2 Wind, sound and noise

Contents

2.1 Global atmosphere

2.1.1 Air, its mass and density

Pull the closed end of a garden hose out of a bucket filled with water and take it with you upstairs to the fifth floor. Above 10m, water is replaced by vacuum like vapour (mercury has vacuum above 76cm). Apparently, atmospheric air pressure on the bucket (1 bar, 100 000Pa, 100 000N/m^2 or old fashioned: 0.987 atm, 10 197.162 kgf/m^2)[58] can not push it higher. So, the mass of approximately 500km air above 1m^2 Earth's surface should equal approximately 10m^3 water or 10 000kg. Because the surface of the Earth is ample half a billion km^2 there is ample 5 x 10^{18} kg air, less than a millionth of the Earth's mass (6 x 10^{24}kg). At sea level density ρ of air is 1 290g/m^3 [59] which equals 3 x 10^{25} particles (*Fig. 215*).

2.1.2 Wind, its force and power

So, if your own cross section is 1m^2, then in one second at a wind velocity of 1m/sec (3.6km/hr), 1m·1m^2= 1m^3 air (1.29kg) would hit you. Fortunately much of this mass immediately starts flowing sideward around you (see chapter 2.6.4). Otherwise it would not 'pass by' and a train of many m^3 (many times 1¼ kg) moving air in front of you had to be resisted. But you are only changing its direction and velocity, braking it by 'negative acceleration', which is felt as a force, because force=mass·acceleration as we learned from Newton.

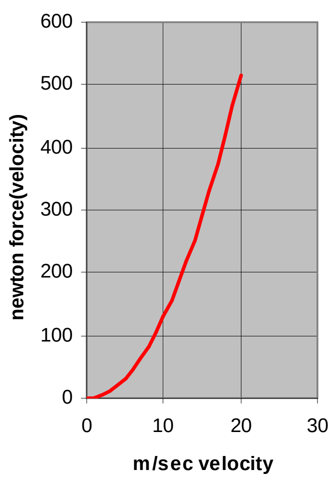


Fig. 213 *Wind force (= air mass x velocity/sec) Air mass = density x volume and air volume = height x width x length. Because air length = velocity x sec, velocity occurs two times in the formula for wind force, so force increases parabolically by square of velocity.*

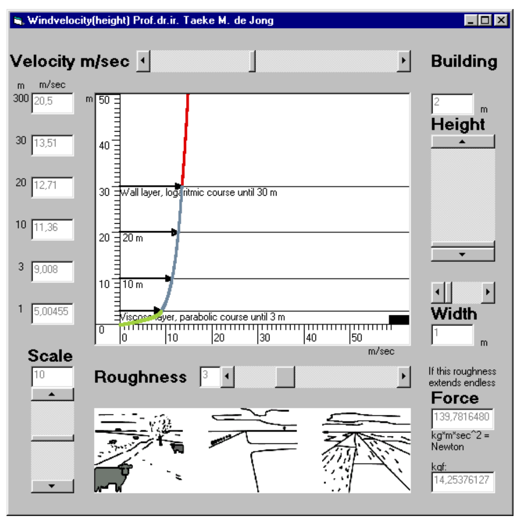


Fig. 214 *Wind velocity increasing by height depending on roughness of foreland. Wind load on a building has to be calculated on every layer of height and summed up to total height. Sideward flow is neglected here*[a]

But, to keep calculations simple we suppose you have to resist 1m^3 of air per second, that is 1.29kg/s at 1m/s, which is a force of 1.29kg·m/s^2 or 1.29N. It is per m^2, so you can also say a 'pressure' of 1.29N/m^2 or 1.29 pascal (1.29Pa). In storm (10m/sec) it will increase to 129N/m^2 (Fig. 213), because now 10m^3 air or 12.9kg hits you in one second also with ten times higher velocity! To get an impression: that force corresponds to the force produced by a child+bike (30kg) hitting you cycling at 15km/hour.

[a] Jong (2001) *http://team.bk.tudelft.nl > Publications 2006 > Windvelocity(height) .zip*

So, to calculate the force or pressure (force/m^2), you have to take velocity *two times* into account. One time you need velocity to calculate the air *mass* hitting you in one second and the second time you need velocity to calculate *acceleration* (velocity per second) to determine force because force=*mass·acceleration*. So, wind force increases parabollically by *square* of wind velocity (see Fig. 213)[60]. However, these figures are valid on 1m height average, where ‘storm’ in grass land corresponds to 10m/sec (36km/hr) , but at 10m and 20m height it corresponds to 24 and 26m/sec at the same time. The velocity increases with the altitude first like a parabole, then logaritmically and at last exponentially in the ‘boundary layer’ influenced by the ‘roughness’ of the Earth (see Fig. 214).

