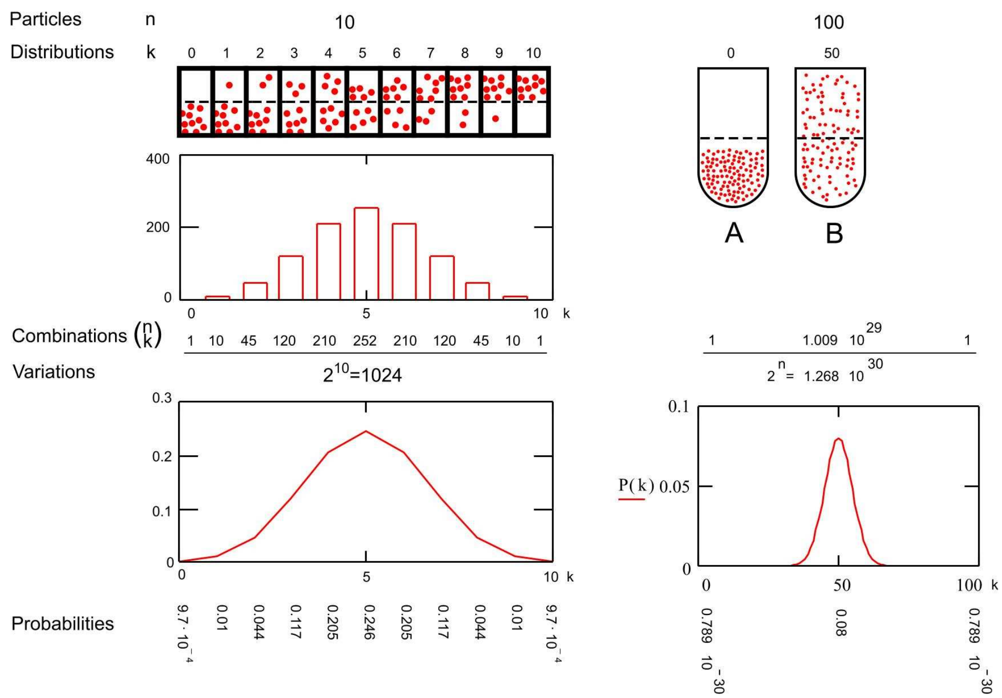


Fig. 5 The decreasing probability of concentration with a growing number of particles

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].

[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

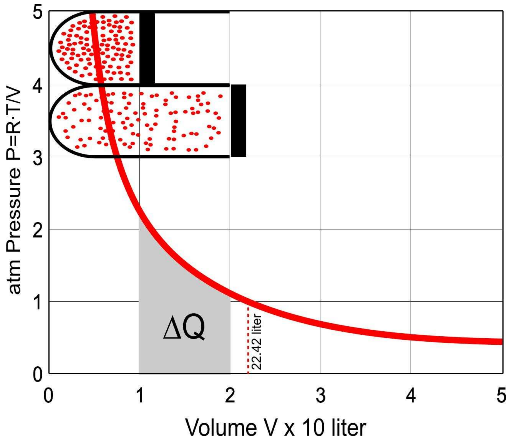
In *Fig. 9* P is the pressure (force/m^2) and V is the volume (m^3). So, on balance P·V is 'force times distance': energy (expressed in newton·m: joule). T is the temperature in degrees of Kelvin (K).

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*).

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

Fig. 10 Extending 1 mole of gas (22.42 liter at 1 atmosphere) from 10 to 20 liter keeping T at 0^oC 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).

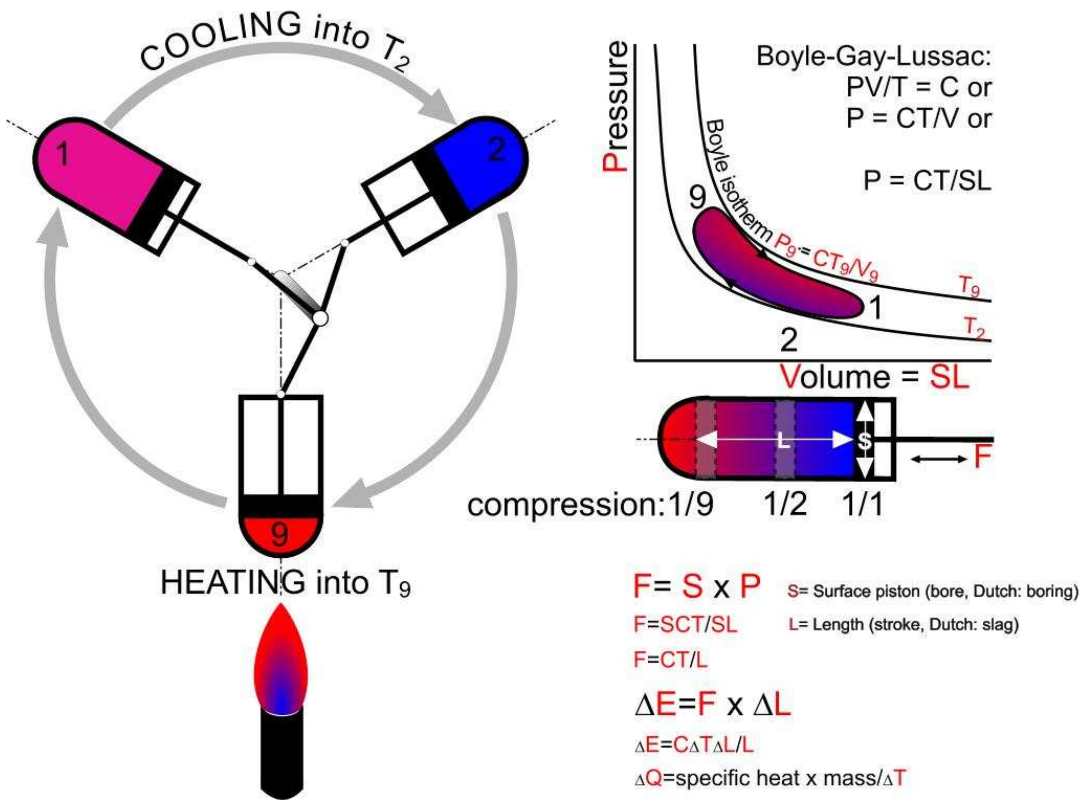


Fig. 12 Carnot-engine

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 respective 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.

[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]

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

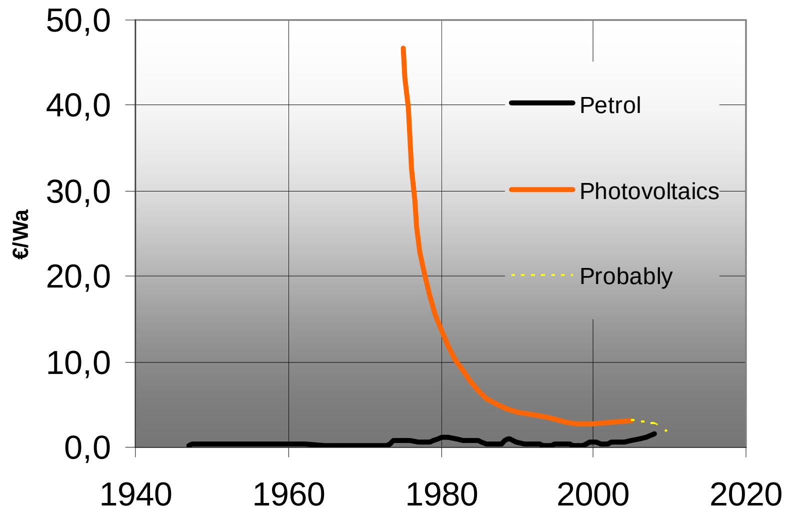


Fig. 14 Decreasing costs of solar cells and petrol[a], possibly developing according to [a].

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).

[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.

[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.

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

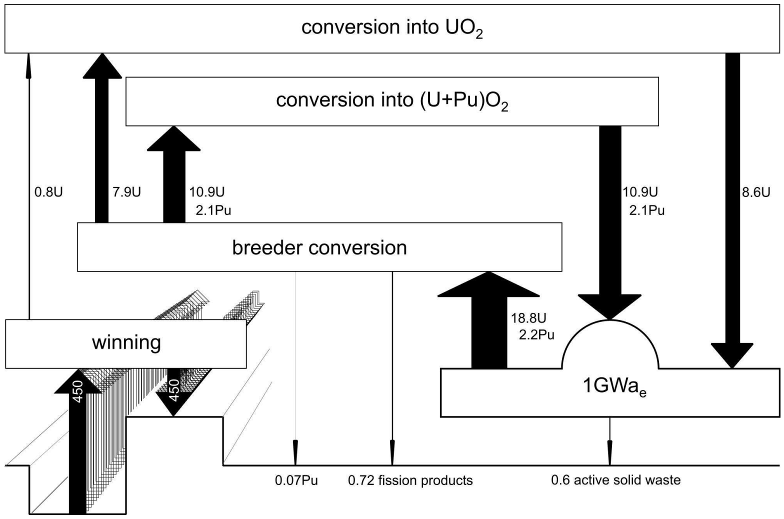


Fig. 18 Nuclear fuel cycle of a fast breeder reactor in 1000kg, producing 1 GWa_e [a]

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

[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.

[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.

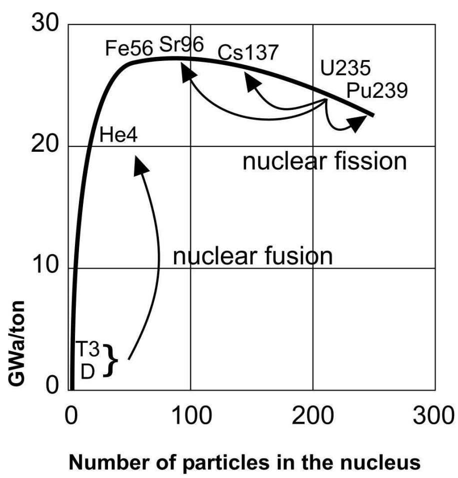


Fig. 20 Bond energy of nuclei as a function of the number of particles[a]

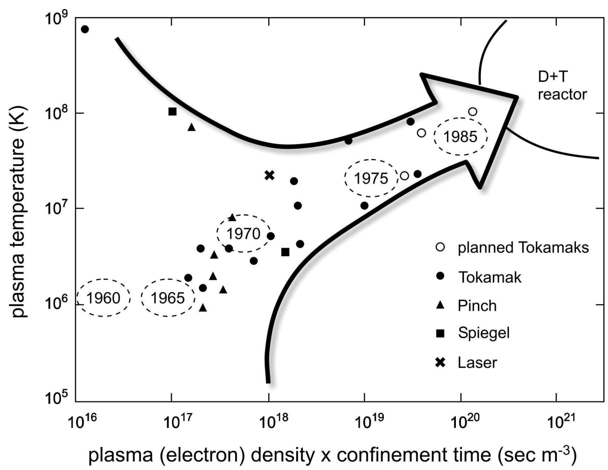


Fig. 21 Progress of nuclear fusion as expected in 1982[b]

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 20^{th} 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

[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*).

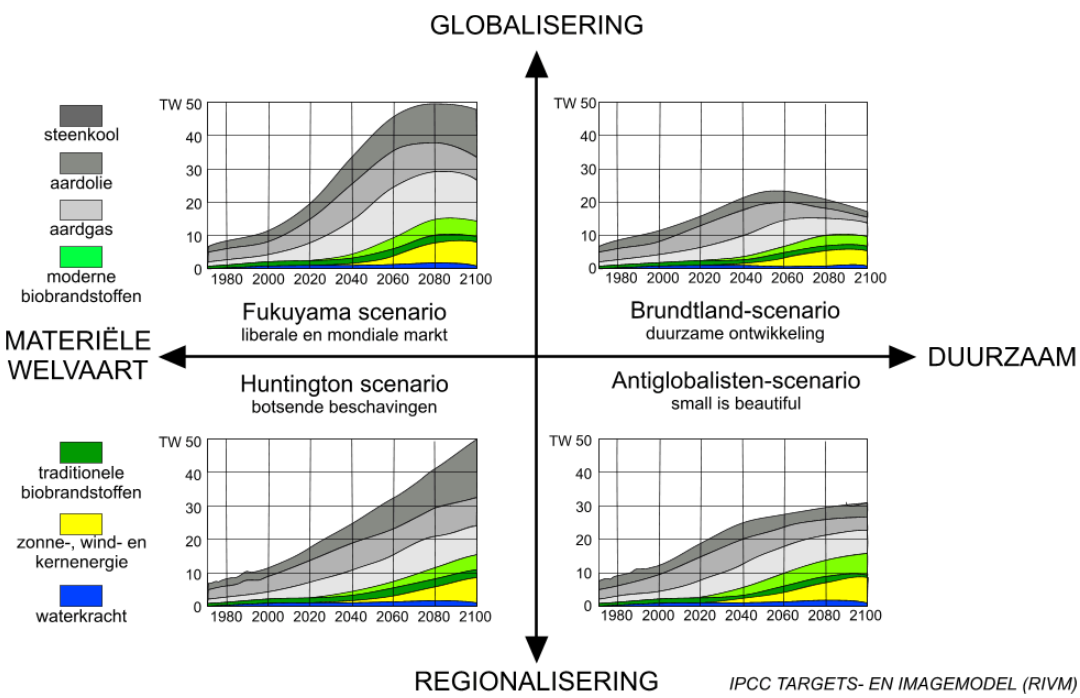


Fig. 22 Energy scenarios[a]

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

[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].

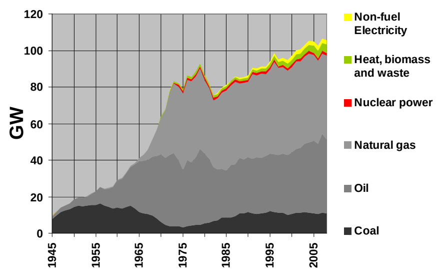


Fig. 23 Development of Dutch energy use 1945-2008 ..

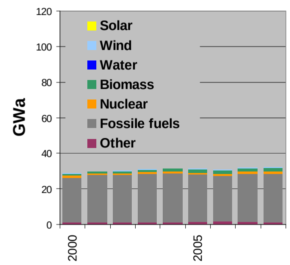


Fig. 24 .. of which used by power stations 2000-2008

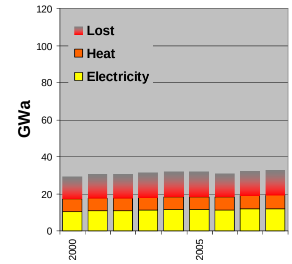


Fig. 25 .. of which used as electricity, heat and lost

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.

[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.

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

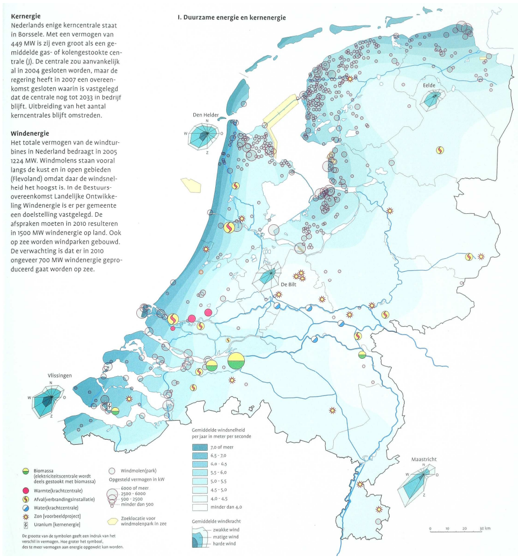


Fig. 29 Sustainable energy sources and nuclear power in the Netherlands 2007[a]

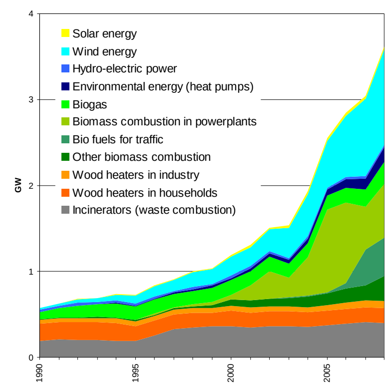


Fig. 30 GW sustainable energy sources between 1990 en 2008[a]

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*).

[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

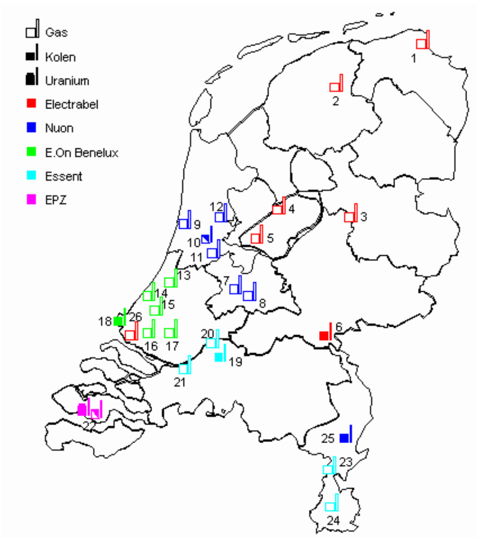


Fig. 31 Power stations in The Netherlands[a]

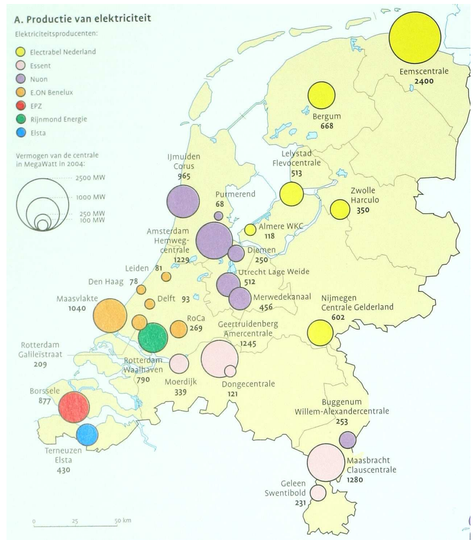


Fig. 32 MW capacity per power station of Fig. 31[b]

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*.

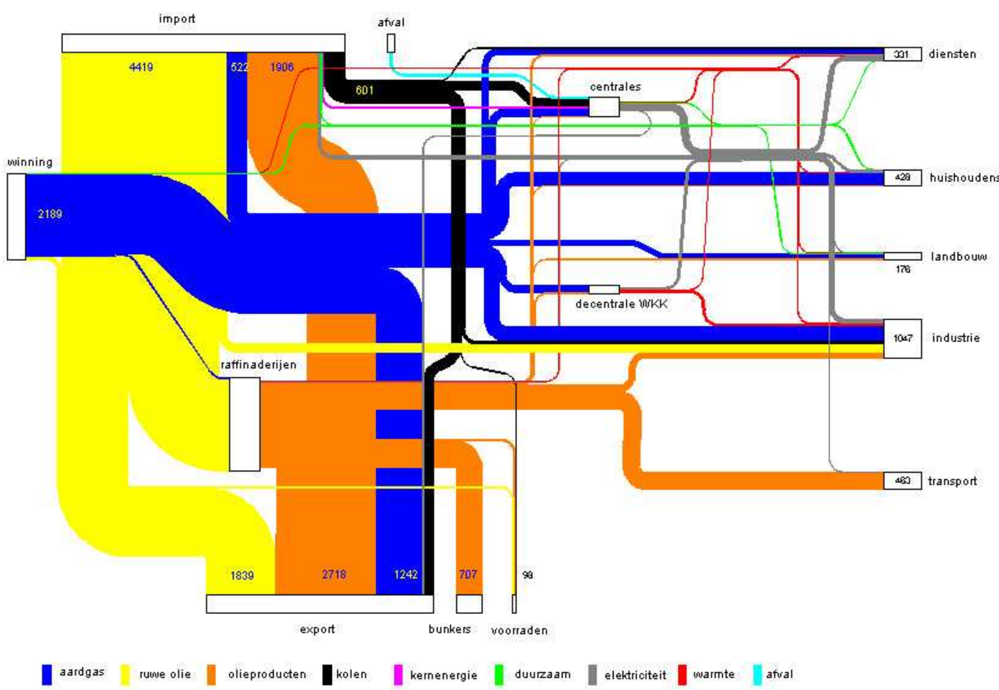


Fig. 33 Energy flows through The Netherlands, 2000 (x PJ equalling 31.7 MWa)[d]

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.

[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 α=23,46°

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 α = 23,46° with any perpendicular on that ecliptic surface.

The angle β between polar axis and sunrays varies around 90° 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° + α. On March 21st β = 90°, on June 21st β = 90° - α and on September 23rd again β = 90°. 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° 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° – 23,46° = 66, 54° latitude (arctic night).

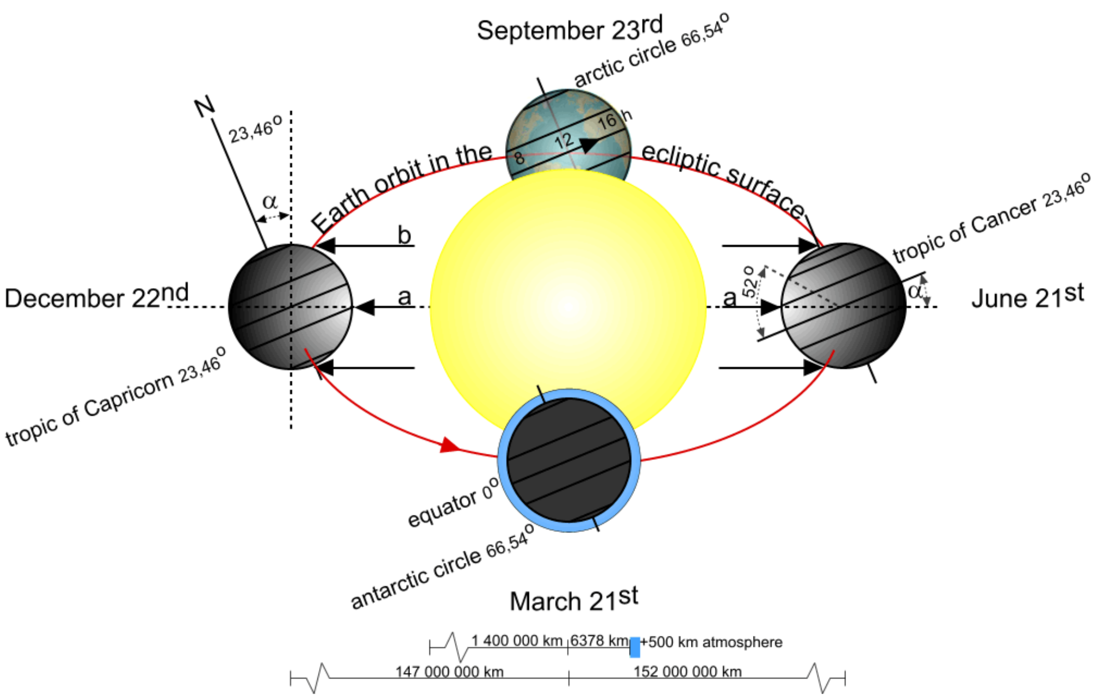


Fig. 35 *The orbit of the earth around the sun*

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° 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 ($\beta = 90^o$ 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 $\cos(\lambda)$ x 677W.

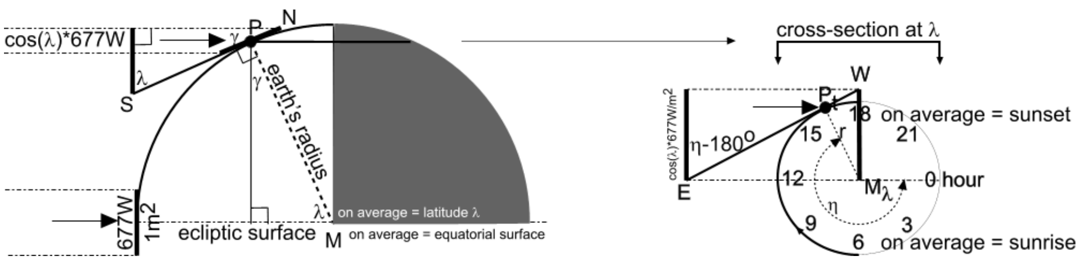


Fig. 36 *The maximally received solar capacity at latitude λ;daily fluctuations with the hour angle η.*

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 $\cos(\lambda)$ x 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^o, at 18 o'clock 270^o. Between these hours the maximum capacity $\cos(\lambda)$ x 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^o latitude, a global parallel crossing the building for Electrotechnical and Civil Engineering on its campus. The cosine of 52^o 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 $\cos(\lambda)\cdot 677$W 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.

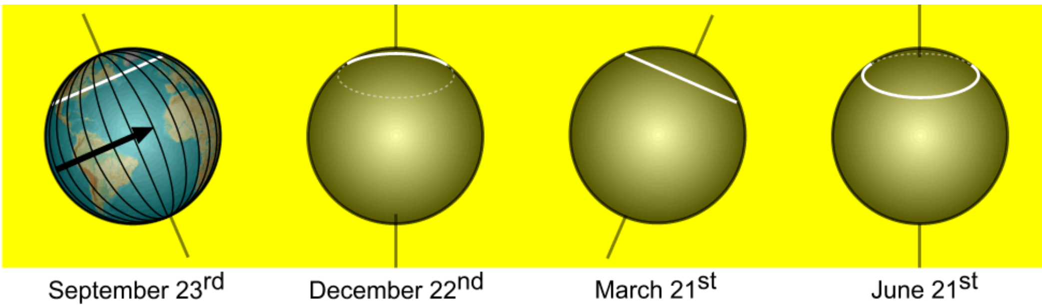


Fig. 37 *The yearly nodding earth with a parallel λ=52^o seen from the sun*

December 22nd the earth is maximally canted $\alpha = 23.46^o$ backwards related to the sunrays. At noon we receive: $677 \cdot \cos(52^o \mathbf{+ \alpha}) = 170$ W/m^2. Canting forward on June 21st we have to subtract α: $677 \cdot \cos(52^o \mathbf{- \alpha}) = 595$ W/m^2. Inbetween we need a variable 'declination' $\{\delta \mid +23.46^o \leq \delta \leq -23.46^o\}$ 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 $\lambda - \delta = 90^o - \gamma$.

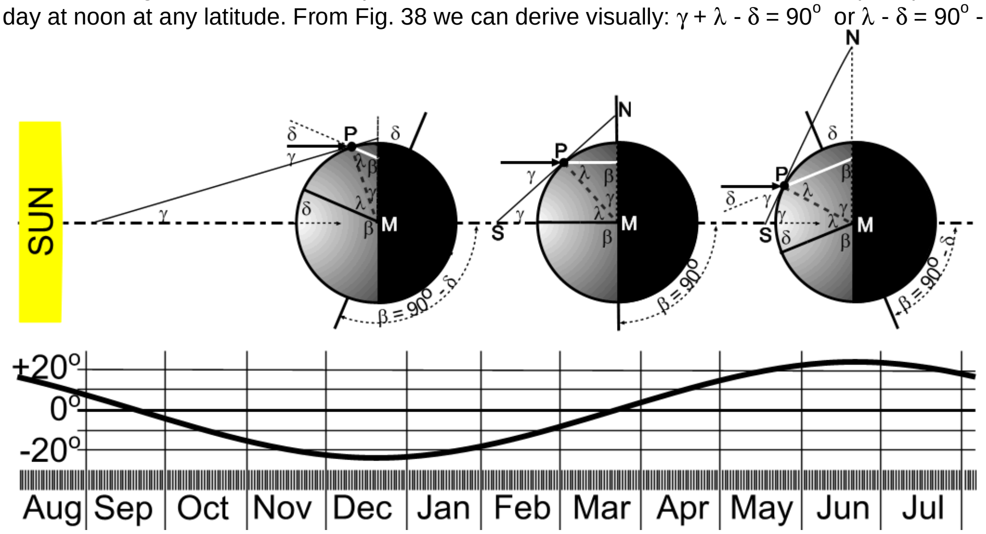


Fig. 38 *Declination δ*

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 x $\cot(\beta)$/r x $\cos(\lambda)$, while h = $r \cdot \sin(\lambda)$.

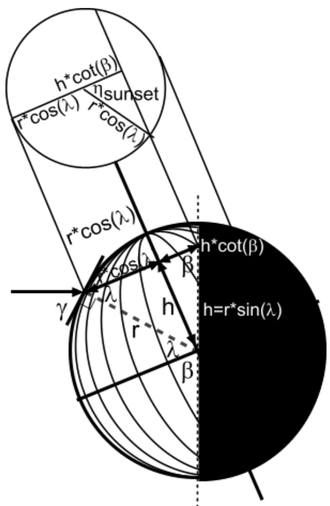


Fig. 39 *Sunset and sunheight at noon varying with β and hour angle η on one parallel circle.*

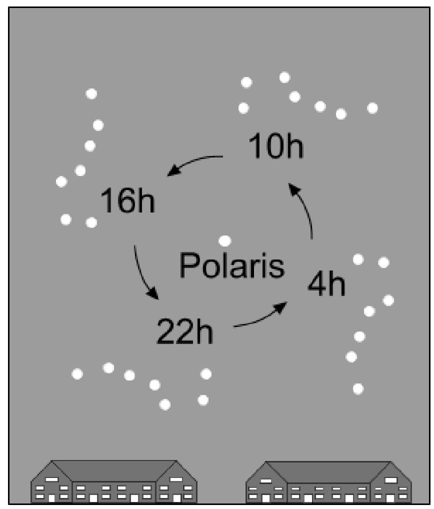


Fig. 40 *Looking back to the universe in the Autumn.*

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

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

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

[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).

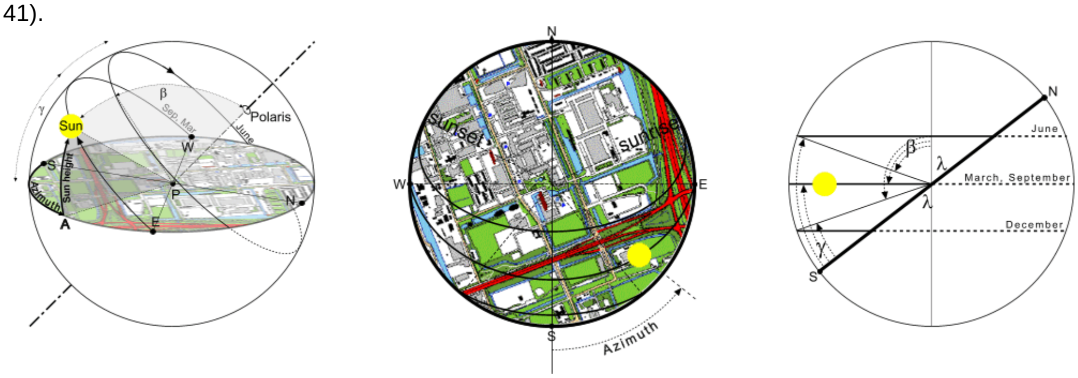
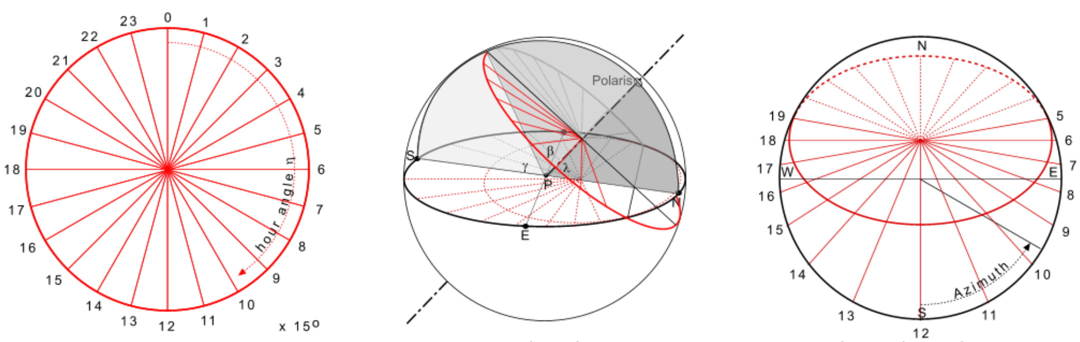


Fig. 41 *Sun bows 3D in a sky dome, map and cross section.*

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.

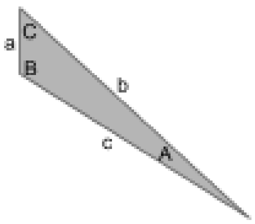


The hour angle η in the parallel surface projected on the Earth's surface.

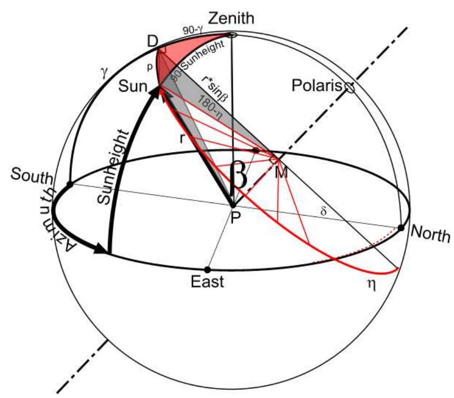
Fig. 42 *The hour angle transformed into Azimuth.*

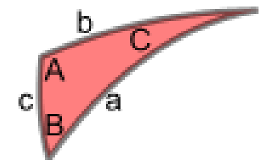
Some formulas

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 ($r \sin \beta$), 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°.

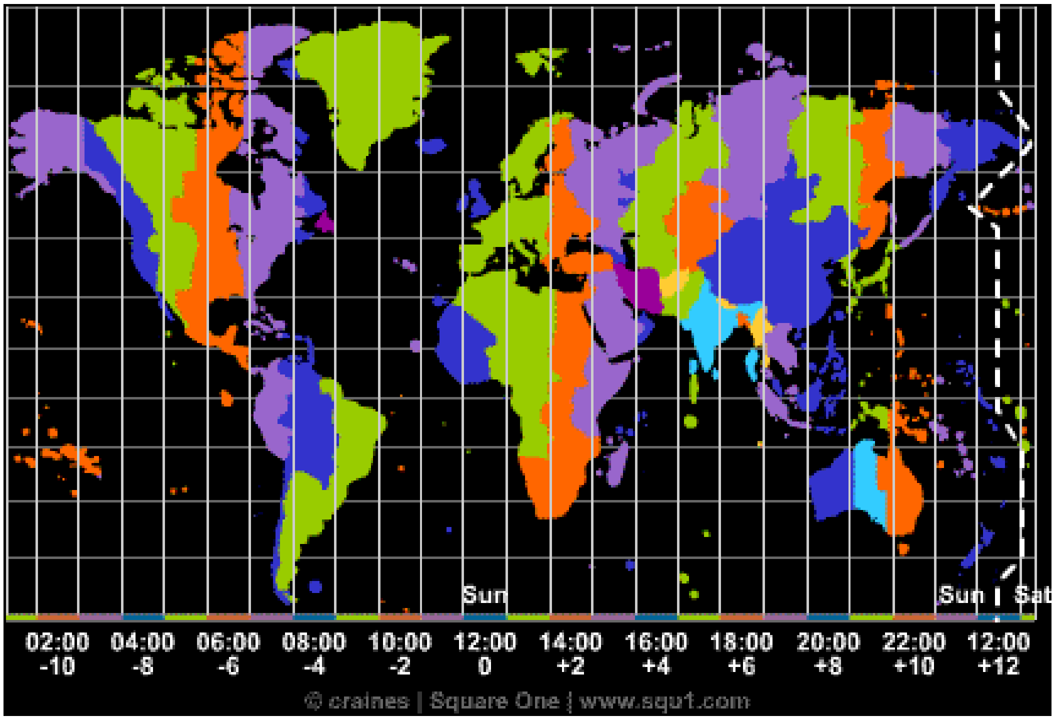


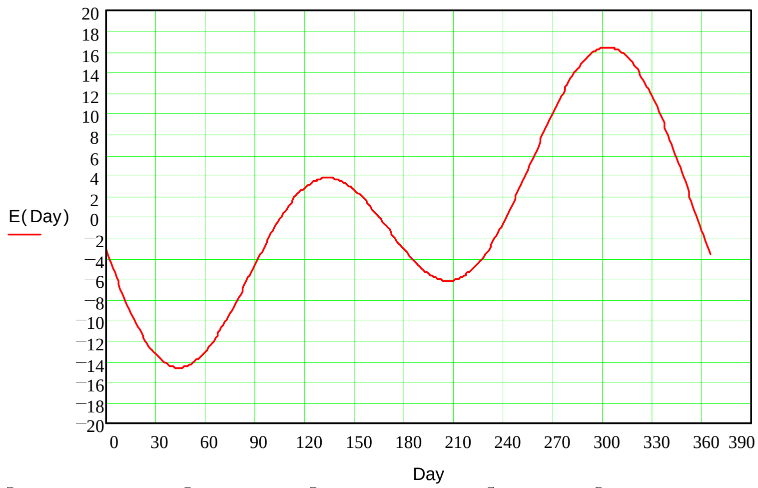
Fig. 44 Time zones[a]

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.

[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*.



$$Day := 0..365$$

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

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				

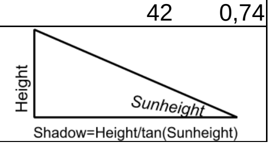


Fig. 48 Solar calculations

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*).

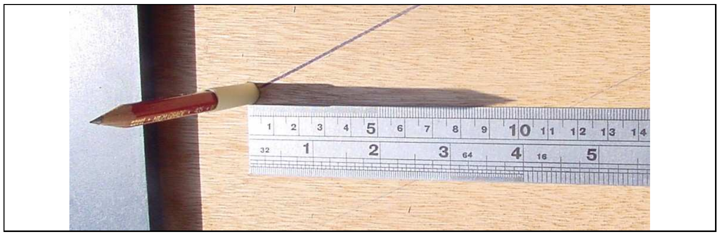


Fig. 49 Fast indoor check of shadow.

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.

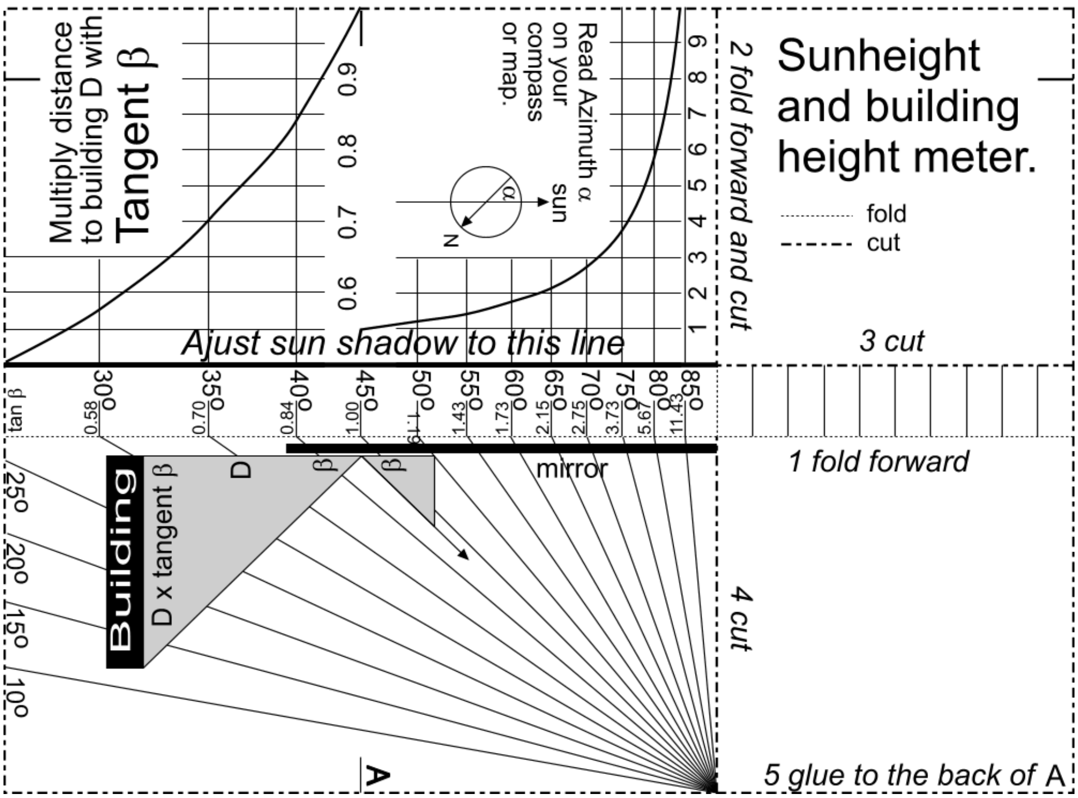


Fig. 50 Cut and fold this paper instrument

Using the paper instrument

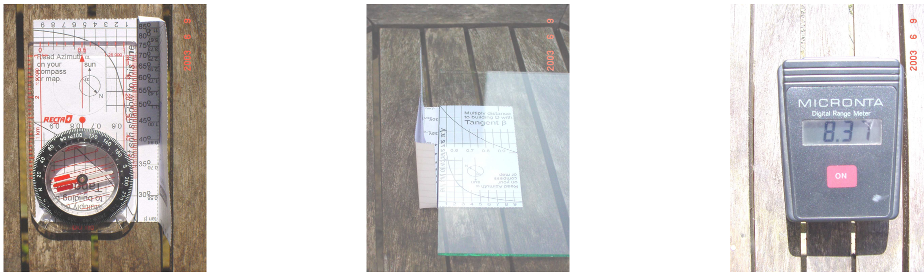


Fig. 51 Measuring Azimuth, sunheight and building height outdoors

Fig. 51 shows a compass directed to the sun by adjustment to the shadow line of a vertical object. It indicates 106^o from North, which is 74^o from South (azimuth). Sunheight appears to be 39^o on the paper instrument. Turning the instrument 180^o partly covered by a piece of glass we read an angle of 40^o (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^o 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

[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.

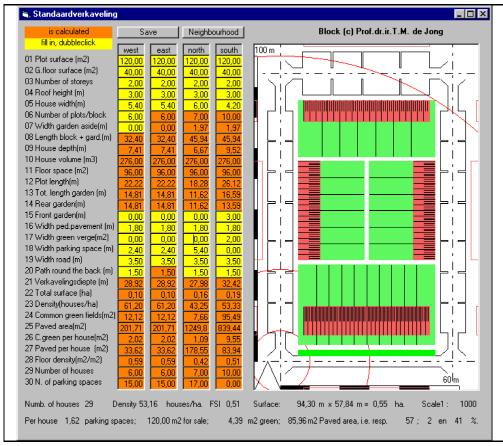


Fig. 53 Plot division taking shadow into account[a]

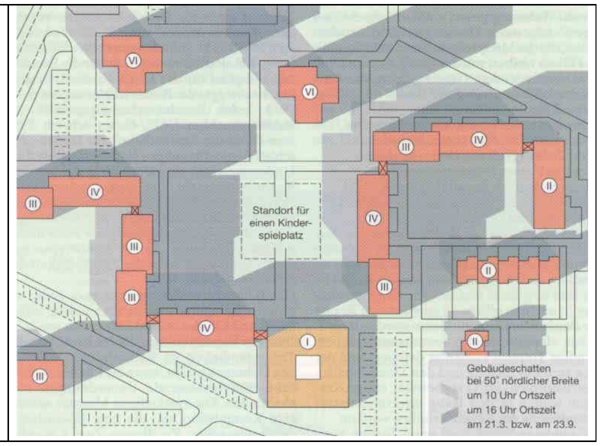


Fig. 54 Avoiding shadow by neigbours according to German regulations[b]

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]

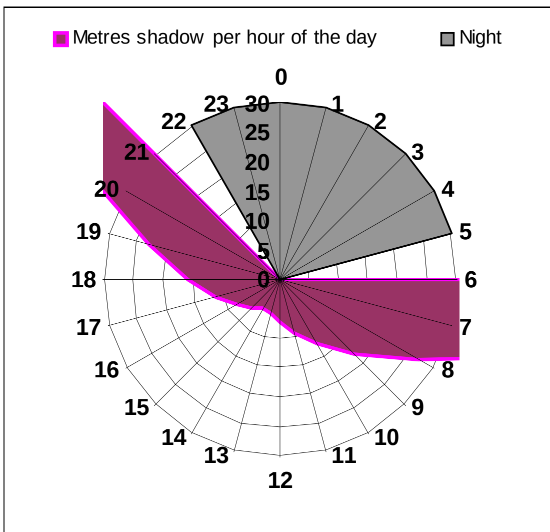


Fig. 55 *Shadows throughout the day June 2nd* [d]

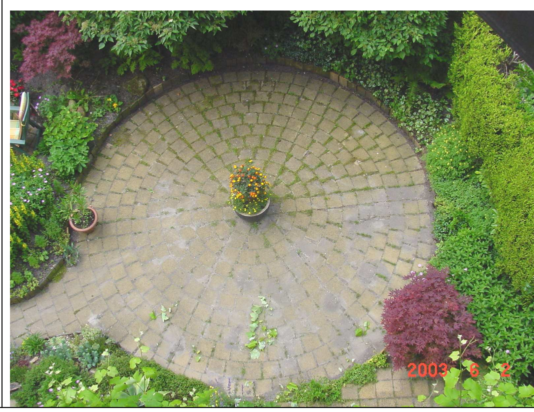


Fig. 56 *A garden on June 2nd at 12 o'clock*

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

[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).

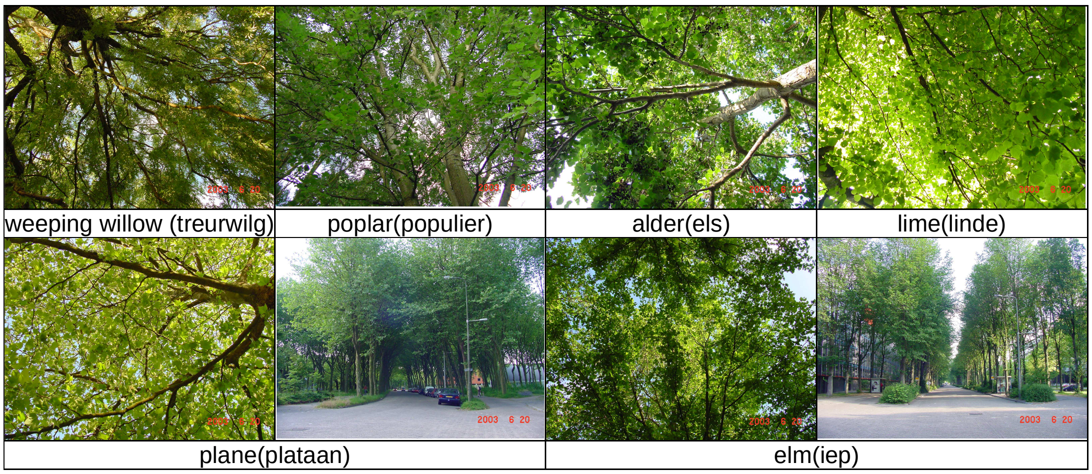


Fig. 60 *Light permeability of trees*

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^oK) 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.