Buildings are wider and heigher than you are, taking up much more m^2 surface. But you can not simply multiply the surface by the force you have to resist on ground level to get the force a building has to resist, firstly because the velocity increases by height. You have to calculate the wind load on an building on every level and sum all these force contributions up to total altitude (see Fig. 214). Download the Windvelocity(height) program with 8 pictures in the same directory and it will estimate the force in layers of 1cm be it neglecting sideward effects. The environment on the ground (roughness) has great influence, determining differing parameters you have to use. Get a feeling how it works by changing wind velocity and roughness in the program. It is a fast and rough approximation. To be more precise you should calculate it at any spot by vector integration in 3 dimensions, including sideward movements, decelerations and accelerations depending on the shape of the building[61].

2.1.3 The atmosphere

However, air density also decreases from 1290g/m^3 at ground level into 1g/m^3 at 50km height (see *Fig. 215*)[62]. So, aeroplanes meet less resistance the higher they fly (until 20km), but propellers and wings will work less effective as well. That is why jet engines are used at higher altitudes with higher velocities.

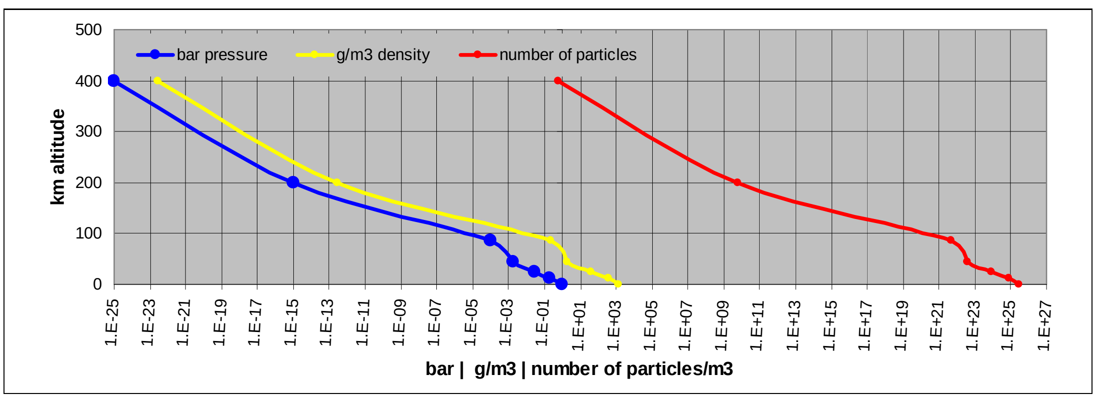


Fig. 215 Pressure, Density, Particles/m^3(height)
A bar is 100000N/m^2 or 100000Pa or approximately 1 atmosphere
1.E+03 in Excel means 10^3

The air temperature has three turningpoints according to the altitude (see Fig. 216)[63].The smallest wave lengths of ultraviolet sunlight entering the atmosphere from 500km altitude are directly absorbed heating the thin air more than 1000^{o}C until it equals heat loss by own radiation. That influence reaches until approximately 100km altitude. Around 50km (mesosphere) the rest of UV light is nearly fully captured by ozone heating the air until 20^{o}C at 50km with decreasing influence between 50 and 10km (stratosphere). On 10km the atmosphere measures - 50^{o}C. However, the main stream of visible and infrared light is not captured and heats up the Earth’s surface, on its turn heating up the atmosphere by convection from below until 10km (troposphere) or radiating it back to universe as invisible infrared light, only captured by CO_2.