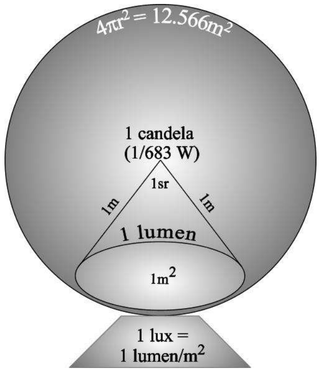
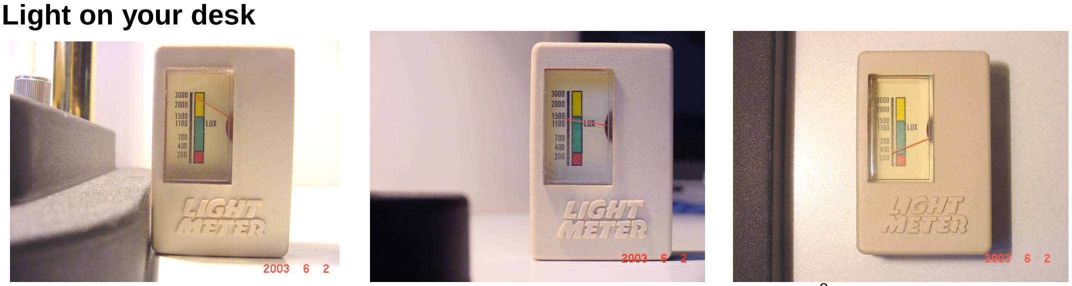


Fig. 61 Candela, lumen, lux

An angle covering 1 spherical m² 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°). 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 m²* on a specific location is 1 lux (lx). So, lx = cd·sr /m².[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° turned laying flat

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

Turning the lux meter 90° (Fig. 62) diminishes the available power/m² 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/m² 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.

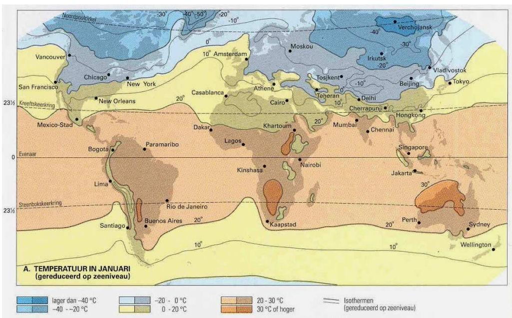
[a] Or in 100 spherical m² at 10m distance (radius). Surface or distance do not matter, only their proportion called 'spherical radius' or 'sr' matters

1.3 Temperature, geography and and history

1.3.1 Spatial variation

The Earth

Latitudinal differences account for the largest global variations (from approx. -40℃ to 30℃) in average monthly temperatures (*Fig. 63* and *Fig. 64*).



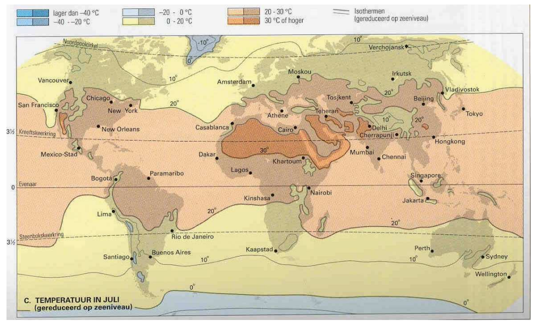
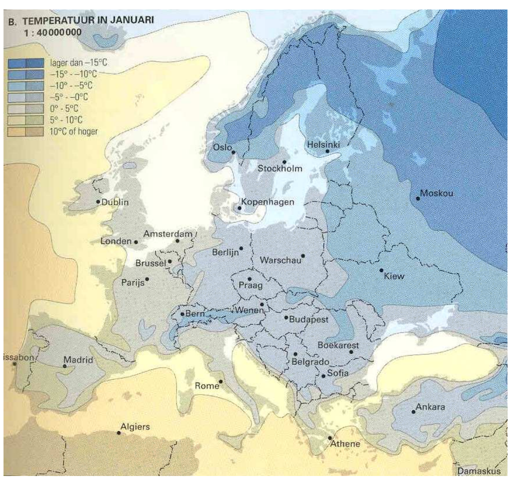


Fig. 63 Global winter temperatures *Fig. 64 Global summer temperatures*[a]

Europe

Latitudinal differences account for most of the average monthly temperature variations in Europe, but these are moderated by the sea from approx. -15℃ t o 25℃ (*Fig. 65* and *Fig. 66*).



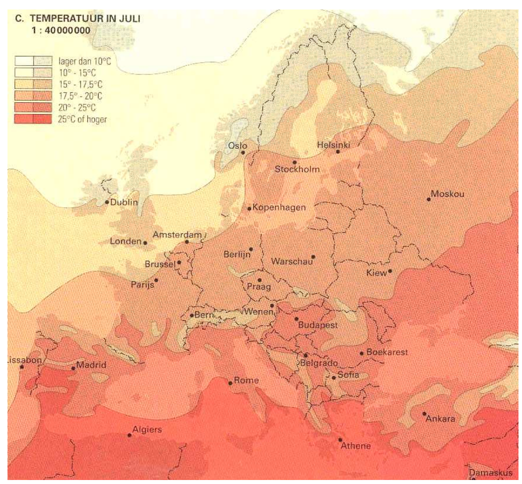


Fig. 65 Winter temperatures in Europe *Fig. 66 Summer temperatures in Europe*[b]

[a] Wolters-Noordhof (2001) page 180
[b] Wolters-Noordhof (2001) page 71

The Netherlands

Latitudinal differences account for most of the average monthly temperature variation in the Netherlands, but they are moderated by the sea, especially in winter, from approx. 3℃ to 17℃ (*Fig. 67* and *Fig. 68*).

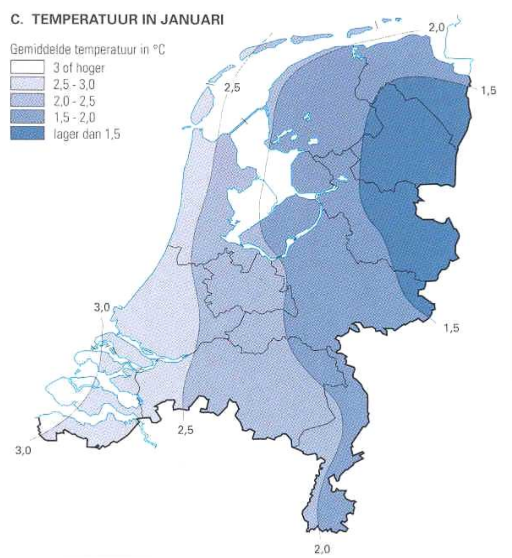


Fig. 67 Winter temperatures in the Netherlands

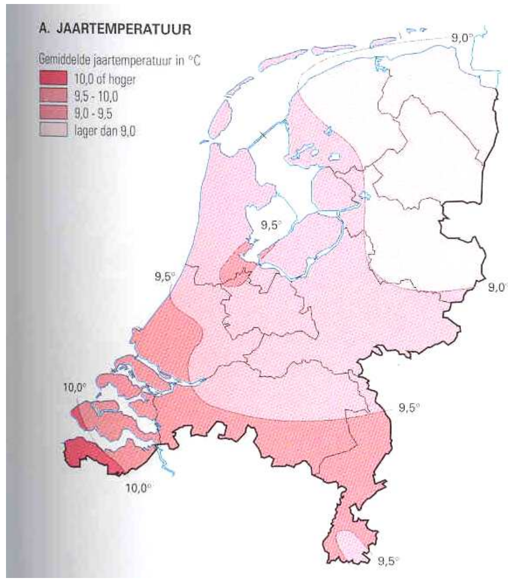


Fig. 68 Year temperatures in the Netherlands[a]

Heat islands

The study of urban heat islands (see *Fig. 69*) has become synonymous with the study of urban climate. Since the increased urbanization and industrialization of the middle of the twentieth century the intensity and the extent of the thermal anomalies has grown. The urban heat island influences physiological comfort, cooling and heating requirements, air circulation and precipitation.

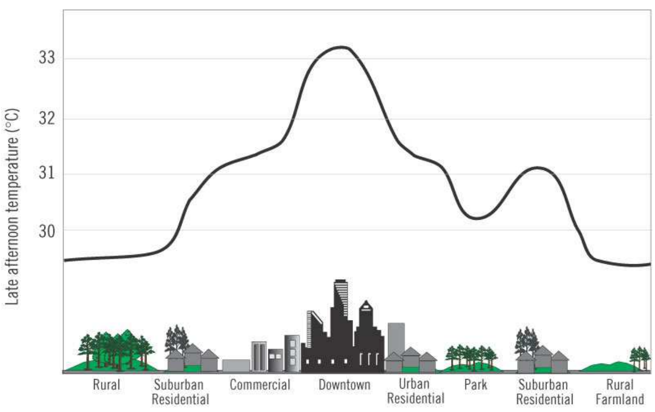


Fig. 69 The urban heat island[b]

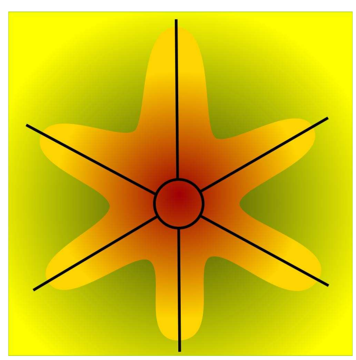


Fig. 70 “Green finger parks” as a contra form of radials in the city

The structure of the city itself influences also the climatic conditions of the city through the density of the buildings, the urban open space, the width of the streets, the crookedness of the streets, the

[a] Wolters-Noordhof (2001) page 43
[b] *http://adaptation.nrcan.gc.ca/perspective/health_3_e.php*

squares and the occurrence of parks and trees aligning streets or squares. Wind velocity will not be discussed in this section.

What causes the urban heat island?

What causes the differences in climatic conditions between an urban area and the surrounding rural areas? The urban heat island is caused by the large heat capacity and the high heat conductivity of urban building material. These facts prevent also a rapid cooling of the urban environment after sunset. This balance causes all kind of movements from the surroundings of a city to the city. The heat island is also equally influenced by other factors such as: rapid runoff of precipitation and as a result a lower amount of evapotranspiration. Through all the buildings and metalled surface the city does not have left over a lot of space where rain can infiltrate the soil. The rain will stream in the sewers and will be discharged immediately. The extra heat in the form of waste heat from urban and industrial buildings the year round together with the heat from the air conditioning in the summer deliver an equally important amount of heat to the city.

Contrast with rural areas

This is in great contrast with the situation in rural areas, where the heat capacity is substantially lower. The heat conductivity is also lower in the rural area. The extra heat delivery by buildings and industry is also nearly negligible.

The differences between urban and rural areas concerning heat capacity and conductivity and the other above mentioned factors make it possible to draft an energy balance between these two areas. This balance alters dependent on the situation such as summer-winter, sunshine or rainfall.

The differences are responsible for pressure differences in the atmosphere and cause equalization by a streaming of air from an area with high air pressure towards an area with a low air pressure. This means a streaming of air from the colder rural area towards the warmer city or a wind blowing towards the city. The wind is relatively cooler then the temperature in the city. The wind will have the Buys Ballot deviation so it will have a deviation to the right on the northern hemisphere and to the left on the southern hemisphere.

Differences in the built up area

Of course there are heat differences in the built up area. It will be obvious that the heat capacity and the heat conductivity will be different for the various urban fabrics. They will be influenced strongly by the cover and the shape of roofs i.e. tiles or bitumen and flat or with inclination, metalled surfaces and parks in combination with water bodies like lakes and canals. Especially the parks with water bodies can have a positive influence on temperature. The temperature there is lower than in the surrounding urban area. If a wind blowing in the city from the rural area outside the built up area passes a large enough park the temperature of the air will cool down. The form of the parks in the built up area plays an important role. Since the air does not flow directly in a straight stream from outside to the centre of a city but with a curve, a belt of parks around the city will not be so effective as “green finger parks” in the form of radials in the city (see *Fig. 70*).

Local variation

In the Netherlands, on 3rd March 1976, the differences in local temperatures, within metres of each other, ranged from -2℃ to 62℃ (Fig.34)!
The air temperature at a height of 1 metre (*Fig. 71*) was 11.8℃.

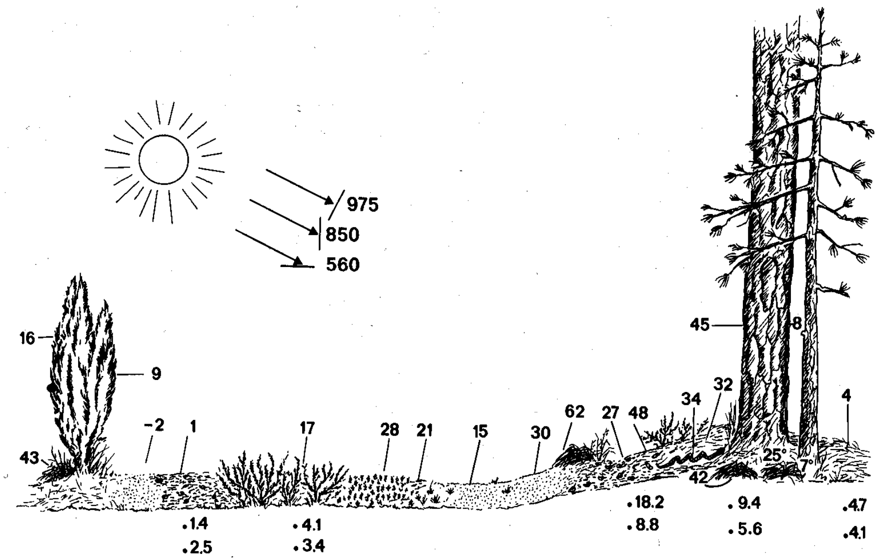


Fig. 71 Surface temperatures along a line perpendicular to edge of a forest[a]

[a] Barkman and Stoutjesdijk (1987) citing Stoutjesdijk (1977)

Individual variation

Plants are long term indicators of local climate and environment (sun, wind, water, soil) while occasional measurements give a random indication of moments.
Plants receiving shadow throughout the day in the growing seasons grow larger and narrower (etoilement) than the same species receiving more sunlight. They look for light rising as high they can (see *Fig. 72*A).

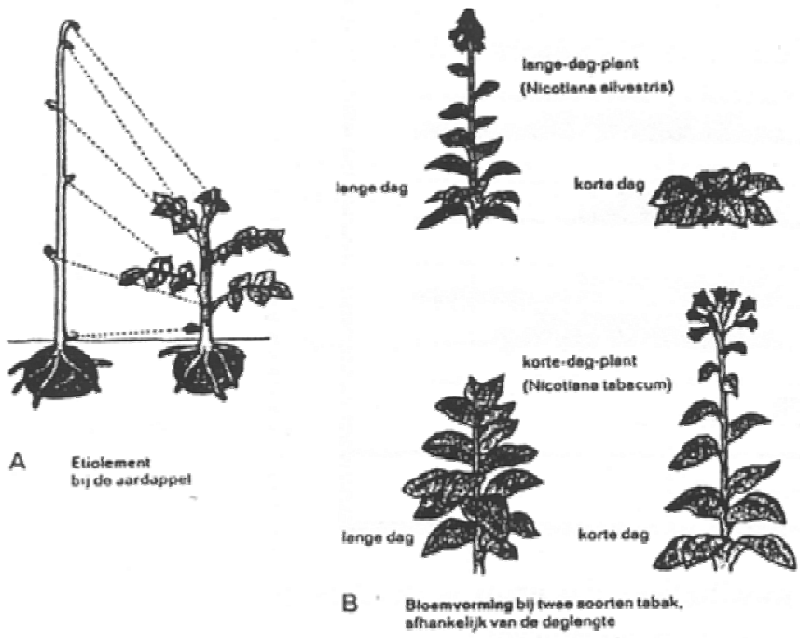


Fig. 72 The influence of variations in light[a]

A plant can not grow if the day is too short (see *Fig. 72*B above).
However, some species are adapted in a way they grow better if the day is short (see *Fig. 72*B below).

The plant species listed below occur so widely that it is well worth while getting to know them.
In the tables below, a number of plants are mentioned in the month in which they can first be encountered in the Netherlands.

[a] Vogel, Günter et al. (1970) page 198, 199

1.3.2 Long term temporal variation

The distance to the sun 'vibrates' in periods of 100 000 years or less, causing ice ages and great differences in wind, water, earth and life stored and named in layers of soil (*Fig. 73*).

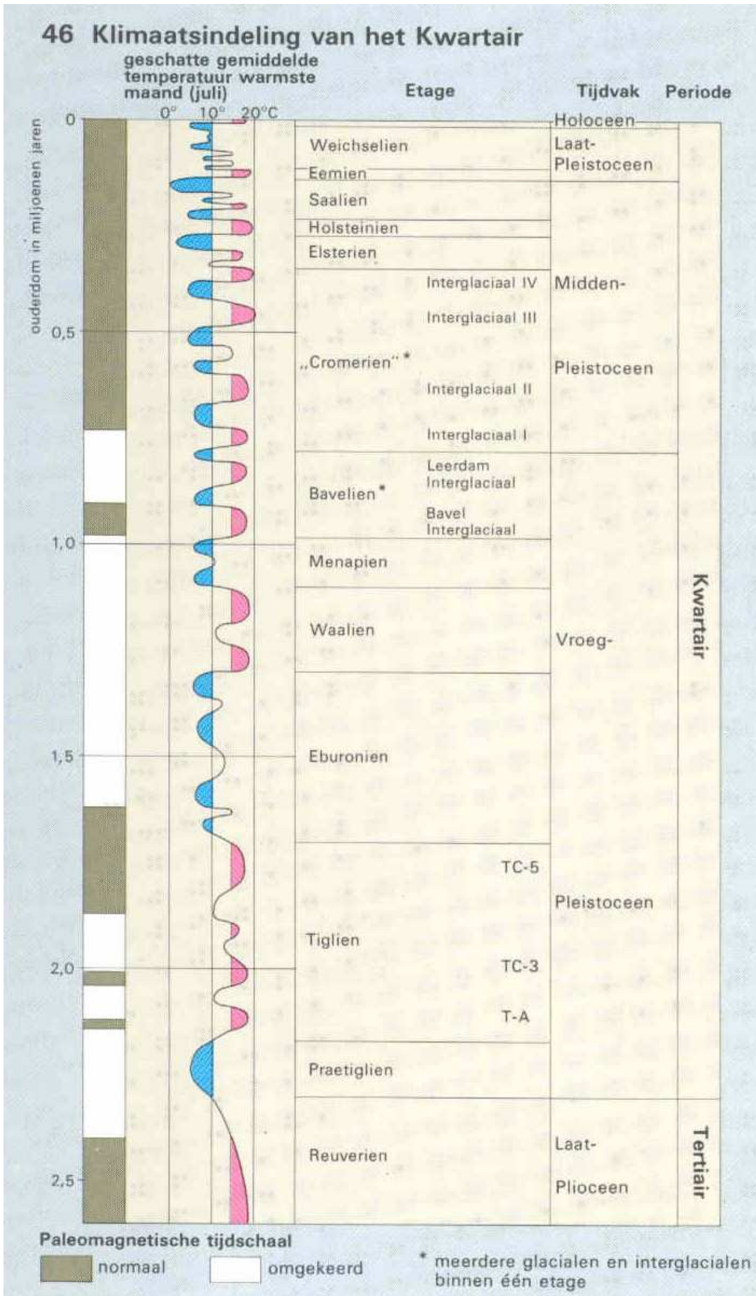


Fig. 73 Temperature fluctuations in The Netherlands in the past 3 million years[a]

These impacts are readable from the topographic history of The Netherlands (Fig. 74).[30]

[a] Sticht.Wetensch.Atlas_v.Nederland (1985)page 13

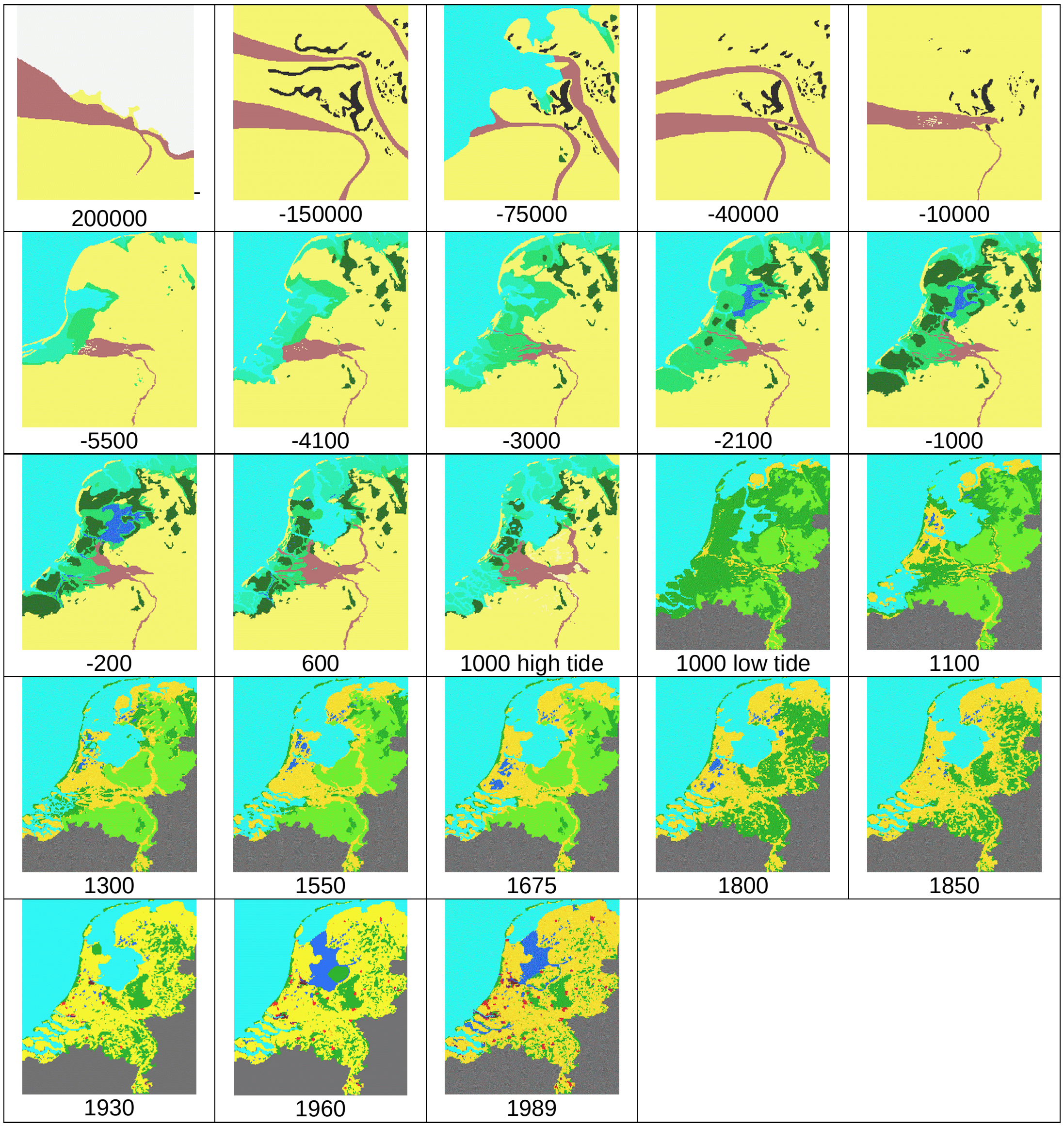


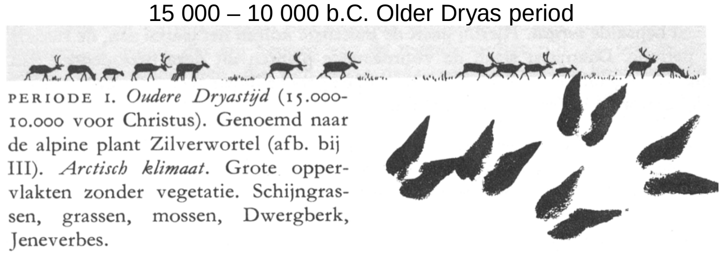
Fig. 74 *De topographic history of The Netherlands*[a]

[a] Universiteit van Utrecht 1987 commisioned by Nederland Nu Als Ontwerp

The Dryas and Alleröd Periods (from 10,000 years BC)

In the famous Lascaux caves, people have made images of mammoths and long haired rhinos. These animals became extinct during the last Ice Age. In Scandinavian countries this period is known as Weichsel and in the Alpine countries as Würm. A tundra plant '*dryas octopetala'* grew in our part of Europe at that time and gave its name to the last cold period of the Weichsel.

15 000 – 10 000 b.C. Older Dryas period



PERIODE I. *Oudere Dryastijd* (15.000-10.000 voor Christus). Genoemd naar de alpine plant Zilverwortel (afb. bij III). *Arctisch klimaat.* Grote oppervlakten zonder vegetatie. Schijngrassen, grassen, mossen, Dwergberk, Jeneverbes.

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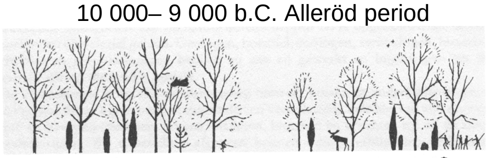
Fig. 75 The end of the Weichsel ice age, the Dryas period[a]

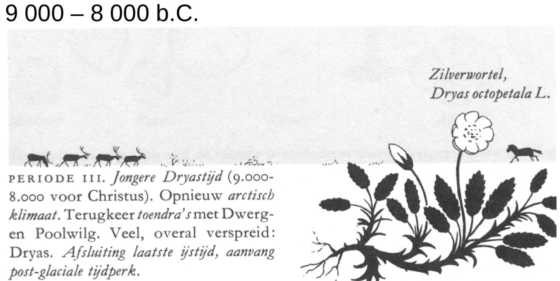
Fig. 76 Vegetation during the Dryas period[b]

10 000– 9 000 b.C. Alleröd period



PERIODE II. *Allerödtijd* (10.000-9.000 voor Christus). Het klimaat in deze tijd is *sub-arctisch* geweest met krachtige noordenwinden. Hier en daar ontwikkelden zich lichte bossen van Berk, Populier en Jeneverbes. Uit deze periode stammen de eerste sporen van aanwezigheid van mensen.

9 000 – 8 000 b.C.



PERIODE III. *Jongere Dryastijd* (9.000-8.000 voor Christus). Opnieuw *arctisch klimaat*. Terugkeer *toendra's* met Dwerg- en Poolwilg. Veel, overal verspreid: Dryas. *Afsluiting laatste ijstijd, aanvang post-glaciale tijdperk.*

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Fig. 77 Sub-divisions of the Dryas [c]

[a] University of Utrecht 1987
[b] Vedel and Lange (1974)
[c] *Vedel and Lange (1974) p 216*

The PreBoreal and Boreal Periods (from 8,000 BC)

In the warmer periods that followed the Dryas, people learnt how to hunt smaller animals using correspondingly smaller stone tools. The Mesolithicum, the Middle Stone Age, had already started, and peat was also beginning to form due to the warmer climate.

About 8,000 BC the oceans began to rise again, because of the melting ice, and the North Sea filled with water again.In the Netherlands, peat formation began late in the Boreal Period, after the cold extensions of the Dryas and Pre-Boreal, and this continued into the warm and humid Atlanticum. The rising sea levels flooded western parts of the country.

Pre-Boreal (8,000 BC) Early Boreal (7,000 BC)

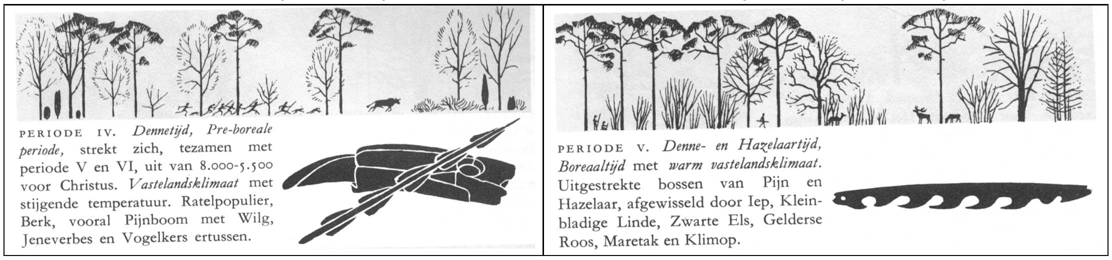


Fig. 78 The landscape of the Pre-Boreal and Early Boreal [a]

Approximately 5,500 BC the sea formed off-shore bars that during the ebb tide were blown higher, forming dunes. In the Waddenzee, behind the dunes, fine sand and silt were deposited, successively, on top of the peat base. The silt became the 'old' or 'blue' marine clay of (the provinces of) Holland.

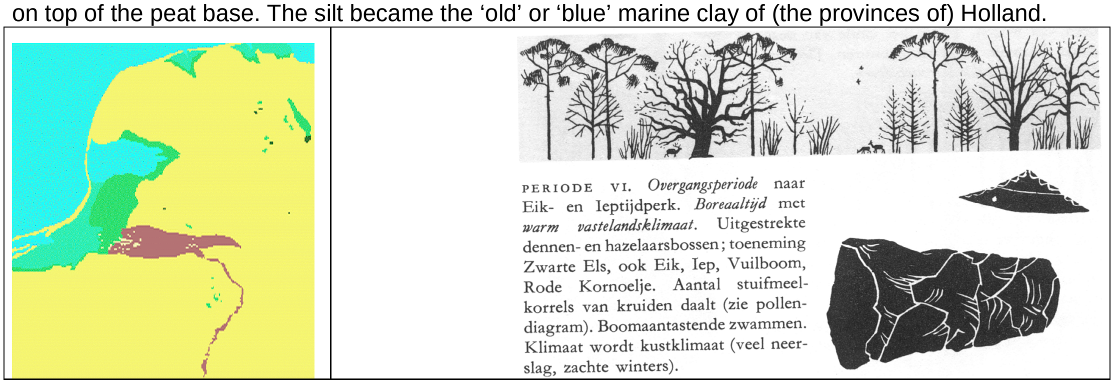


Fig. 79 The Boreal landscape. (from 5,500 BC) [b]

[a] Vedel and Lange (1974)
[b] University of Utrecht(1987), Vedel and Lange (1974)

Atlanticum (from approx. 4,000 BC)

While ever the sea continues to rise, the coast and the peat advance. Approx. 3,000 BC the rise in sea level began to slow down; the off-shore bars remained intact and these broadened out seawards to form a strong coast.

A new row of dunes was laid down in front of the old ones and the peat that had grown on top of the blue marine clay, in so far as the sea had not washed it away, was dug out later. Peat streams first became estuaries and then reverted back to peat streams again. The sea cut into the Sub-Boreal peat leaving channels in which fine sand was deposited. Subsequent drainage caused a reversal in relief.

Atlanticum (4,100 BC). Atlanticum (3,000 BC)

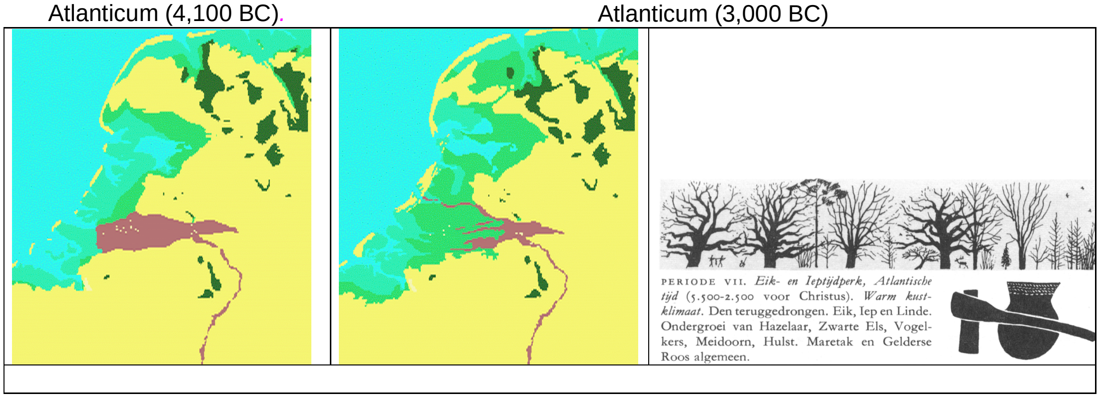


Fig. 80 The landscape of the Atlanticum[a]

The Sub-Boreal (from approx. 2,000 BC)

Approx. 2,100 BC, rivers carred fresh water into the lagoon behind the off-shore bars, causing widespread peat formation

Fig. 81 The Sub-Boreal landscape[b]

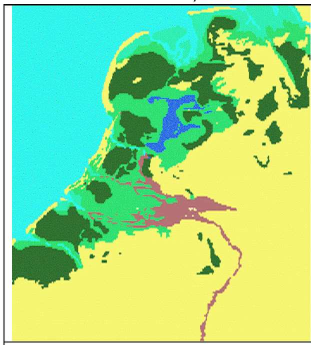
Late Boreal and Sub-Atlanticum, from 1000 BC.

Approx. 1,000 BC: The stagnation of water from streams also causes *hoogveen* (i.e. peat formations above the water table) to develop on the lower parts of sandy ground (e.g., the Peel and Drente).

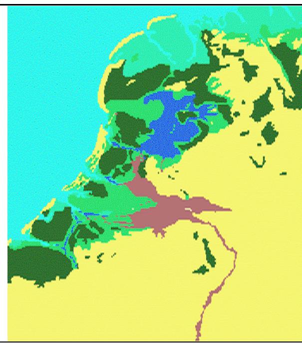
Approx. 200 BC: peat erosion also occurs along the shores of the Almere lake (Zuiderzee area), thereby extending the lake.

[a] University of Utrecht(1987), Vedel and Lange (1974)
[b] University of Utrecht(1987), Vedel and Lange (1974)

Late Sub-Boreal, 1000 BC



Sub-Atlanticum, 200 BC



PERIODE IX. *Beukperiode, Subatlantische tijd* (vanaf ongeveer 400 voor Christus). In deze tijd neemt de neerslag toe en de zomertemperaturen dalen nog verder, waardoor voor Nederland een normaal, *koel kustklimaat* ontstaat. Beuk en Haagbeuk gaan domineren, Berk, Populier en Jeneverbes zijn algemeen geworden; het voorkomen van de Eik wordt minder.

Fig. 82 The Sub-Boreal landscape and Subatlanticum[a]

The Roman period and early Middle Ages, from 100 BC.

Approx. 100 BC: The sea attacked again and large areas of the *laagveen* (i.e. peat formations below the water table) were washed away: this continued for centuries. Bloemers, Kooijmans et al. (1981) and Klok and Brenders (1981) describe Roman relics from this period in The Netherlands like Corbulogracht (*Fig. 84*).

Approx. 600 AD: The sea first broke through in the North to create the Waddenzee and the Zuiderzee.

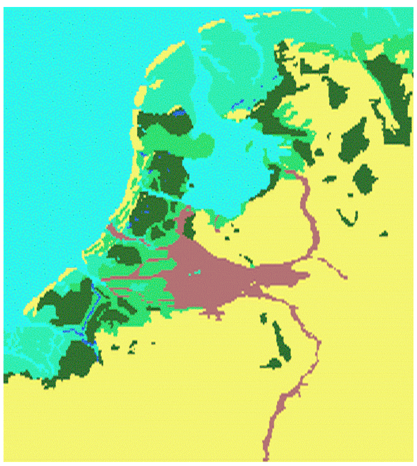


Fig. 83 The landscape of the Early Middle Ages, 600 AD[b]

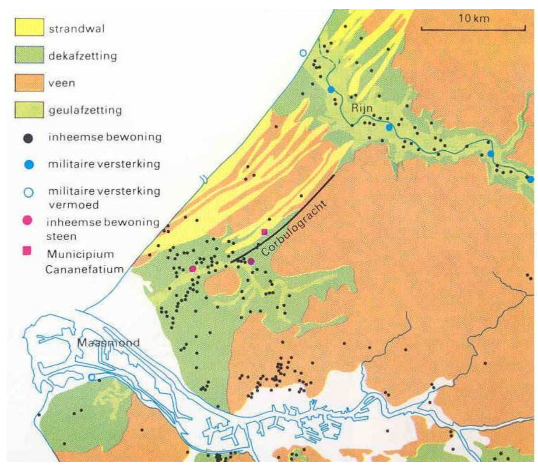


Fig. 84 Roman sites[c]

[a] University of Utrecht(1987), Vedel and Lange (1974)
[b] University of Utrecht
[c] Bloemers, Kooijmans et al. (1981) page 99

1.3.3 Seasons and common plants

Wetland and water

Few shoreline and water plants flower before may.

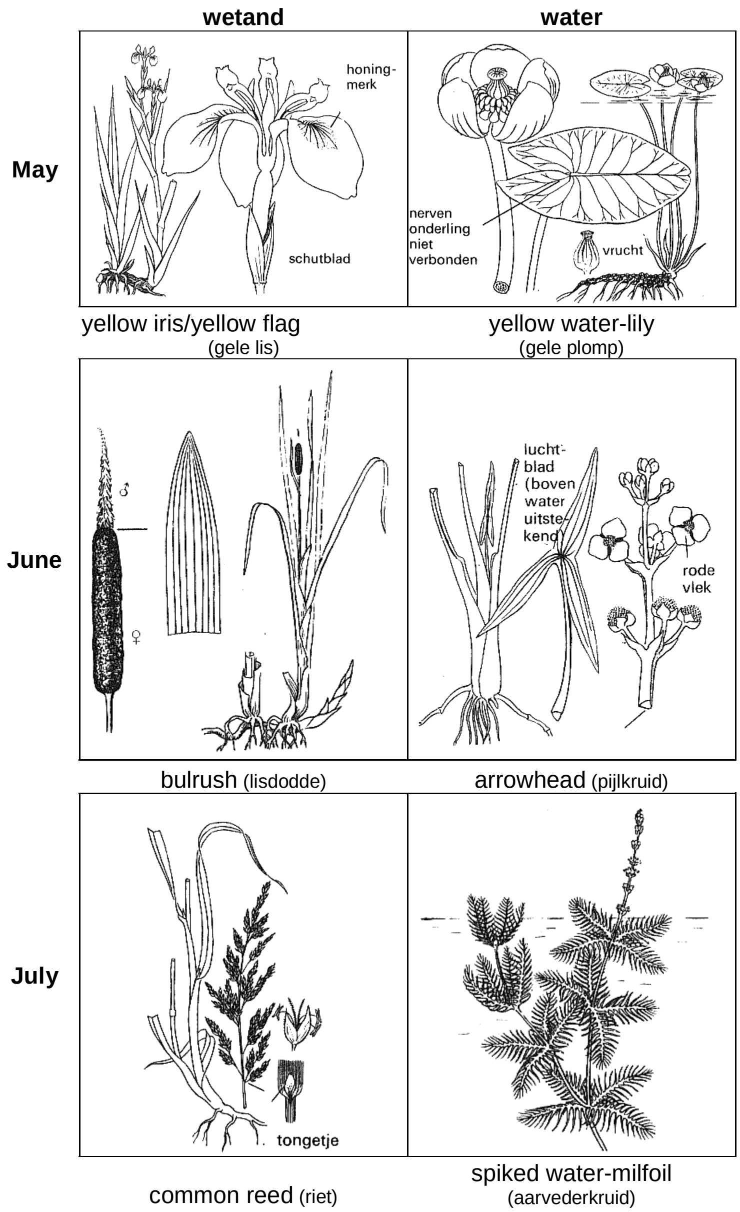


Fig. 85 Flowering periods wetland and water[a]

[a] Kelle and Sturm (1980)

Disturbed and ruderal grounds

If one comes across pioneer vegetation in a certain season, then one can assume that the ground has been recently disturbed. If one comes across plants that grow on rough ground (ruderals), then one can assume that the soil was disturbed one or more years previously.
There are few plants growing on rough ground that flower before March.

pioneering-plant **ruderal**

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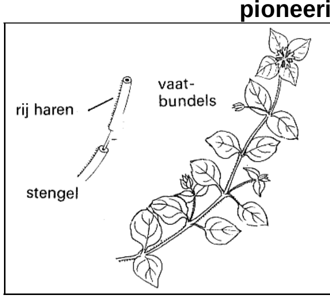
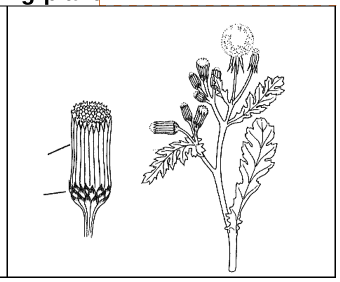
Bouwkundestudenten zijn niet geïnteresseerd in de op blz. 45 t/m 51 genoemde plantensoorten.

Jan

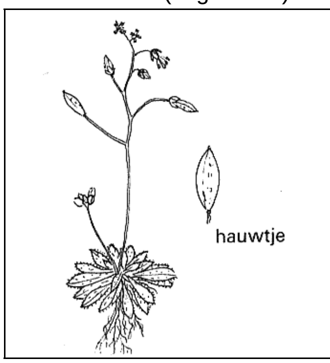


chickweed (vogelmuur)

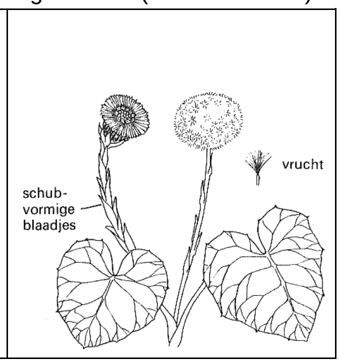


groundsel (klein kruiskruid)

Feb

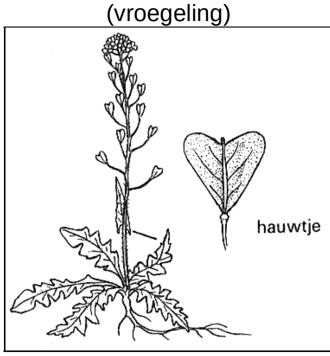


common whitlowgrass (vroegeling)

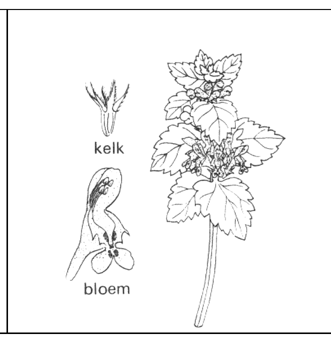


coltsfoot (klein hoefblad)

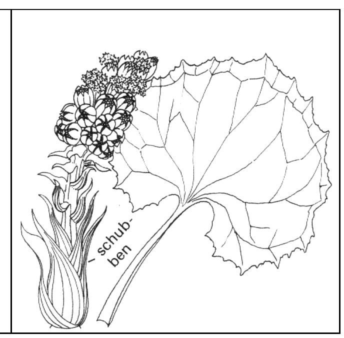
March



shepherd's-purse (herdertasje)

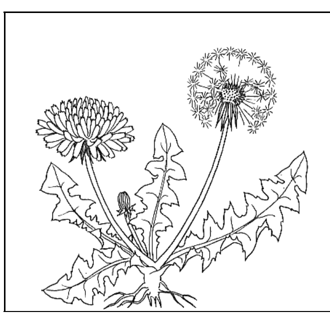


purple dead-nettle (paarse dovenetel)

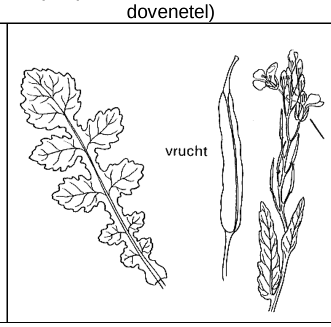


giant butterbur (groot hoefblad)

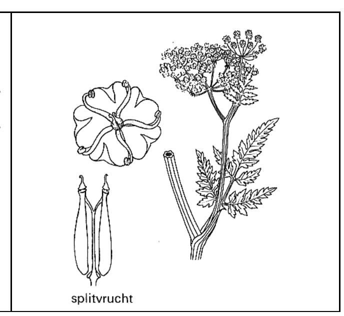
April



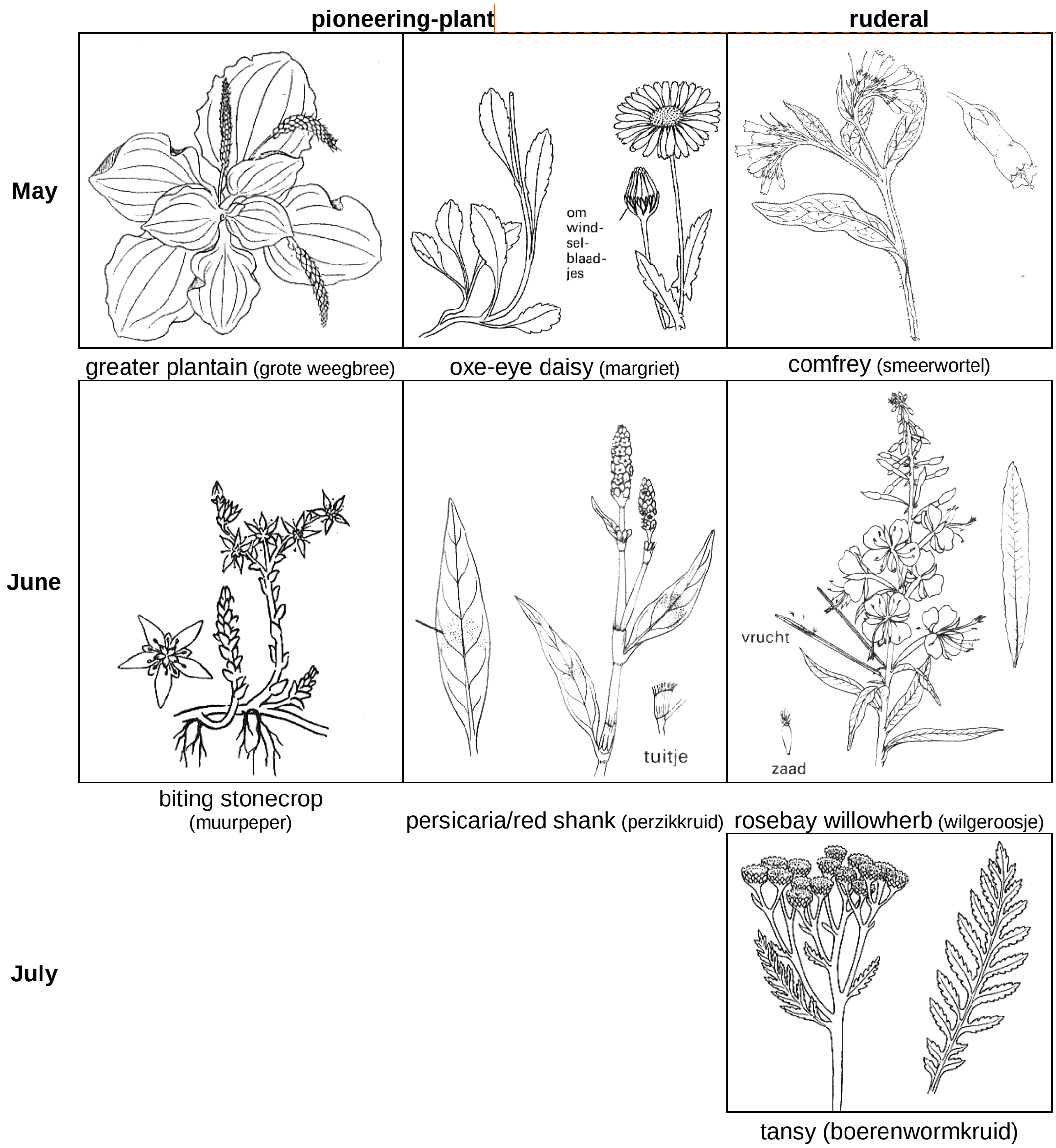
dandelion (paardebloem)



rape (koolzaad)



cow parsley (fluitekruid)



Comment [B5]: Page: 62 Bouwkundestudenten zijn niet geïnteresseerd in de op blz. 45 t/m 51 genoemde plantensoorten.