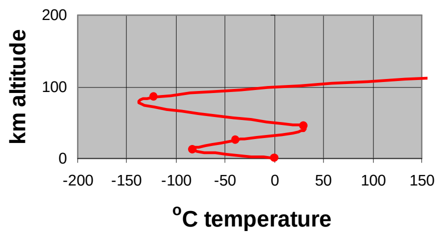


Fig. 216 Air temperature(altitude)

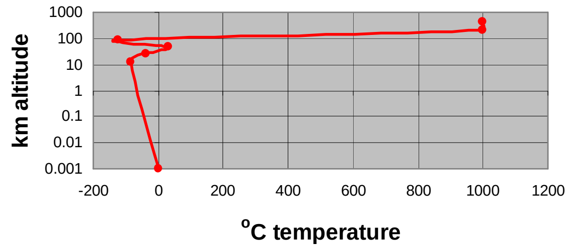


Fig. 217 Air temperature(log(altitude))

An air bubble heated by the Earth's surface climbs up in the troposphere expanding by decreasing environmental pressure. The aquired heat content is dispersed in a larger volume. So, its temperature decreases until it matches the environmental slower decreasing main temperature and rising stops. Meanwhile from a specific temperature onward damp could condensate to steam and ice resulting in cumulus clouds rising with drying air. They show a flat bottom indicating a temperature boundary for condensation is passed[64]. By condensation solar heat is released, giving the steaming air bubble an extra push upward.

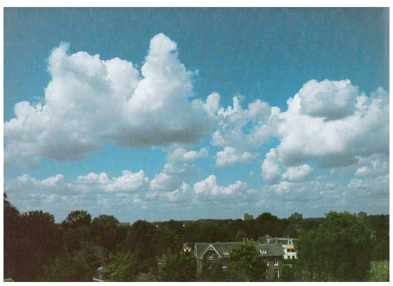


Fig. 218 Cumulus clouds with flat bottom[a]

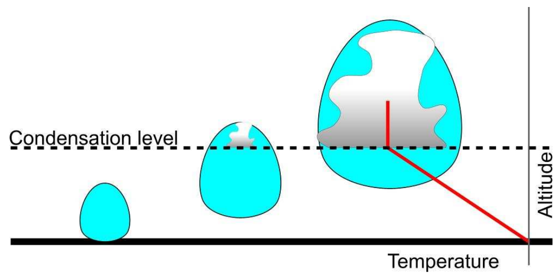


Fig. 219 Air bubble condensating

2.1.4 Climate

The Earth turns Eastward 360° in 24 hours. The equator is 40 000km long[65], as Napoleon ordered to determine the length of a metre. So, at the equator we have a velocity of 1 670km/hour and we are 3g lighter than at the poles by centripetal force. That force has stretched the Earth's radius 22km outward compared with the radius toward poles when Earth was yet a turning droplet from a sneezing sun. The same still happens to equatorial atmosphere: it is thicker there than at the poles[66].

Equatorial air heated and saturated from moist by tropical temperatures climbs fast and high (see Fig. 220). Shortages on the ground are supplied by 'trade winds' from South East and North East[67]. Coming from North and South they are not used to equatorial high speed Eastward. Seen from the ground their inertia give them a Westward drift. But they are pulled along with rough grounds. Then, once heated they climb higher than everywhere else on Earth, because of centripetal forces. Moreover, environmental density and temperature decrease slower here with so much competing air bubbles around, stimulated by an extra push from condensation causing tropical showers below.

But they continue to loose heat by expansion and radiation into the universe and reach the point they can not rise anymore because their temperature matches the environment. Where to go? Pressed by their upward pursuers they fly back high Northward and Southward getting colder and colder by radiation as an outburned balloon. They land in a subtropic latitude slower Eastward turning as if they came from South East causing subtropical high pressure and cyclones in struggle with winds departing direction South West into tropics as they did themselves in their youth. They join them at last causing a horizontally rolling spiral movement at larger scale between tropics and subtropical regions

[a] Bont, G.W.Th.M. de; Zwart, B.; KNMI (1985) *De wolken en het weer* (Zutphen) Terra

or they travel direction pole participating in a second rolling movement as South-Western winds we know so well in The Netherlands.