Fig. 86 Flowering times pioneers and ruderals[a]

There are few pioneering plants that begin to flower after June.

[a] Kelle and Sturm (1980)

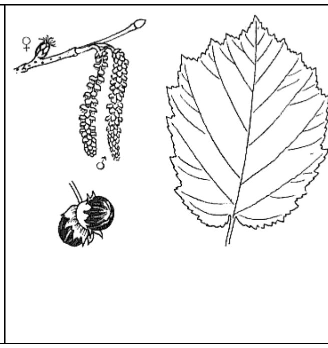
Grassland and forest

If one encounters woodland vegetation, then the soil has remained undisturbed for a longer time.

grass land | **wood/forest**

Jan

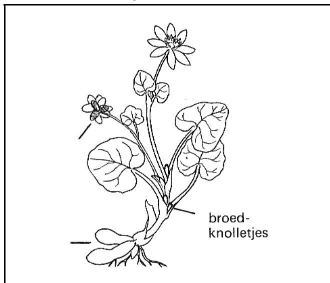
daisy (madeliefje)



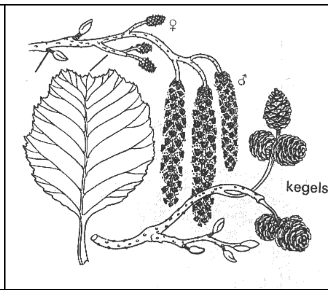
hazel (hazelaar)

snow drop (sneeuwklokje)

Feb



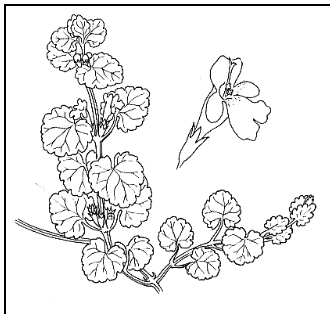
lesser celandine (speenkruid)



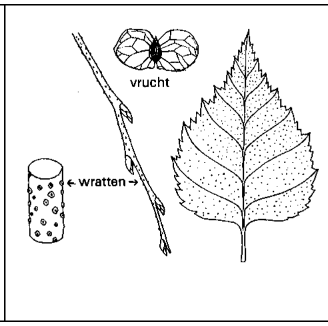
alder (zwarte els)

cornelian cherry (gele kornoelje)

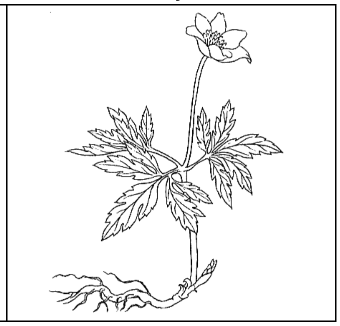
March



ground ivy (hondsdraf)

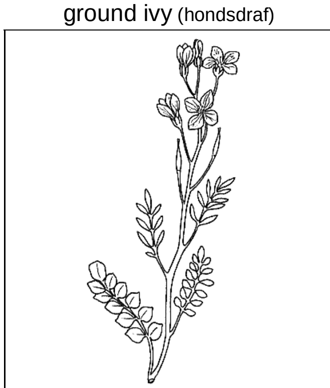


silver birch (ruwe berk)

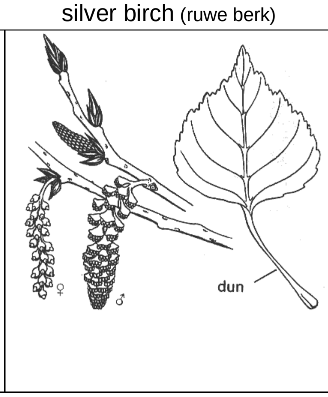


wood anenome (bosanemoon)

April



lady's smock/ cuckooflower (pinksterbloem)



poplar (populier)

broom (brem)

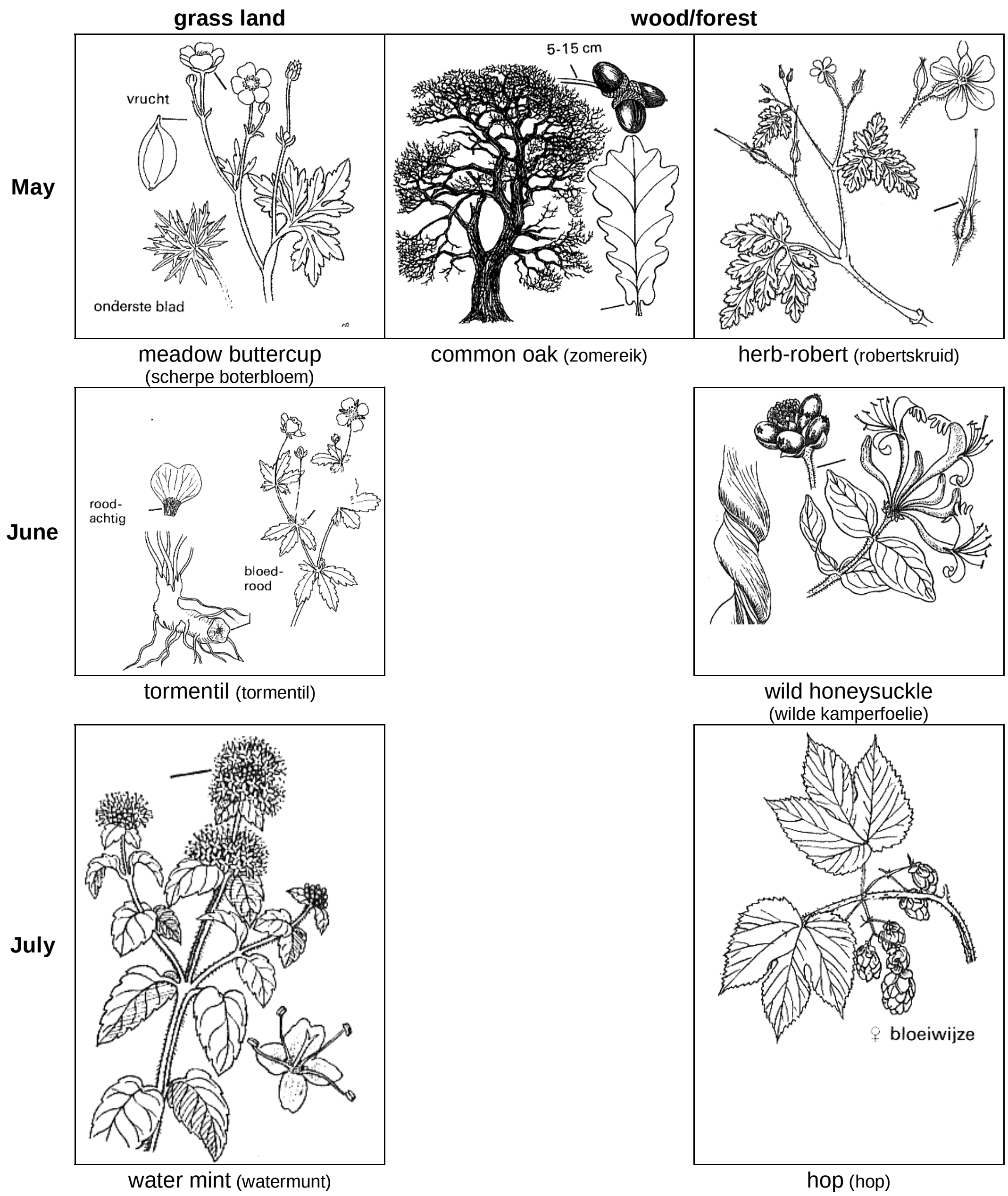


Fig. 87 Flowering times on grass land and in forest[a]

Few trees flower after May.[31 32]

[a] Kelle and Sturm (1980)

Mowing Grasslands

Grassland plants indicate frequent mowing, however, from the nature of grassland vegetation and on the basis of the above table, one should be cautious to mow in flowering periods if you do not want to disturb animals like butterflies.[33]

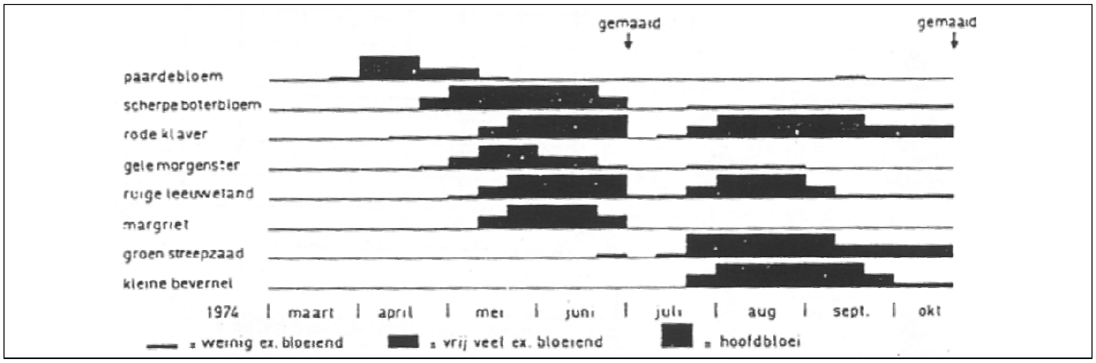


Fig. 88 The effect of mowing on various species[a]

Some species show a second flowering period after mowing.

Mowing to remove minerals

On poor soils one encounters special plants in greater diversity than on rich soils. There, they are pushed aside by very common species like stinging nettle (brandnetel).
For more than 10 years already there has been a mowing policy in Zoetermeer that is directed towards ensuring that the food content of roadside vegetation is drastically reduced by regularly removing biomass:

Aantal soorten				Maaibeheer	
Tak	1982	1988	Verschil (%)	Freq.	Tijdvak
Afrikaweg	107	118	+9	1	2e helft augustus
Amerikaweg	96	124	+23	2	2e helft juli/2e helft sept.
Australiëweg	112	141	+21	1	1e helft sept.
Aziëweg	102	112	+9	2	2e helft juni/2e helft sept.
Aziëweg, natte middenberm¹	83	76	- 9	1	2e helft sept.
Oostweg	111	139	+20	2	2e helft juli/2e helft sept.
Europaweg²	—	42	—	2	2e helft juni/2e helft sept.

Het totale aantal soorten over de het hele hoofdwegennet steeg in deze periode met ±10% van 200 naar 222.
1) De brede, natte middenberm van de Aziëweg is in deze periode van een drainage voorzien.
2) De Europaweg was in 1982 nog niet aangelegd.

Fig. 89 Mowing management in Zoetermeer[b]

Over a period of 10 years, impoverishing the soil does not appear to lead to a large increase in the number of species growing there. Obviously, more time is needed for this to happen.

[a] Londo (1987) page 103
[b] Vos (1990)

1.4 Planting by man

1.4.1 Introduction

The key thing to remember when designing and using planting elements is that you are dealing with living material.[34] Architects work with dead material; buildings are not living organisms. Trees grow, and young trees have a form, different from mature trees. They look different in winter and change under the influence of climatic conditions. A plane tree, for example, has a pyramidal form when young and then 'sags' when older. Trees attain their typical growth form when they are 15 to 20 years old and keep it until they are 80, but by then they will have acquired an individual 'character'. Shrubs usually achieve their mature form after about 10 years. Perennials and roses reach maturity in just 2 to 3 years.

Planting effects

The following illustrations give an impression of the wealth of effects that can be achieved with planting.

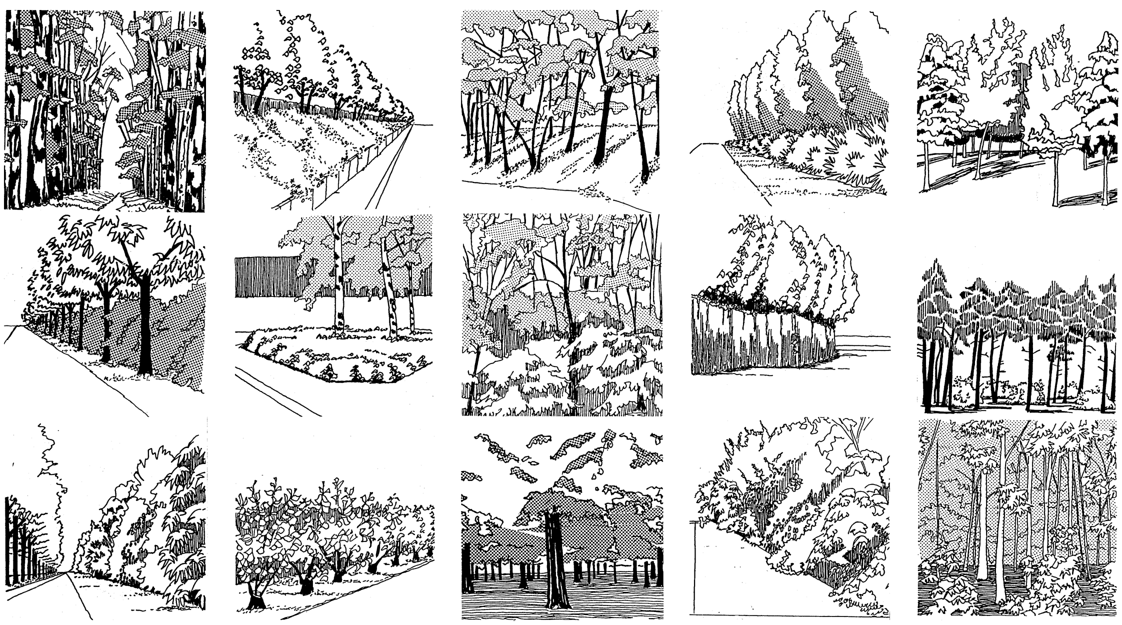


Fig. 90 *Visual effects of planting*

Conceptual framework

Introduction

The conceptual framework is a language to express and convey planting effects. To describe a particular effect we can draw from the themes and related visual forms described below. The overall effect. Depends on the role of each theme.

Themes

The degree of screening[35]
Height is an important consideration when deciding on planting elements. Their height determines how much of the objects behind the planting can be seen. The degree to which they are hidden is called the degree of screening.

The degree of transparency
The visibility of objects behind the planting also depends on how much can be seen through the planting. This is referred to as the degree of transparency.

The degree of uniformity
When looking at a planting element we can examine the diversity of species in relation to the height of the composition to determine vertical variation in texture.

The degree of continuity
In the same way, the diversity of species along the length of the planting element can be examined. The horizontal variation in texture is important.

Structure[36]
The manner in which trees and shrubs are placed to create a unified composition has a strong influence on the other themes. Structure plays a major role in creating the overall effect.

Edge profile
In urban areas planting elements are usually narrow and consist, essentially, of two edges. The profile of these edges has a major influence on the appearance of planting elements.

The degree of naturalness
The mood or atmosphere created depends to an important extent on whether the composition has a formal, artificial appearance or an informal, ‘natural’ feel.

Characteristic Forms

Each theme can manifest itself in different ways characteristic forms. These can be clearly indicated by introducing terms for all the possible forms.

The degree of screening

Fig. 91 *Edge: maximum planting height 0.5m*

Fig. 92 *Articulation: planting height between 0.5 and 1.5 m*

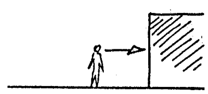


Fig. 93 *Partition: planting height between 2 and 5 m*

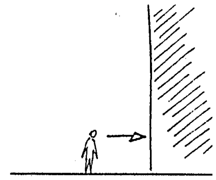


Fig. 94 *Screening: planting is higher than 5 m*

The degree of transparency

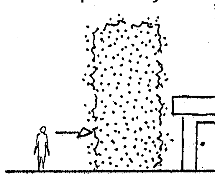


Fig. 95 *Wall: the planting blocks all vision*

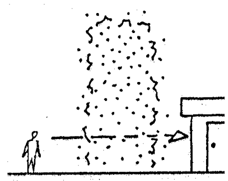


Fig. 96 *Curtain: even, partial visibility through the planting*

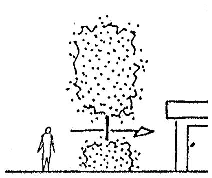


Fig. 97 *Window: opening in the planting*

The degree of uniformity

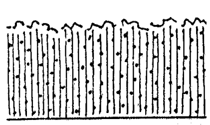


Fig. 98 *Even: no clear vertical variation in texture*

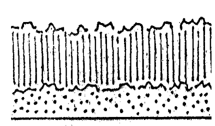


Fig. 99 *Layered: clear vertical variation in texture*

The degree of continuity

Fig. 100 *Constant: no horizontal differences in texture*

Fig. 101 *Rhythm: differences in texture at regular intervals*

Fig. 102 *Accentuation: random striking differences in texture*

Edge profile

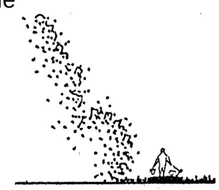


Fig. 103 *Receding*

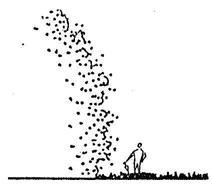


Fig. 104 *Upright*

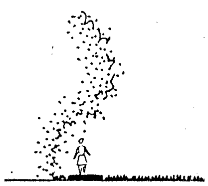


Fig. 105 *Overhanging*

Degree of naturalness

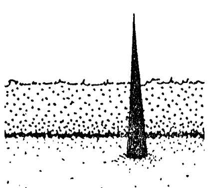


Fig. 106 *Straight and 'hard': the planting has straight contours and 'hard' boundaries*

Fig. 107 *Ragged and 'soft': the planting has irregular contours and vague edges*

Structure

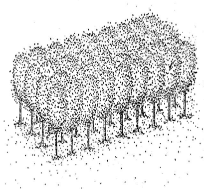


Fig. 108 *Trees*

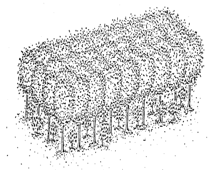


Fig. 109 *Trees with occasional shrubs*

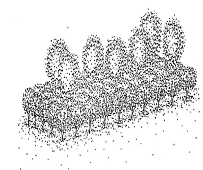


Fig. 110 *Shrubs with occasional trees*

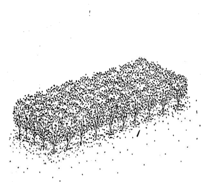


Fig. 111 *Shrubs*

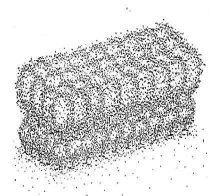


Fig. 112 *Trees with a shrub margin*

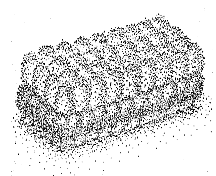


Fig. 113 *Trees with a shrub layer*

Design tools

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Blz. 59, 60 Section)???

Each of the characteristic forms described above can be created using different design tools:

Edge
- Native stock trimmed to form a hedge
- Low-growing non-native plants

Articulation
- Native stock trimmed to form a hedge
- Smaller, non-native shrubs

Partition
- Native shrubs with or without trimmed edges
- Larger non-native shrubs

Screening
- Tree planting, no crown raising
- Tree planting with shrub layer; the trees and shrubs must intertwine

Wall
- Native species with a dense, compact habit
- Non-native evergreen species
- Wide spacing and sufficient thinning to allow full growth and the development of complete foliage cover
- No crown thinning, branch reduction or crown raising
- Broad plant bed

Curtain
- Species with an open and loose habit
- Small distances between plants, which encourages them to grow upwards
- Crown thinning, branch reduction and crown raising is possible
- Narrow plant bed

Window
- Native shrubs pruned to the right height
- Low, non-native shrubs
- Widely spaced shrubs for full growth and good foliage cover
- Trees with upright crowns
- Trees with raised crowns

Even
- Large number of species, individually mixed
- Small number of species with very similar textures
- One species

Layered
- A few layers with very different textures
- Each layer consists of one species or a few species with very similar textures

Constant
- In species-rich planting the length of the planting element must be many times its height (minimum 100 m)

Rhythm
- Striking individual trees or shrubs planted at regular intervals

Accentuation
- Striking individual trees or shrubs at irregular intervals

Receding
- Free growth along the edge
- Shrub margin in front of tree planting

Upright
- Use of woodland planting as hedge
- Tree planting with low branching crowns

Overhanging
- Edge pruning in a margin of trees and shrubs
- Crown raising in an margin containing only trees

Straight and hard
- Pruning for shape
- Straight, clearly defined edges
- Rhythmic or striking accentuation along the edge
- A sharp silhouette
- Layered

Ragged and soft
- Vague, ill-defined edges; abundant herbs in the edge
- Individual mixing of striking species
- Ragged silhouette

The effect over time

Planting schemes can be grouped according to the way they develop from the time of planting until they reach full maturity.

The first group consists of planting schemes with a pronounced static character. Stated simply, the effect of such planting schemes changes little over time, they just become higher and fuller. These planting schemes are simple, containing just a few species which each have a clear place and contribute to the overall long-term effect.
In contrast, the second group consists of planting schemes with a distinctly dynamic character. A typical example is traditional woodland planting schemes: species-rich, individually mixed planting. The roles of the individual species constantly change, creating a succession of visual effects over time.[37]

The final group of planting schemes are those with a cyclical development. The visual effect is obtained by periodic rigorous pruning back to restore the same visual effect.

Design techniques

Each of the planting groups described above can be linked to a number of specific design techniques to choose from.

Static planting

- The structure of the planting and the role played by each species in the visual effect is determined beforehand.
- The way the visual effect will develop is clear from the start; specific maintenance work will need at certain times to achieve this effect.
- When the planting has reached maturity the purpose of maintenance work is to maintain vitality and a tidy appearance.
- Radical rejuvenation measures are delayed as long as possible.
- The 'nurse crop' system cannot be used.[a]
- Use of long-lived species.
- Rows of different species.

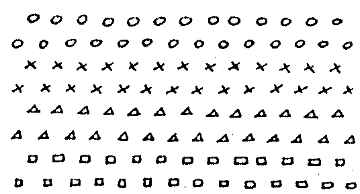

Fig. 114 *Static planting technique*

Dynamic planting

- Indicate the characteristic forms that will determine the appearance of the planting (e.g. transparency)The structure of the planting and the role of each species in creating the visual effect are not fixed in advance. During the growth of the planting there are certain moments when the designer and technical maintenance staff have to decide how the planting scheme will continue to develop. The choice is influenced by the previous visual forms.
- The 'nurse crop' system can be used.
- Plants may be individually mixed.
- Species with different life cycles may be mixed together, although this makes maintenance more complex and expensive. The most manageable system is to keep to the life cycle of the main plants.
- The plant bed must be at least 50 m wide; any narrower and it is extremely difficult to manage the visual effect. The planting will acquire a ragged appearance with, in places, considerable differences in height, texture and transparency.