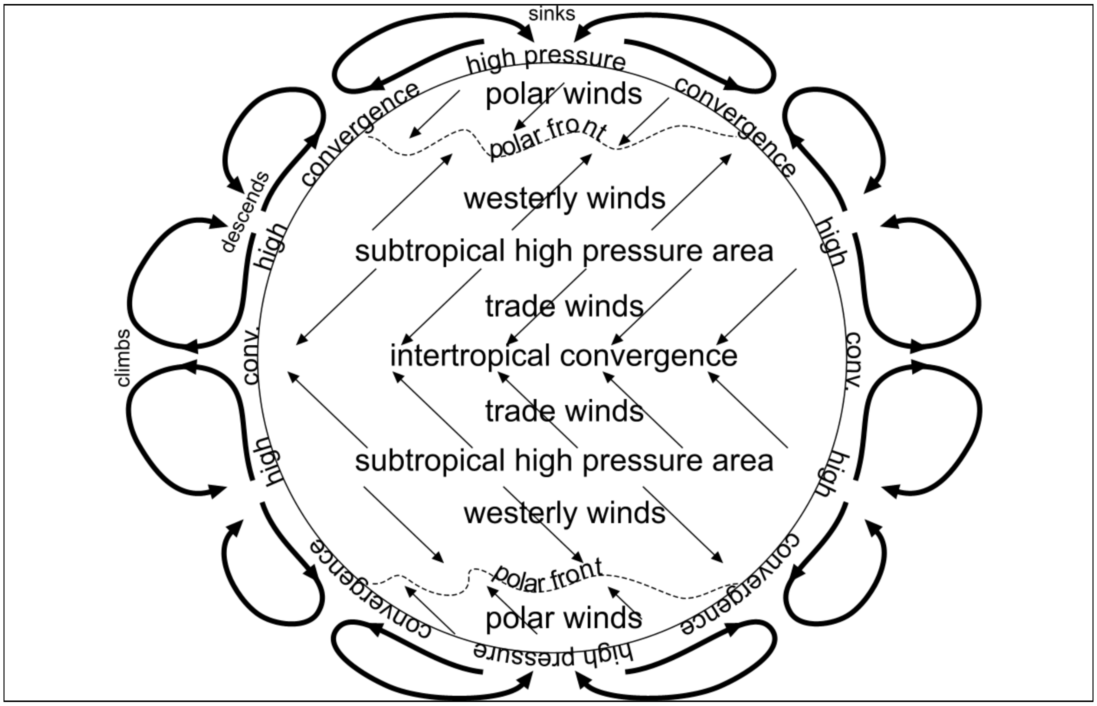


Fig. 220 *Gobal wind circulations*[a]

From the poles cold, heavy sinking air is swung by a turning Earth in all directions as polar winds. Parallel whirlings drag eachother like gearwheels in turning cells. Nobel prize winner and founder of chaos theory Prigogine (1977) boiled water in a very regular and stable pan like Bénard did in 1904 and saw regular cells emerging as structured 'order' out of chaos. Something like that could happen on a very stable, regularly heated Earth. But the Earth is turning and nodding (see Fig. 37), shaking its atmosphere like busdrivers their passengers. And it has continents heating up faster than oceans, having less water to evaporate. Disturbed by so much global and local causes meteorologists never can predict the weather of next week because little events have great consequences in the world of chaos like the proverbial butterfly causing a tornado some years later elsewhere. What is cause? However, in the long term we find some regularities (three 'rolling' cells from equator to pole) in the sum of turbulences called wind.

2.1.5 The urban impacts of wind

Local velocity of wind affects:

1. wind loads on buildings, plantation and objects in streets and gardens.
2. the energy use of buildings;
3. the potential profit of wind turbines;
4. the dispersion of air pollution;
5. the comfort of outdoor space;

In Fig. 213 we already showed the parabolic course of impact 1.
In Fig. 221 up to Fig. 224 on the vertical axis estimates of the other impacts are represented as a working of average wind velocity classes from 0,5 (0-1) up to 19,5 (19-20) m/sec on the horizontal axis.

[a] After Bucknell (1967)

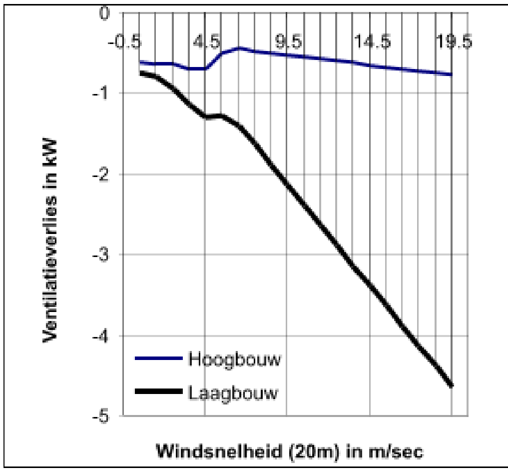


Fig. 221 *Ventilation characteristic*
Ventilation losses from dwellings increase according to the velocity of wind particulary in non airtight houses[68]. However, from 4 m/sec people close their windows. So, in this interval more wind *decreases* ventilation losses.