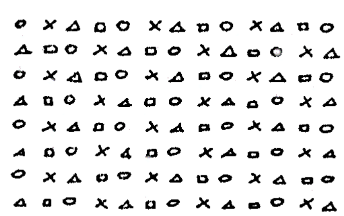

Fig. 115 *Dynamic planting technique*

[a] In this system the planting mixture contains a number of species which grow faster than the permanent species. Their function is to protect the main planting during the initial years of growth and are removed after a number of years (see § 0)

Cyclical planting

- The appearance of the planting is fixed beforehand.
- The desired appearance develops too quickly but is repeated; the effect is dominated by periodically cutting back to just above ground level.
- The timing of pruning is based on the fastest growers – depending on their rate of growth, once every three to seven years.
- The 'nurse crop' system cannot be used.
- Only species amenable to hard pruning can be used.
- A wide range of species can be used because species do not have the chance to suppress other species.

Restrictions on the choice of plant material

Both the nature of the plant material and the environment in which it is planted impose a number of limitations. If these limitations are not properly taken into account in the design, the desired visual effect will not be achieved.

The range of influential factors can be divided into two groups:[38]

- The characteristics of the plant material itself, called 'iron laws'.
- Environmental influences, in this case the urban environment.

Iron laws

Introduction

The native species available for planting differ widely in two respects:

- Light requirement
- Rate of growth

These differences drive two processes that are always at work in woodland planting schemes:

- The natural process of forming open spaces in woodland
- Process of species supressing other species

Because these processes always occur they are often called referred to as 'iron laws'.

The natural process of forming open spaces in woodland

Under natural conditions, herbs are in time overgrown by shrubs, which in turn are eventually shaded out by trees. The planting 'hollows out', as it were, from the middle. Eventually, the middle of the planting area will consist mainly of trees; shrubs can maintain themselves only along the edges. What develops is, in effect, a natural woodland profile. This process repeats itself when trees die and fall. In the open spaces where sunlight reaches the ground, herbs spring up again, only to be overgrown by shrubs, etc.

This profile does not develop in artificial urban environments because the plant beds are usually far too narrow. This means that in urban areas 'woodland planting' based on this natural process can only contain a segment of the natural profile of the woodland edge. There are a number of possibilities:

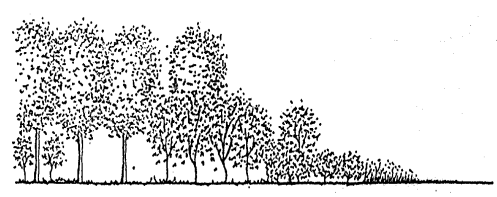

Fig. 116 *Woodland profile*

These are called 'planting forms' – in effect, no more than combinations of trees and shrubs derived from the natural woodland edge.

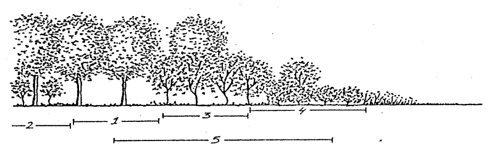

Fig. 117 *Planting forms*

If the process is not the basis of the design, a further option can be added to the list:

In such a planting scheme the process must be continually checked, which requires intensive maintenance. The appearance easily degrades if maintenance work is not carried out on time.

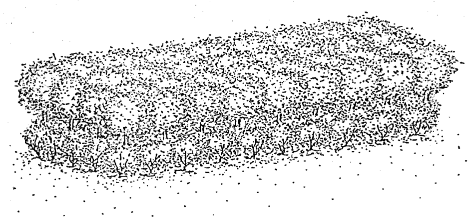

Fig. 118 *Tree layer with a shrub layer*

Each of the planting forms has specific planting and maintenance requirements. These are listed below.

Tree layer

Dimensions:
- minimum width of the plant bed: 15 metres
- in narrower compartments one or two rows of nursery-grown standard trees

Fig. 119 *Tree layer*

Tree layer with occasional shrubs

In addition to the recommendations for the tree layer above:
- the shrubs must tolerate shade
- the trees must cast as little shade as possible

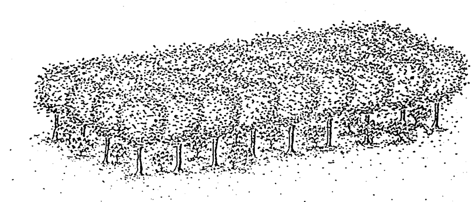

Fig. 120 *the tree layer with occasional shrubs*

Shrub planting

Giving each shrub less space encourages rapid vertical growth. Constraining horizontal growth, though, usually reduces the robustness of each individual shrub.

Fig. 121 *Shrub planting*

Shrub planting with occasional trees

- the trees should cast little shade
- trees should be nursery-grown standards

planted at least 20 metres or more apart
the shrubs must grow more slowly than the trees

Fig. 122 *Shrub planting with occasional trees*

Tree planting with a shrub margin

The recommendations made for the tree layer and for shrub planting apply here; tree planting with a shrub margin is actually these two forms joined together. Again, some additional recommendations can be made:

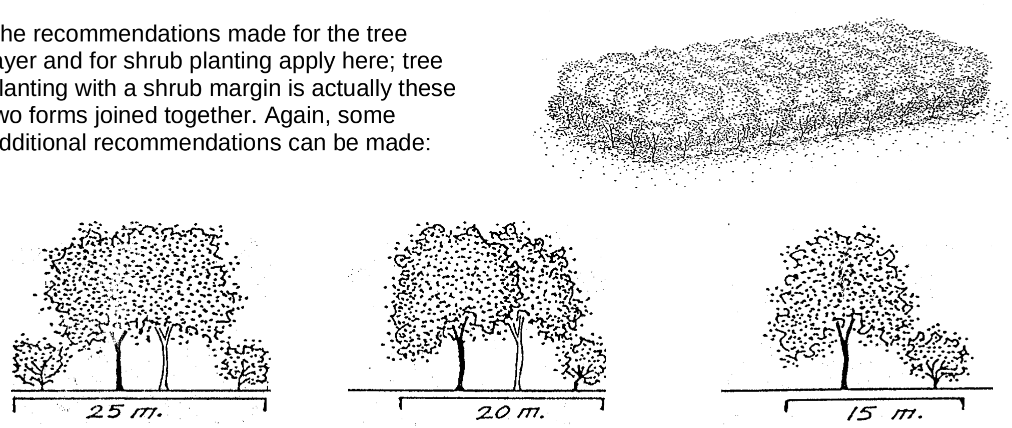

Fig. 123 *Tree planting with a shrub margin*

Dimensions
- minimum width of the plant bed for a symmetrical profile: 25 metres
- minimum width of the plant bed for an asymmetrical profile: 20 metres
- 15 metres is sufficient width for a row of nursery-grown standard trees and a row of nursery-grown shrubs

Plant selection and situation
- sun-loving shrubs can only be planted on open south-facing sites
- a continuous strip of shrubs on north-facing edges is not possible: only a few dispersed shade-tolerant shrubs will be able to survive
- eastern and western edges should be planted with shade-tolerant shrubs

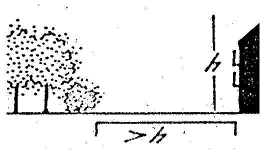

Fig. 124 *This is necessary to ensure sufficient daylight penetration*

Process of species suppression by other species

The environment into which new plants are put (bare soil) is ideal for pioneer species[a] However, planting schemes often involve planting pioneer species and climax species[a] in the same bed. The pioneer species thrive in this environment and soon outgrow the climax species.

We can deal with this in different ways:
- accept the suppression of species
- prevent the suppression of species

Working against the suppression of species is not really possible. Maintaining a rich mixture of pioneer and climax species 'whatever the cost' involves a considerable amount of work. The visual effect is highly vulnerable to any delays in maintenance work.

Accepting the suppression of species

When some slow-growing species have only a temporary role to play in the visual effect, the suppression of species presents no problems. When the planting is still young these species can maintain themselves without difficulty and enhance the appearance of the planting for a while. When the plants grow up they are eventually suppressed and the fast growing species dominate.

This means that:
- the appearance of the planting changes quite a lot during its development, in a sequence of intermediary forms
- this planting type requires relatively little maintenance

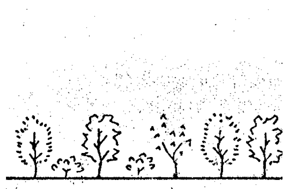

Fig. 125 *Intitial species*

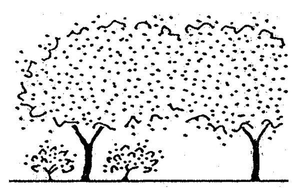

Fig. 126 *suppressed later*

Preventing the suppression of species

If a limited number (1 to 3) of species with the same growth rate are planted none of them will be suppressed.

This means that:
- the appearance of the planting changes little over time
- such planting schemes require relatively little maintenance During its development each species plays the same role in the overall effect.

[a] These are terms from plant ecology and relate to the changes a natural vegetation goes through in the course of time, the succession.

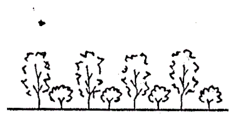

Fig. 127 *Small number of species*

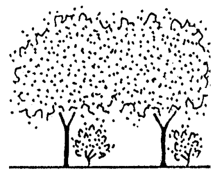

Fig. 128 *not suppressed later*

Artificial succession

A totally different way of dealing with different growth rates is to use the nurse crop system. Pioneer and climax species are planted together, the pioneers (the nurse crop) protect the climax species when they are young. Once the pioneers have fulfilled their function they are cut, allowing the climax species to develop further.

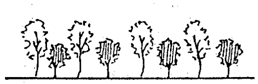

Fig. 129 Nurse crop

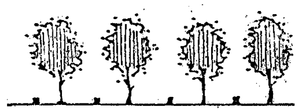

Fig. 130 removed

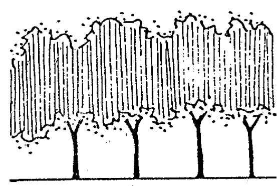

Fig. 131 leaves climax species

This approach means:
- the appearance of the planting changes considerably and suddenly over time; in effect there are two stages, each with its own appearance
- this type of planting requires a relatively high level of maintenance
- the appearance degrades if maintenance falls behind schedule

Urban areas

Introduction

Besides the influences of the plants themselves, the influences of the physical environment surrounding the planting also play a role: in this case, the urban environment.

Data on a number of these factors are available, for example on:
- the soil (profile, mineral composition, organic matter content)
- water management regime
- traffic engineering requirements (sightlines)
- mains services, cables and pipes
- building control (distance to outer wall)
- pollution (exhaust gases, road salt)
- gusts and downdraughts

A few important aspects are discussed below. These are:
- the limited space
- the limited amount of daylight
- informal use (wear and tear)

Limited space

It is only really the width of a plant bed that sets firm limitations on the use of woodland planting in urban areas. The plots in urban areas are often too narrow. Native species in particular need plenty of horizontal space to grow freely. Shrubs can easily achieve a diameter of 5 meters and the crowns of the biggest trees can be as much as 10 metres across or more, given time.

The minimum width of a pant bed must be greater than the width of a spreading shrub because after woodland planting has been thinned the margin will never consist of a straight row of plants.

Minimum width of the plant bed
- Shrubs in woodland planting require a plot at least 6 metres wide.
- A woodland planting that includes trees requires a plot at least 15 metres wide.

Plant beds narrower than 6 metres wide
- Only suitable for woodland planting if at a later stage the margins are continually cut back or pruned.
- Straight row of nursery-grown shrubs or trees.
- The required width can then be reduced to 5 metres. If the margins are also cut back the plot may be even narrower.
- Non-native species with a narrower growth form.

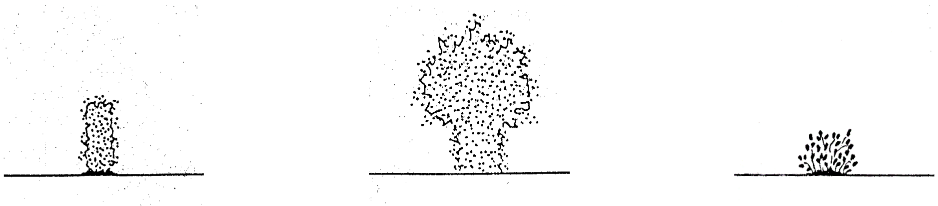

Fig. 132 *Plant beds narrower than 6 metres wide*

Besides a sufficiently wide plant bed, a generous margin is needed if plants are to grow freely and reach their full width.

Edges

On edges you should leave space for later development.

Fig. 133 *Leaving space*

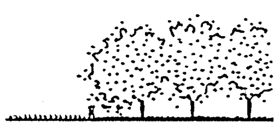

Fig. 134 *for later*

Another possibility is to plant up the whole plot and remove the outside row at the first thinning.

An unplanted strip should be left along the margin of the plant bed. This can be temporarily filled with grass, herbs or ground cover plants.

Fig. 135 *Initial planting*

Fig. 136 *thinning*

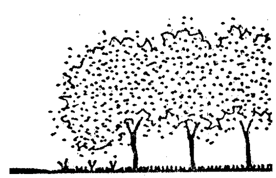

Fig. 137 *for growth*

The stems of the shrubs in the outside row should be no less than 2.5 metres from the edge of the plant bed

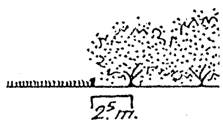

Fig. 138 *Shrub distance*

When trees are included in the planting they should be at least 5 metres from the edge of the plant bed.

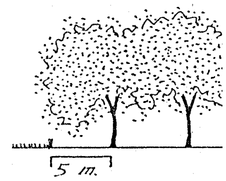

Fig. 139 *Tree distance*

Planting patterns

A regular pattern of rows is the most preferred option for the long narrow plots usually found in urban areas; it permits mechanised planting and hoeing and systematic thinning.

An irregular pattern requires more complex maintenance and makes the visual effect more difficult to control; in narrow plots the planting can easily take on a patchy appearance.

Rows can either be planted to form a square or triangular grid; an important feature of the triangular pattern is that after the first systematic thinning the remaining plants are equal distances apart, which is highly beneficial for their subsequent development.

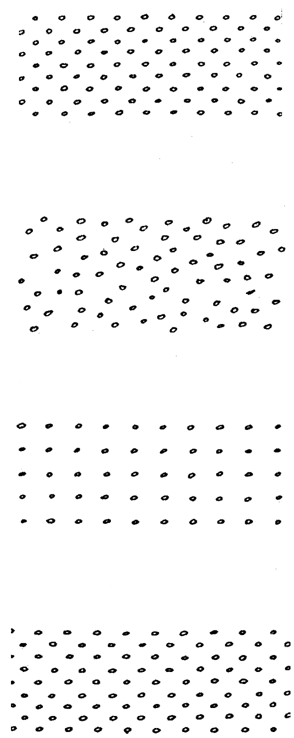

Fig. 140 *Planting patterns*

Limited daylight penetration

The way the edges of the planting develop is heavily influenced by the amount of light. Two aspects play a role here:

The orientation of the edge in relation to the sun.
The location of any nearby objects; other planting and buildings often cut out a lot of light.

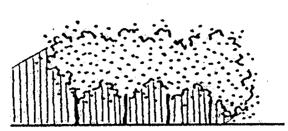

Fig. 141 *Sunlight orientation*

We can deal with these effects in various ways:

- Appreciate the positive aspects of the differences between margins resulting from differences in daylight penetration.
  For example, the differences between a north-facing edge and a south-facing edge can be seen as a special feature. On the shaded side you can look between the stems into the planting; in the background the sunlight filters through the foliage on the other side in a soft green haze. On the sunny side you look at a dense mat of foliage; a few small patches of the darkness beyond are occasionally visible.

- Give all edges the same profile through the careful choice of species.
  If the aim is to ensure a good edging with shrubs, species will have to be planted along the eastern and western edges different from those along the southern or northern edges.

- Careful siting of plants in relation to nearby objects[39].

Fig. 142 *Siting of plants*

  - Trees and shrubs can become straggly and thin if the distance between the plant bed and a nearby object is less than the height of that object.
  - Spreading, well formed trees and shrubs and a dense margin can develop where the distance between the plant bed and a nearby object is greater than the height of that object.

Informal use (wear and tear)

Plants in urban areas are exposed to heavy use. Paths may be worn by people walking through planting elements and children may play in them.

Such wear and tear can be resisted. This is often desirable for planting elements in semi-public spaces, such as residential courts, where residents can exert informal social control to prevent damage to planted areas. Narrower strips of planting are particularly vulnerable and the survival of the whole planting element could be at risk.

- Preventing informal use
  - The first step is to locate the planting element with sufficient care: study the walking routes and level of use in general; maybe even cancel the planting altogether.
  - Plant species that are hard to walk through, such as thorny bushes, but do not forget that these can severely hamper maintenance work and are not suitable near schools or playgrounds.
  - Another option is to add exotic species to the woodland mix. These give the planting a more graceful appearance which can evoke greater respect from the public, particularly if they feel attached to the area.

Instead of preventing informal use there may be opportunities to make use of it. This may be possible in planting with a clear public function in a more anonymous location. In such places, informal use of planting elements can enrich the functional value of the public domain. Moreover, planting areas in public spaces are usually larger and so informal use is no threat to the survival of the planting element as a whole. Plots accessible to the public must be at least 25 to 30 metres wide (deep).

- Accepting informal use
  - When managing a *fait accompli*, e.g. surfacing a short cut worn through regular use, the special qualities (e.g. a certain sense of secrecy) of cutting through the vegetation is destroyed.
  - Not replanting open spots in the planting.
  - Use species that are resilient to wear and tear.
  - Opportunities can be created, for example by tipping a pile of sand in the planting area so that children can make a mountain bike arena.

1.4.2 Planting and Habitat

Factors

The suitability of planting depends on climatological conditions (wind, light, seasons)[40] and physical conditions (soil, groundwater level, air and the space available above and below ground). A different selection of plants is needed behind the dunes along the coast than on a site in a fenland polder or on the sandy soils of Noord-Brabant.
As a designer, you will at first be tempted to base your choice of plants on spatial qualities to do with dimension, form (habit), colour and structure. A further consideration is whether the site is in a rural or an urban environment, where there are special restrictions.

Whatever the scale at which you are working, the final detailing is crucial. Financial resources will often be an important consideration (particularly if planting or transplanting older trees is involved).

Climatological conditions

Wind

Wind, usually from the sea, is an important factor in the west and north of the Netherlands; frost in the east and south. The effects of wind must be fully considered as it exerts considerable pressure on twigs and branches (in leaf). In rural areas, the direction of the prevailing wind can often be read from the shape of the trees.

Poplars grow rapidly and quickly make a spatial impact, but are ‘not solid enough’. At about 40, branches tend to split and so many trees are felled at around this age. Poplars are not the trees to plant if you want them to be around in 100 years time, although they can live for a long time. As solitaires, it may be worth the extra work, but not for an avenue.

Unfortunately, many a good tree succumbs to our autumn storms; the poorest specimens have by then lost their leaves, but those that still have a good leaf cover are exposed to the full force of the wind.

But wind is not restricted to rural areas. The taller buildings built in recent years create considerable ‘downdraughts’. In front of the Robeco building in Rotterdam some trees have been planted to absorb these downward gusts so that passing cyclists are not literally blown through the air! Climatological conditions, therefore, do play a role in urban planting.

Light

Light pollution (albeit only at high levels) and salt (road salting in winter, fish stalls on the market) are disastrous for trees. Light requirement and ‘drip damage’ are more important factors affecting shrubs, and trees with dense crowns permit only a very little undergrowth. The so-called ‘woodland planting’ (plots with trees and shrubs) dating from the 1970s often cause problems now. The trees are large and the undergrowth is dying off purely due to insufficient light. Of the original large plots full of trees and shrubs, only the edges will eventually remain, the planting being hollow under the tree canopy in the middle. If you want the shrubs top remain, plant the trees far apart or choose trees with open crowns that let a lot of light through. ‘Drip damage’ can be a significant problem; some hedges (e.g. Yew) are very susceptible to drip damage, other, like Beech or Sycamore, are unaffected.

Seasons

Planting should look attractive the whole year round. Some trees and plants bloom in winter. Autumn colouration can also add variety.

Spring (flowering)[41]

- trees: alder and willow (March); cherry and magnolia (april); apple, horse chestnut, hawthorn (may)
- Shrubs: hamamelis, forsythia (March); currant, rhododendron (April); azalea (May)
- bulbs/tubers:
- early: (February/March): snowdrop, crocus
- late: (April/May): narcissus, tulip

Summer[42]

- trees: horse chestnut, catalpa (july); golden rain (June)
- shrubs: hibiscus, hydrangea, roses and perennials

Autumn (colours)[43]

- trees: sycamore, birch, hornbeam, sweet chestnut, hawthorn, honey-locust, oak
- shrubs: whitebeam, currant, spindle

Winter

- berries: hawthorn, privet, ornamental apple
- evergreen shrubs: rhododendron, holly, viburnum
- shrubs with berries: currant, whitebeam, ivy, privet, rose

Winter (flowering)[44]

- tree: *prunus subhirtella* 'autumnalis' (flowers November/December and again in April)

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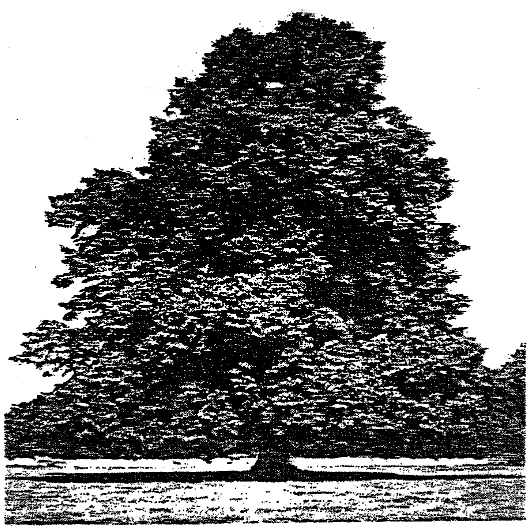


Fig. 143 *Lime (summer)*

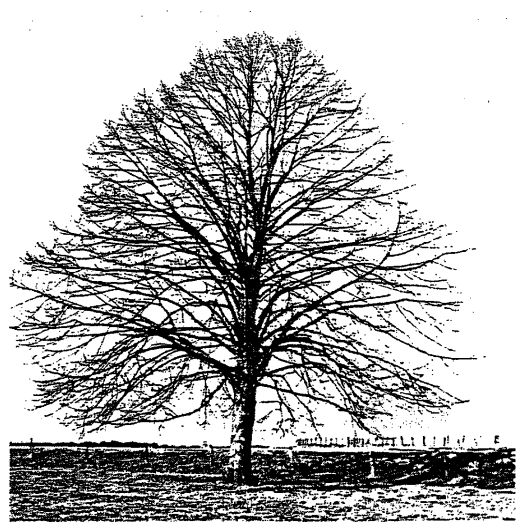


Fig. 144 *Lime (winter)*

Physical conditions

Pysical conditions concern soil, groundwater, air and space for roots.[45]

Soil

Roughly speaking, soil in the Netherlands can be classified into clay, peat and sandy soils (and all the intermediary forms). Plants on sandy soils – often in windy locations – have adapted by reducing the size of their leaves (e.g. sea buckthorn, juniper), by growing hairs on their leaves (mullein) or by taking on light or greyish colours.

Examples of coastal trees:[46]

- alder
- poplar
- oak
- willow
- rowan

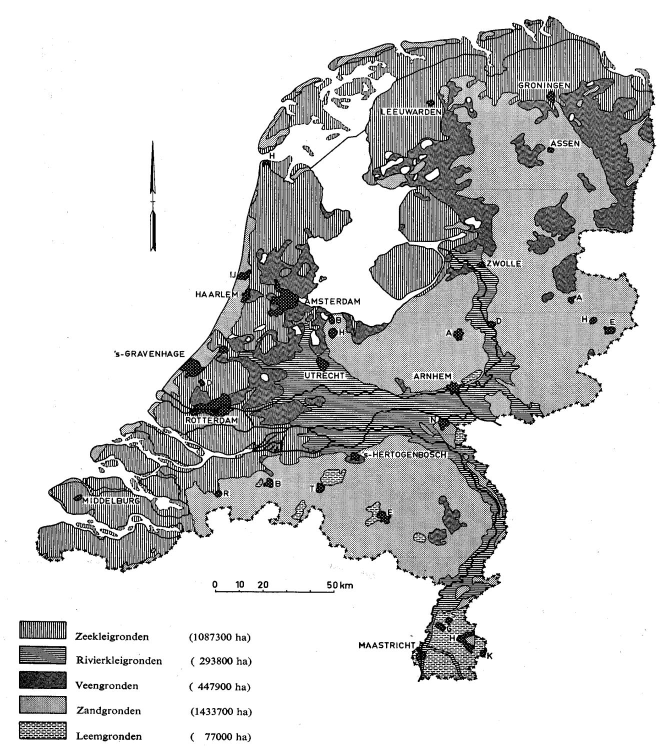
Because of their structure, clay and loamy soils retain water for a long time. They are often cold in spring, and less oxygen is available than in sandy soils.

Examples of trees on clay/loam soils:[47]

- alder
- horse chestnut
- birch
- cherry

Another important factor is the presence of calcium, which supports a different type of vegetation; a base-poor dune vegetation contains different plants to calcareous dune valley vegetation. Peaty areas are acid and always moist; nutrient levels are a crucial factor. alder and rowan do well in nutrient-rich peat, birch in nutrient-poor peat. Well-known shrubs suitable for acid soils are rhododendron and azalea. If they are planted in other soil types, peat will always have to be added to the soil.[48]

The above also applies, in principle, in rural areas, where plants still have a 'feel' for the soil. Clearly, in purely urban environments the original soil is less important for plants, particularly trees.



Sea clay
River clay
Peat
Sandy soils
Loamy soils

Fig. 145 *Soils of The Netherlands*

Groundwater

If the water table is too high, few trees and shrubs will be able to survive. Tree roots will develop poorly and not anchor the tree well in the ground; as a result they are easily blown over. Of course, too little groundwater is not good, either; the plants wilt.

Trees which can grow in wet conditions are: Alder, Birch, Poplar and Willow. [49]
Trees that can grow in dry conditions are a few Maple species, Birch, Hornbeam, Acacia and a few Poplar species. During the growing season (May to August) tress take up large quantities of water from the soil.

In an urban environment, trees depend on a number of sources of water:

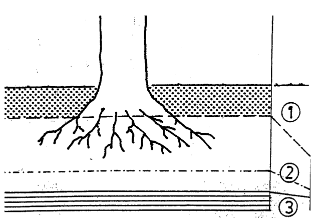
- Groundwater

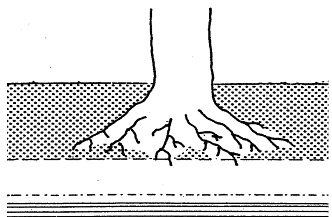
- Capillary water ('sucked' up from the groundwater through the soil)
- Pendular water (precipitation that clings to the surface of particles in the aerated zone)

The demand for water in summer is greater than the amount of pendular water. The extra is drawn from the groundwater; the water table falls in summer, but it is replenished again in winter from rain and snow.

Much water in the city goes straight into the sewer; the more 'porous' the paving is the better this is for the trees. But the water must remain for as long as possible in the pendular water zone. Humus is a valuable component in the soil because it retains a lot of water.

The best situation is a water table that fluctuates around 1.25 m under the soil surface (1.50 m in the summer and 1 m in the winter).[50] Under these conditions trees can become well established and firmly anchored. If a tree cannot take up enough water, the roots go in search of more. The root ball of a healthy tree reflects the size of the crown.





1. Soil containing humus
2. Capillary zone
3. Water table

Fig. 146 Spring

Fig. 147 Autumn

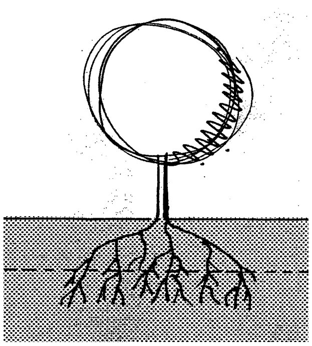


Fig. 148 *Groundwater level approx. 1.25 m:Roots and branches: above ground = below ground*

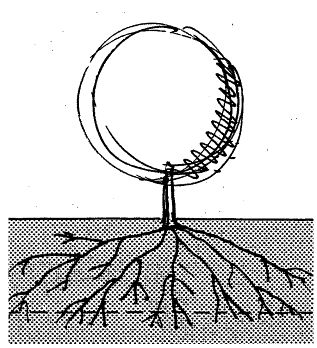


Fig. 149 *Deep groundwater level: roots 'search out' water*

Air

Trees in built-up areas – except trees in parks and gardens – grow in a habitat that simply cannot be compared with a site in a wood or open landscape. The soil in the country is open (to air and water) and fallen leaves provide a supply of nutrients. Conditions in urban areas are very different. Paving requires well compacted soil; but trees need open soils. Air is kept out by the closed road surface and compacted soil, which leaves almost no pore volume for air to penetrate.

In open soils, about 50% of the volume is air; below 15% oxygen, roots become stunted, at 11% oxygen they start to die. All paving seals the surface of the soil and so open spaces – slotted flags or widely spaced paving bricks – are essential. Trees cannot develop roots under asphalt surfaces (0% oxygen). The pressure and vibration caused by heavy traffic further compacts the soil.

In ‘sinking’ areas (peat soils) in the West of the Netherlands the paving has to be raised every so often, even up to 30 or more centimetres at a time. As a result, many trees receive too little oxygen and die. Oak and Beech always die, Lime trees grow a new layer of roots if the additional soil layer is no deeper than 25 to 30 cm. Elms and Planes tolerate these conditions quite well.[51]

A. Sinkhole
B. Sawn kerb, min. length 500
C. Kerb type Cru 80
D. Tree grille Cruquius concrete blue limestone colour 1200 x 1200 x 120
E. Air grate
F. Dark paving brick (size, 20x6.6x6)
G. Dark paving brick (Waal size, 20x5x7)

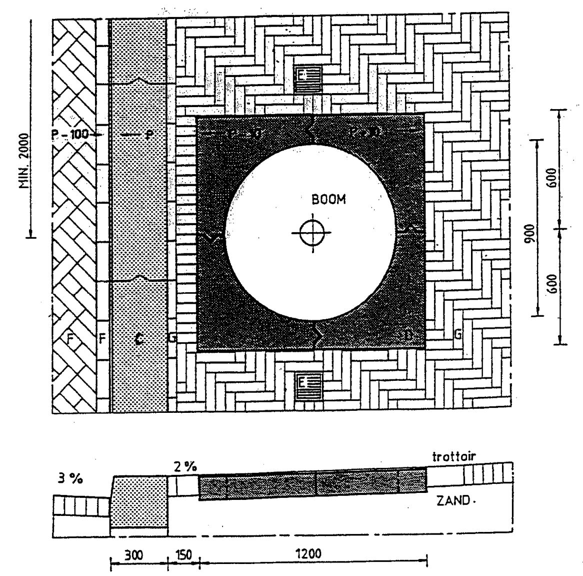


Fig. 150 *Tree pit*

Root corridor and tree pit

Urban trees cannot be viewed in isolation from their environment; they are one of the factors that define the public domain in the city. Street trees add to the quality of public spaces and have a different effect in each place. When planting trees in urban areas it is wise to design a strip for trees only, with no cars, cables and pipes or street furniture: a ‘corridor’. This ‘plantpit’ can be finished with a 10 cm layer of sand, with paving on top (with no risk that the paving will sink any faster than the surrounding area).[52]

If this is not possible, a tree pit of 2 x 2 x 1 m should be made and filled with suitable tree soil. Tree soil is light soil, contains approx. 4% humus, is well aerated and well drained, retains water well and contains sufficient nutrients. Where more air is required in the soil, perforated drainage pipes can be used as ‘air pipes’ to ensure better aeration of the soil.

In many places, though, hard road surfacing and numerous mains services and cables leave no room for planting. In these situations the minimum area required for a tree is 7.5 m on both sides (i.e. 15 m apart) because otherwise they will have an even greater struggle for survival. The more open the structure of the topsoil, the better this is for the tree.

It is important to choose a good tree grille. Square tree grilles are often used in paved areas because these fit well into the pattern of most paving materials. Cast iron or metal tree grilles are attractive, but expensive. Accumulation of dirt and rubbish in the space between the grille and the soil (approx. 10 cm) can be prevented by filling this space with Argex pellets until right under the grille. These are light, expanded clay granules (reddish brown) which considerably improve aeration. Another attractive solution is to use gravel. A cheaper option is 30 x 30 cm slotted flags. In parking areas always ensure that the tree trunk is protected.

Cross-section
Pavement
Tree corridor
Road / main sewer
Pavement / cables
and pipes

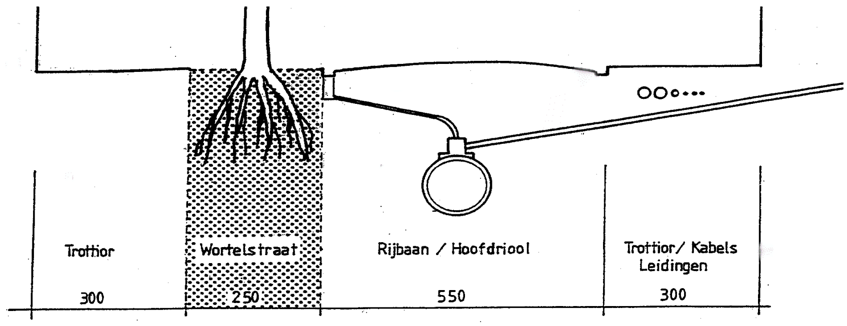


Fig. 151 *Cross-section*

Types of trees

Size, form, structure, colour

Size and form not only depend on climatological and physical factors, but also have a major impact on the streetscape. In spatial terms, they may or may not provide structure or accentuate the spatial composition (see Tree Structure Plan Amsterdam). Texture relates to the shape, size and arrangement of the leaves and it is very important when detailing to ensure compatibility with the materials used. Colour speaks for itself. A significant fact is that light green tints have the effect of expanding spaces, dark green and red-brown make spaces seem smaller and can create a sombre atmosphere. Copper-leaved trees are striking, particularly as solitaires, such as copper beeches on farms (also sycamore/maple, apple, cherry, oak).

Choosing a tree

When choosing trees, consider the amount of space above ground. If you meet the conditions discussed above (tree pit, soil, etc.) there is a chance that the trees will grow to maturity and attain their full size. Plane trees can easily have branches 10 m long, and so they should be planted 12 m from buildings. If the pavement is not very wide, choose a tree a size or two smaller or a tree with a columnar crown. If not, the crown will soon grow up against wall and must either be pruned each year, or the tree felled and another species planted.

Size classes of trees:[53]

- Size class 1: 15 m and taller
- Size class 2: to about 10 m
- Size class 3: to about 5 m

Size 1 trees develop crowns at least 15 metres across. Large dense crowns must be avoided in small streets, where trees with light open crowns are to be preferred (e.g. Gleditsia/Honey Locust). For most residents the minimum acceptable distance between crown and wall is about 2 metres. Obviously, planting distances will bear some relation to the location of the doorways, drives and passages along street frontages.

Planting distances

If trees are planted very close to buildings, drastic measures are repeatedly needed to ensure enough daylight penetration. Sometimes these measures can be so drastic that the resulting remnant of the tree may no longer make a positive contribution to the streetscape.

To plant trees that can develop freely with the minimum number of complaints, you need to weigh up the following considerations:

- The nature of the building facade
- The distance between the trees and the building
- The distance between the trees
- The tree species
- The pruning method

In real terms, this means that when planting new trees, *minimum distances* must be adhered to. Greater distances should be used when planting trees with a broad, dense crown, such as plane and horse chestnut.

Trees may only be planted at shorter distances than given in the table:
- When planting trees with a columnar or thin crown
- Along 'blind' walls
- When special pruning methods are used, such as espalier, pyramid pruning and pollarding
- When only a few trees are planted along a street frontage

Rows of trees let through very different amounts of daylight, depending on whether the crowns of the trees join together (closed) or are spaced apart. This makes it important to note the relevant planting distances for the various size classes.

Planting

As a rule trees are planted between 1 November and 15 April. They are then resting and have the best chance of becoming established.

Standard sizes of trees for planting are:
- 14–16 cm girth (approx. 5 cm diameter)
- 16–18 cm girth (approx. 6 cm diameter)
- 18–20 cm girth (approx. 6.5 cm diameter)

The price ratio for these sizes is 1:1.5:2.

Planting distances for rows of trees:

Size class	open row (spaces between crowns)	closed row (crowns touching)
size class 1	> 18 m	5–10 m
size class 2	> 12 m	5–8 m
size class 3	> 9 m	< 5 m

Minimum distance between the buildings and the centre of the stem[54]

size class	min. distance stem to building
size class 1	6 m
size class 2	4 m
size class 3	3 m

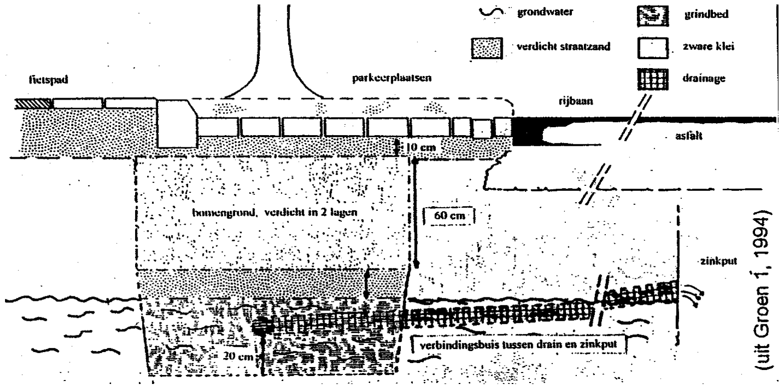
In urban renewal areas where high levels of vandalism are expected it is better to plant fewer larger trees rather than a larger number of thinner trees.

Transplanting

Trees with stems about 30 cm diameter can be transplanted; the larger the tree, the more expensive the operation. Trees with bigger stems can be transplanted, but their chances of survival are much smaller. Ensure that the root ball is as large as possible (min. 3 m across and 1–1.5 m deep). If you know well in advance that a tree will be transplanted the roots can be cut when the tree is still standing, and new hair roots will grow to form a neat compact root ball. This can be done is summer or winter.
The latest method is to soak the root ball in winter. This then freezes to create a solid ball of soil and roots. The tree can then be lifted out with a crane and transported by trailer to its new site. After planting (good pit and tree soil, etc.) the tree should be pruned to restore the balance between the root system and the crown. Prices depend on size, transport options (disconnecting the overhead tram lines, transplanting at night, etc.) and financing. Transporting a Horse Chestnut with a stem diameter of 45 cm over a distance of 1 km (difficult journey, disconnection of tramlines and transport by night) costs about € 10,000 per tree.

groundwater (grondwater)
compacted street sand (verdicht straatzand)
gravelbed (grindbed)
heavy clay (zware klei)
drainage (drainage)

Bicycle path (fietspad)
Parking places. (parkeerplaats)
Tree soil, compacted in two layers (bomengrond verdicht in twee lagen)
Road (rijbaan)
Asphalt (asfalt)
Soakaway (zinkput)
Pipe between drain and soakaway (verbindingsdrain tussen drain en zinkput)



(Source: *Groen* 1, 1994)

Fig. 152 *Modern tree pit design for the trees in the Plantagemiddenlaan, Amsterdam*

1.4.3 Tree planting and the urban space

Visual effects

Different visual effects can be reached applying loose groups and solitaires, rows, rhythm, screens, walls or diferent canopies.[55]

Loose groups and solitaires

The plants are allowed to grow in their natural form and are often used to create a contrast between a 'hard' architectural element and a loosely structured planting scheme. A 'loose' planting scheme can only be used when there is sufficient space available. Solitary trees are, in effect, 'green monuments'; they often stand in special locations and have a striking form (e.g. a Lime tree in the village square).

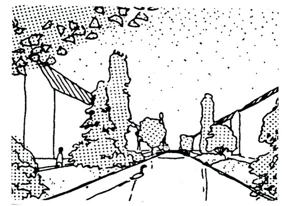


Fig. 153 Loose groups

Rows

A planting scheme in which the distance between trees is so great that the crowns cannot meet. Rows are often used for long, regular street frontages. The free-standing trees provide some visual articulation along the length of the street. In rows the specific characteristics of the tree species are the key visual features: each crown is clearly set off against the buildings.

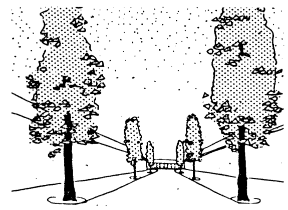


Fig. 154 Rows

Rhythm

Comparable with a row, but in this case the trees are planted in such a way that the visual articulation they provide is integrated into the design structure of the built environment. A rhythm may consist of solitaires. This planting pattern can be a good solution for situations where there is not enough space for continuous planting schemes. Instead, many trees can be planted on corners or other regularly occurring sites where there is more room.

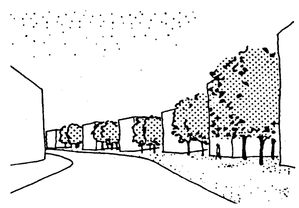


Fig. 155 Rythm

Screen

A screen is a transparent wall of trees through which the facades of the buildings are more or less visible, depending on the viewpoint. A screen is best created using species with an open crown in which the branches do not grow in one main direction so that they easily flow together to form a visual whole. Elms are good trees for creating a screen. Some other species, if planted close together and with some extra pruning, can also be used to create a screen effect. A problem, though, is that if the trees are planted close together the transparent effect can easily be lost.

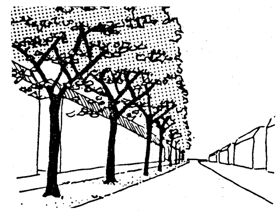


Fig. 156 Screen

Wall

A wall consists of multiple rows of trees planted short distances apart so that the crowns grow into each other. If tree species that develop dense crowns are used (e.g. Lime) it may even be possible to plant just one row; the trees must then be no more than 8 m apart. In the summer this planting scheme creates the effect of a 'green wall'. It is important that the trees form a continuous whole. If the planting distances are too great or if too many trees are missing from the row, the wall effect is largely lost.

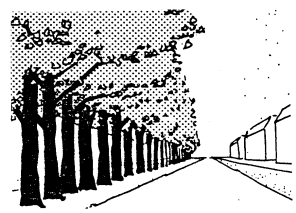


Fig. 157 Wall

Canopy

A canopy consists of multiple rows of trees short distances apart and with intertwining crowns. The most suitable trees species are those with a broad, fairly open crown. The canopy effect is largely lost if the trees are planted too far apart to form a unified mass.

Fig. 158 Canpy

Habitat

The choice of tree species, pruning method and intensity of the maintenance regime are determined partly by the street profile. The biggest problems arise in narrow streets with trees that are too large. In narrow streets with pavements between 3 and 5 metres wide, only trees with a narrow pyramidal or columnar crown should be planted. Trees with a broad pyramidal crown or a definite spreading habit must be planted at least 7 m from the nearest building.

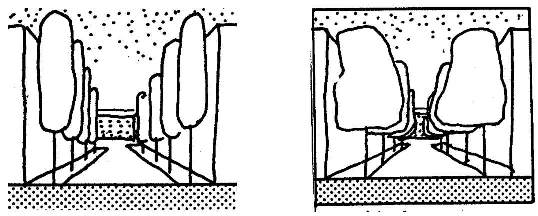


Fig. 159. Columnar or pyramidal crowns in narrow streets

Trees in size classes 2 and 3 are also suitable for planting in these situations. Fig. 160 shows a cross-section through a narrow pyramidal tree in a narrow street. This tree requires a lot of pruning:
Crown thinning: pruning branches back to allow daylight penetration to the buildings
Possibly crown reduction: shortening lateral branches to prevent them touching the buildings
In wider streets with pavements at least 6 m wide it is possible to plant trees that have a more spreading habit. The maintenance work required is comparable with that in example *A*.

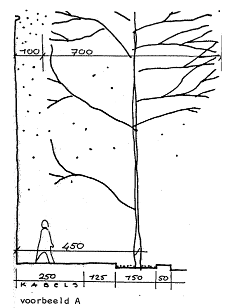


Fig. 160 *Narrow columnar habit*

Fig. 161 shows a tree with a columnar crown has been used. These require less pruning: only crown raising and possibly a little thinning. Unfortunately, few species have this habit. The well-known *Populus nigra* 'Italia' cannot be planted in narrow streets because its very shallow roots push up the hard surfacing (heave). This species requires a zone about 5 m across free of hard surfacing.

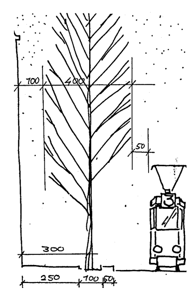


Fig. 161 *Pyramidal habit*

Fig. 162 shows a tree planted near a private garden. In these cases, medium-sized trees should be planted no less than 5 m away from the edge of the garden. For trees with a spreading habit, like Plane and Horse Chestnut, this distance may need to be as much as 15 m. This distance must be adhered to prevent:

- the tree blocking out all light to the garden;
- undue sucker growth in the garden;
- spreading branches.

In special cases, meetings can be held with local residents/users about planting trees in or near private gardens, but firm maintenance agreements will have to be made.

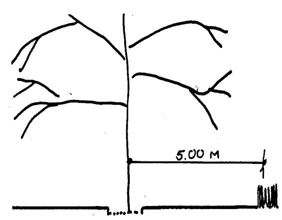


Fig. 162 *Tree close to private garden*

The sensitivity of certain species to climatological influences, particularly when they get older, can pose considerable problems. The most striking example is vulnerability to wind. Large, spreading branches are highly dangerous and may lead to liability problems for the party responsible for maintenance (usually the municipal council).

Achieving the desired visual effect

Besides the habitat of the trees, other essential factors in achieving the desired visual effect are the choice of species and planting scheme. If, for example, a screen of trees is to be planted in a street, the designer will have to decide whether to use a slow-growing species at short distances apart or a fast-growing species planted further apart. In narrow streets, however, fast-growing species will soon cause problems and it is better not to use them.

There are three methods for achieving a reasonably good planting(visual effect(time)) in a relatively short time:

- plant slower growing trees at short intervals;
- plant a mix of fast and slow growing species;
- plant semi-mature trees (more than 10 years old).

Re 1: Planting at short intervals quickly yields a reasonably good visual effect. Short distances between trees are often necessary to obtain a screen or wall effect. An advantage of planting trees close together is that the trees compete for light and quickly grow upwards, giving an upright habit with straight stems. A disadvantage is the extra pruning that is often required.

Re 2: Mixing species with different growth rates requires intensive maintenance work which must be carried out promptly. It is only recommended for planting in broad strips of vegetation (woodland planting). The advantage here is that slow growers are ‘forced up’ by faster growing species. This only works with some species: elms can be combined with poplars; oaks grow too slowly and are eventually shaded out.

Re 3: Another option is to plant semi-mature trees at their final distances apart. Semi-mature trees, however, find it hard to adapt to their new habitat and it takes a few years before they grow at their normal rate again. Moreover, transplanting is an expensive business. An advantage of container trees is that they can be planted easily and successfully at any time, even outside the planting season. This makes these trees highly suitable for use in special situations: rapid restoration of planting schemes in squares or along an important road, or after accidents, etc. However, container trees are often slow to become established and can be ‘overtaken’ by smaller, root-balled trees.

Planting distances

When deciding on the planting distances needed to achieve the desired visual effect the following points should be considered:

- the final diameter of the crown of the tree
- height of the tree
- the habit of the tree (tree shape, height/width ratio, openness of the crown)
- the root system
- shading of nearby buildings
- width of the road and path (for canopy effect)
- the relation between the final height of the tree and nearby buildings
- the period needed to achieve the desired visual effect

A number of examples are presented to explain points 1, 2 and 3.

Road and street planting, seen from the carriageway

Seen from the carriageway, rows, screens, walls and canopies create increasingly enclosed effects.

Visual contact with the wider environment. Trees planted at 20 to 30 m intervals form an open row which permits a good view of the wider environment (trees of size class 1) (See Fig. 163).

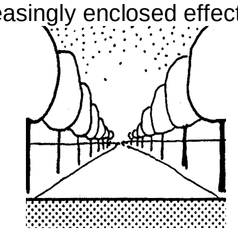


Fig. 163 *Screen/row*

Greater delineation of the road; a wall gives a stronger effect than a screen. Planting intervals should be no greater than 10 m to allow the crowns to grow together. A careful choice of species is necessary because not every species grows well in this configuration (See Fig. 164).

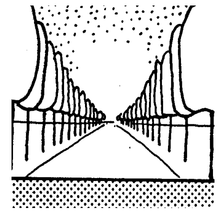


Fig. 164 *Wall*

The vault: the trees have an upright habit (with branches at an angle of 45 to 60 degrees). The crowns just meet to form a very high 'roof'. A narrow road planted with Elms creates this effect well (See Fig. 165).

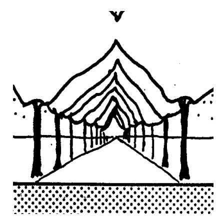


Fig. 165 *Canopy, vault*

The flat canopy: mature broad pyramidal trees or trees with overhanging branches give a flat, broad canopy. The branches grow at an angle of 0 to 45 degrees. Trees that can be used to create this effect are Oak, Horse Chestnut and Lime (See Fig. 166).

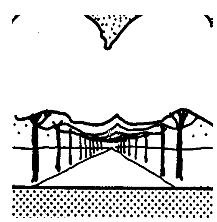


Fig. 166 *Flat canopy*

The cathedral effect: two rows on either side of the road, the crowns of the inner rows are lifted higher than the outer rows(See Fig. 167).

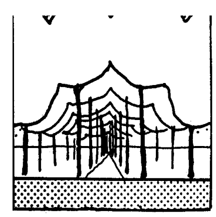


Fig. 167 *rows are lifted higher than the outer rows*

Planting distances

Planting distances have a considerable effect on the urban environment according to the applied size class.[56]

Closed screen or wall

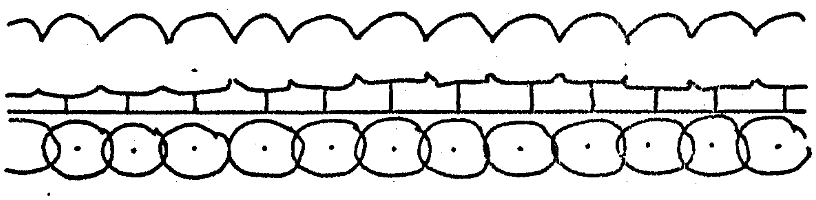


Fig. 168 *Trees of size class 1; planting distance 5–12 m; open under the crowns*

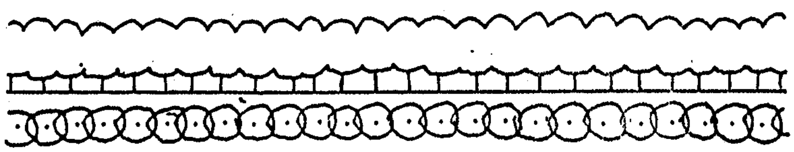


Fig. 169 *Trees of size class 2; planting distance 3–8 m*

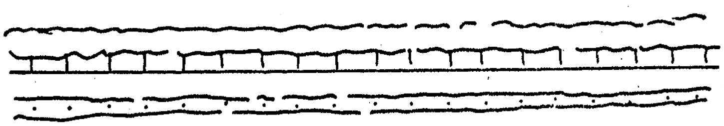


Fig. 170 *Trees of size class 3; planting distance 2–4 m*

Row

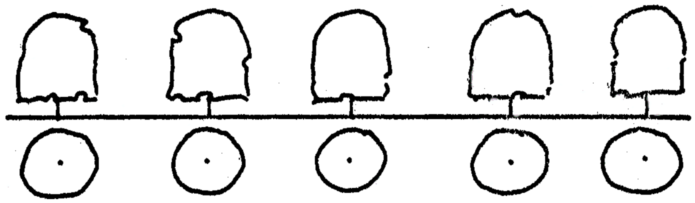


Fig. 171 *Trees of size class 1; planting distance 20–30 m*

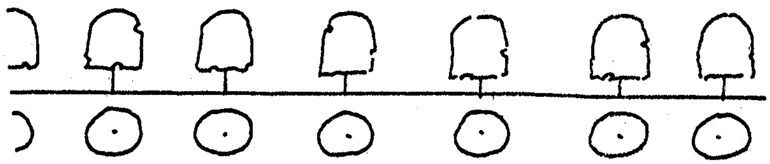


Fig. 172 *Trees of size class 2; planting distance 15–30 m*

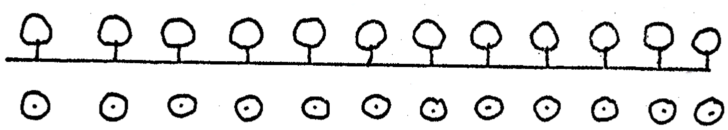


Fig. 173 *Trees of size class 3; planting distance 10–20 m*

Silhouettes of the different trees

Fig. 174 *Alder (els)*

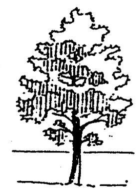


Fig. 175 *Black Poplar (populier)*

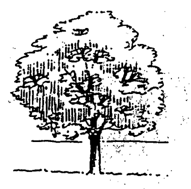


Fig. 176 *Ash (es)*

Fig. 177 *London Plane (plataan)*

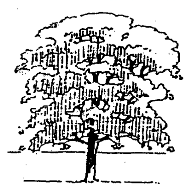


Fig. 178 *Elm (iep)*

Fig. 179 *Common Oak / Pedunculate Oak (eik)*

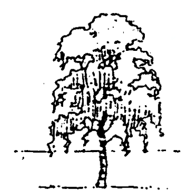


Fig. 180 *Downy/White Birch (witte berk)*

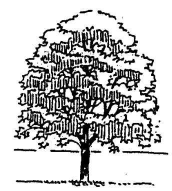


Fig. 181 *Sycamore / Great Maple (esdoorn)*

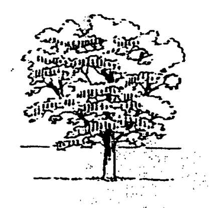


Fig. 182 *Locust Tree / False Acacia (acacia)*

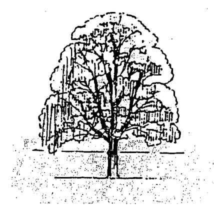


Fig. 183 *Common Lime (linde)*

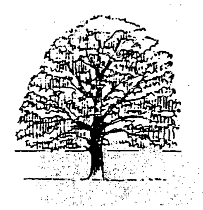


Fig. 184 *Common Beech (beuk)*

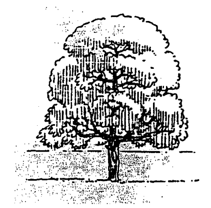


Fig. 185 *Horse Chestnut (kastanje)*

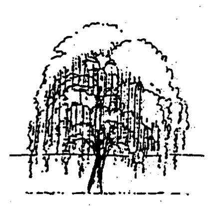


Fig. 186 *Weeping Willow (treurwilg)*

Fig. 187 *White Willow (schietwilg)*

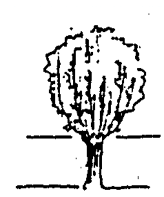


Fig. 188 *Pollarded Willow (knotwilg)*

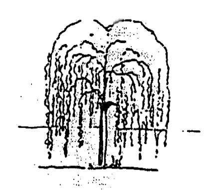


Fig. 189 *Weeping Ash (treures)*

Pruning

There is a balance between the amount of leaves and roots a tree has. If too much growth (above ground) is cut away the tree will compensate for its shortage of leaves by throwing up many new shoots. Pollarded trees such as Poplar and Willow must be pruned each year. Trained trees/espaliers are grown for their architectural form. Examples are:

- Lime
- Plane
- Hornbeam

A nursery grown tree has been pruned in the nursery to obtain a clear stem height of 2 m while its natural form is maintined. During the first 5 to 10 years the crown of the tree will require some light pruning. Trees close to the edges of a road must have their lower branches remove to ensure sufficient clearance for passing traffic.

Trees do not last forever, so do not hesitate to remove old specimens with a limited life expectancy and plant younger trees!

Crown raising

Trees planted along roads and paths should have their lower branches removed. This crown raising (to a height of about 2.5 m) is started when the trees are still young. Depending on the situation, a street tree will have to undergo further crown raising over the years. In some cases up to as much as 7 m above ground level (species with hanging branches).

When raising a tree crown thought should be given to obtaining the right balance between the length of the stem and the crown (2:3 or 1:2). It is an unattractive sight for a tree of 14 m to have a clear stem height of 7 m. In these cases it is better to go for an asymmetrical crown. In the example above the tree may have its crown raised to 4 m on the pavement side, but up to 7 m. on the side above the road. This gives the streetscape a much better appearance. The rows of elms planted along canals are a good example of asymmetrical crown raising. In some cases, pruning will still be necessary on the side facing the buildings to ensure sufficient daylight penetration.

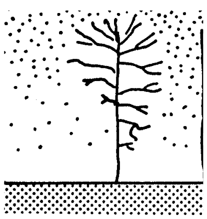


Fig. 190 *crown raising near building*

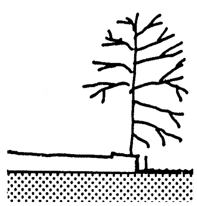


Fig. 191 *crown raising along a canal*

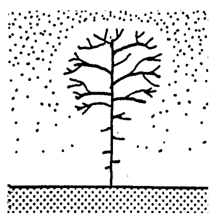


Fig. 192 *partial crown lifting*

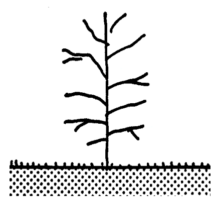


Fig. 193 *crown raising in grass*

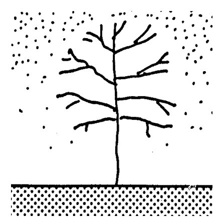


Fig. 194 *crown raising in a street*

Crown raising heights

planting stock	2.5 m
residential streets	3 m
main roads	4.5 m
tram lanes	4.5 m
trees with hanging branches	to 7 m
asymmetrical: housing side	2.5 m
asymmetrical: canal + quayside	2.5 m
asymmetrical: canal + grass	0–2.5 m
in grass	0–2.5 m
in ground cover	0–2.5 m
in low shrubs (to 1.5 m)	0–2.5 m
in medium-sized shrubs (to 2 m)	2.5 m
in tall shrubs (from 2 m)	2–7 m

Summary

The choice of plants depends on:
1. The site and growing conditions
2. Growth characteristics and habit of the planting material
3. The appearance of the planting and the atmosphere it creates
4. Practical aspects (function and goal)
5. Cost and available funds

1. Site and growing conditions
- natural landscape
- cultivated landscape
- urban area
- nature and character of the buildings (tall buildings create windy conditions)

Growing conditions

Soil type
- Sand nutrient rich
- Peat nutrient poor
- Clay
  - calcareous / lime rich
  - non-calcareous / base poor
  - acid
  - good/poor structure
  - humus content

Groundwater levels
- high – wet
- low – dry
- water retaining capacity of the soil

Climatological conditions
- sheltered
- exposed
- coastal
- urban area
- industrial site
- wind
- frost

Light requirement
- open site / full sun
- semi-shade
- full shade

2. Growth characteristics and habit

Tree dimensions
- Size class 1
- Size class 2
- Size class 3

Shrub dimensions
- Evergreen – taller than 4 m
- Deciduous 2–4 m
- 0.5–2 m
- less than 0.5 m

Crown shape and habit of trees
- spherical
- spreading
- broad pyramidal
- narrow pyramidal
- columnar
- weeping

Crown shape and habit of shrubs
- groundcover
- spreading
- upright
- compact
- overhanging

Texture
- leaf shape
- leaf size
  - large
  - medium
  - small
- leaf arrangement

Leaf colour
- light green – dark blue-green
- light to dark brown
- yellow
- variegated

Blossom
- flower colour
- flowering season early spring
- spring
- summer
- autumn
- fruit
- autumn colour
- bark

3. Appearance

Visual effect
- ankle height
- knee height
- waist height
- breast height
- eye level
- above eye level

Mutual relation between elements
- harmony
- contrast
- rhythm
- decorative value

4. Practical aspects
- winter hardness
- vitality
- disease resistance
- abundant and/or long-lasting blossom
- function in the plan
- spatial layout
- relation to buildings
- relation to existing planting
- client’s wishes
- wind protection
- shade
- traffic guidance
- noise reduction
- enclosure
- ground cover

5. Costs
- purchase costs and required dimensions
- intensity of maintenance
- length of implementation period
- available financial resources

1.4.4 Hedges

Hedges divide the space where a fence or wall is undesirable. The primary function of a hedge is always separation, most obviously to divide two uses, for example to divide a private space (garden) from the public space. Hedges provide a natural background for other plants; thorny hedges form an impenetrable barrier. Hedges have an important spatial effect. They can be classified into those which divide up the space in which they stand ('free-standing') and those that form part of a larger mass immediately behind them.[57]

When the spatial impacts of hedges are examined more closely, it seems obvious to classify them by height. According to their application, we can then distinguish: edges (to approx 0.5 m high), partitions (0.5–1.5 m) and full screens (more than 2 m high). Their respective applications are: as an edge when used to mark out patterns or a composition of lines, as partitions when their function is to resist or direct movement, and as a full screen to visually seal off a space.

One spatial effect of hedges is to facilitate comprehension of the scale of the space and the elements in it, because the hedge has a consistent size (height) which serves as a reference on a human scale. Another spatial effect is created if the hedge is quite long and forms a connecting element that provides continuity. For this purpose hedges do not have to be trimmed; a row of shrubs (a 'loose hedge') can also create this effect. Besides their spatial effects, hedges may also, possess a number of intrinsic characteristics.

Natural (loose) habits of shrubs can be tightened up by pruning to form a hedge. These neater forms give hedges a more cultivated appearance, and the hedge is a symbol of continuous human intervention in the natural process of growth. A trimmed hedge can be used in two ways:
As a contrast with 'looser' forms in the surrounding area, or with a less cultivated environment (e.g. a neat hedge around a farm, set in an agricultural or quasi-natural landscape).
As a harmonising element; the regular 'architectural' shape of the hedge harmonises with an architectural, usually urban, environment.

Hedges may have an *ornamental value*, which cannot be seen in isolation from the above – the contribution the hedge makes to the appearance of the wider environment. The characteristics of hedges discussed above make them an ideal means to accentuate a prominent location.

Hedges have two major disadvantages. First, they have to be pruned regularly, in some cases two or three times a year. Second, they take up considerable quantities of nutrients, which are then not available for any plants near the hedge, making regular fertilisation necessary.

Hedges for marking out spaces

Hedges between the main road and bicycle lane or footpath

These hedges are planted for traffic safety reasons: they make crossing impossible and at night they prevent glare from the headlights of oncoming traffic. These street profiles are only found in post-war urban areas and non-urban areas. Trimmed hedges require a lot of maintenance, though, and in these situations can easily be replaced by untrimmed hedge/shrub planting if there is sufficient space, or, in places where the safety function is not essential, by a normal verge.

Hedges along watercourses

(See Fig. 195)These are also planted for safety reasons, to keep children away from the water. *The hedge is a friendlier type of fence*. The need for and value of hedges in the neighbourhood should be determined. Such hedges do not remove the danger altogether, but keep it at a distance and make it less threatening, but, because of this very effect, can make the (unknown) danger much greater.

In addition to the functions mentioned above, these uses of hedges can enhance appreciation of the scale of the space in which they stand.

Hedges as a visual screen to hide (mainly) parked cars

(See Fig. 198)This use of hedges is particularly dependent on the environment. They are suitable for this purpose in an urban environment, but in other environments they can easily be replaced by an untrimmed hedge or shrubs. It may even be worth considering removing some taller plants; owners often want to see their parked cars from the house.

Hedges as space-shaping elements

Hedges can create their own separate (sub)rhythm different in character from the larger space they are part of. An example is a garden surrounded by a hedge, possibly in a park, the regular form providing a contrast that sets off the space. In this case the trimmed hedge is an essential element. Should the situation within the hedges 'not work', it is better first to see if another use of the space can improve the situation before deciding to grub up any hedges. Hedges are planted around playgrounds and seating areas mainly for safety reasons because they stop children running onto the road. Besides this strictly functional aspect, hedges also provide 'shelter' and 'security' for the play area. In other words, the hedge marks out a territory.

The same quality of 'security' or 'cover' is provided by hedges surrounding a sitting area with benches. A trimmed edge is justified around such areas if they form a contrast with the loose forms in the area and so create their own place, or if the site is located within a paved area where the use of hedges adds an architectural dimension and has a practical effect of saving space (the 'paved character' relates to walls as well as horizontal surfaces).

Hedges as edging for a mass

The hedge as linear element

A tall or medium-sized hedge can provide a background for roses, for example, or a border. Removing such a hedge often destroys the appearance of the border and is only advisable if the border is of a sufficient size.

Hedges that form a pattern or composition of lines

Very low hedges, which are essentially an edging, are found around borders of roses or perennials. Often they are laid to give the border a less dreary look when there is little to see in the border itself. This situation has value only if two conditions are met:

The height of the hedge is in proportion with the planting material in the border
The hedges themselves form a particular pattern that is interesting enough when the roses of perennials have been pruned or cut down.

Use of these types of hedge is only justified in prominent places or in situations where there is very little green. Moreover, their maintenance is time-consuming in proportion to their length. Sometimes a compromise solution is acceptable to reduce the length of such hedges.

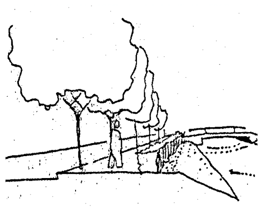


Fig. 195 *Hedge along watercourse*

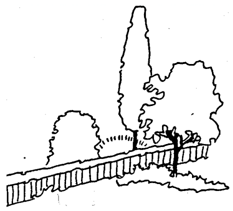


Fig. 196 *Contrast*

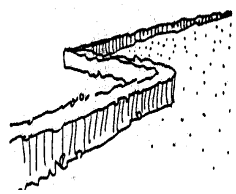


Fig. 197 *Hedge in open space*

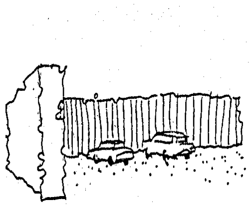


Fig. 198 *Hedge bordering car park*

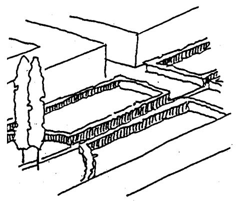


Fig. 199 *Harmony*

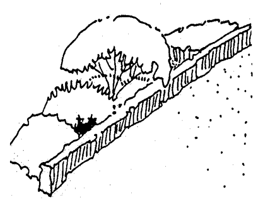


Fig. 200 *Hedge as part of a mass*

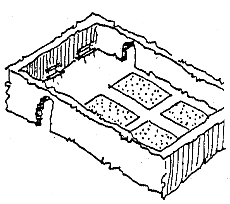


Fig. 201 *Hedge enclosing a garden*

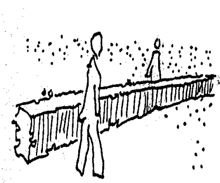


Fig. 202 *Partition*

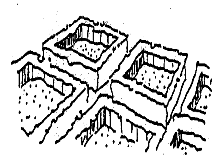


Fig. 203 *Edges*

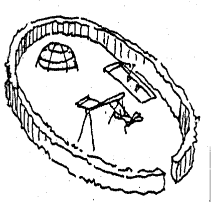


Fig. 204 *Hedge round a 'place'*

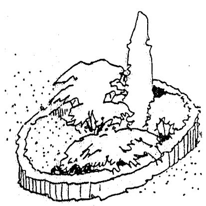


Fig. 205 *Hedge bordering shrub bed*

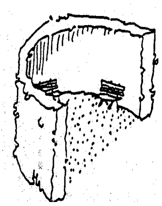


Fig. 206 *Complete screen*

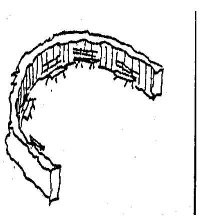


Fig. 207 *Shelter for seating*

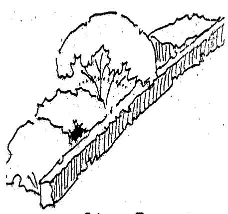


Fig. 208 *Edge*

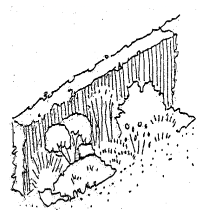


Fig. 209 *Background to border*

	Planting distance	Loose/regular	Growth rate
Evergreen hedges			
box (*buxus sempervirens*)	$5/m^1$	regular	
holly (*ilex aquifolium*)	3 à $4/m^1$	regular	
common yew (*taxus baccata*)	$3/m^1$	regular	
holly (*ilex aquifolium*)		loose	
privet (*ligustrum ovalifolium*)	3 à $4/m^1$	regular	
size 40–60			
deciduous hedges			
hornbeam (*carpinus betulus*)	$4/m^1$	regular	
beech (*fagus silvatica*)	3 à $4/m^1$	regular	
hawthorn (*crategus monogyna*)		loose	
blackthorn (*prunus spinose*)		loose	
rose – botanical roses		loose	

Growth rate: number of years until the plant reaches a height of 1.5 metres (depending on habitat, soil type and maintenance)

Pruning hedges

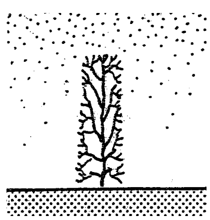


Fig. 210 *vertical*

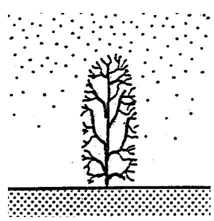


Fig. 211 *rounded*

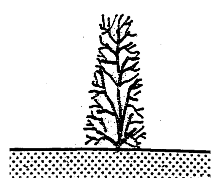


Fig. 212 *tapered*