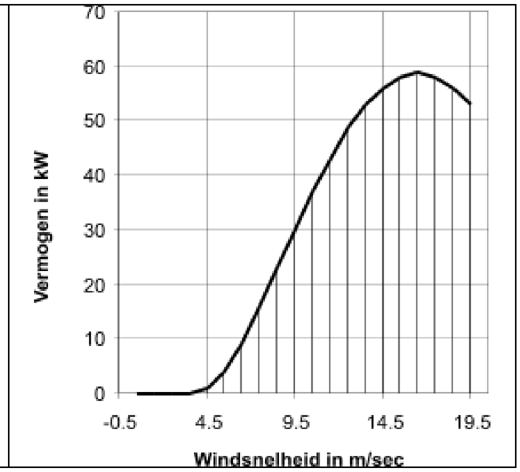


Fig. 222 *Powercharacteristic*
The produced power of this standard wind turbine increases up to 60 kW on a wind velocity of 16 m/sec. Most wind turbines brake on higher velocities to avoid damage[69].

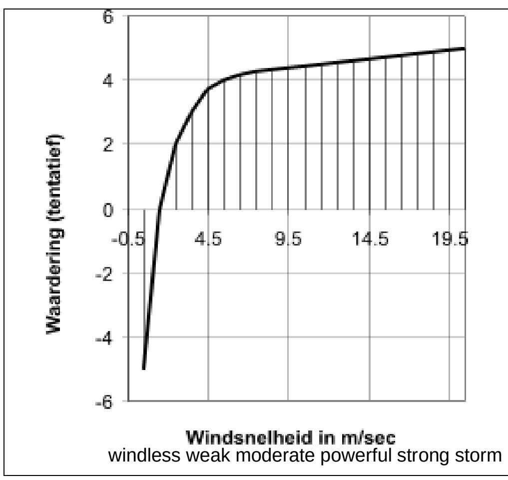


Fig. 223 *Air dispersion characteristic*
This tentative diagram represents air pollution disperses best by storm, but that impact is already reached on moderate wind.

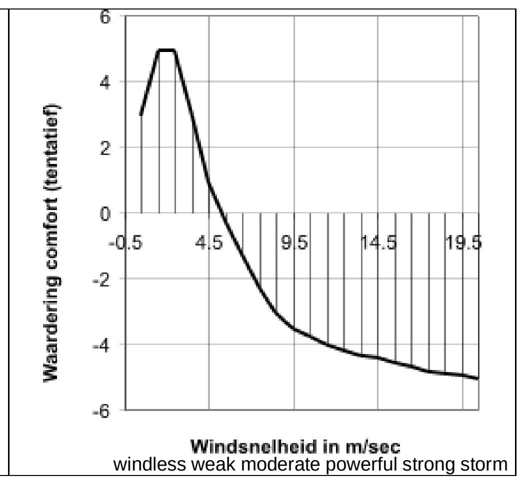


Fig. 224 *Comfort characteristic*
In this tentative diagram is supposed that a weak wind with an average velocity of 1-3m/sec is appreciated most.

Fig. 221 is used by Vermeulen (1986), point of departure in this chapter. In that time, high rise buildings were much more airtight than low rise buildings. That difference will be less today, but to show the impact of wind on energy use of buildings the 1985 span is most illustrative and still relevant. When after all, convection losses, losses by precipitation (drying up of buildings) neglected by Vermeulen and Jong (1985) would be calculated as well, an equivalent and even stronger positive relation than for former low rise buildings could be actual. An actual total energy loss characteristic then, could have an other form, but the line of reasoning remains the same. Minimisation of energy losses desires minimisation of wind velocity anyway. The fourth impact requires rather optimisation (not too much, but not too little as well). For higher velocities the aim is also minimisation of wind velocity. However, the second an third impact on the contrary require maximisation of local wind velocity. So, their aim is contrary to the first and last impact. In this representation temperature influences (relevant for Fig. 221 and Fig. 224) are still neglected.

Local average wind velocity can be influenced by environmental planning and design on national (r=100km), regional (r=30km) and different local levels (r= {10, 3, 1, 0.3 en 0.1}km). Measures on these levels are discussed in this chapter. They are not all equally applicable. Sometimes they have a theoretical of experimental character with little profit. Then they have a didactic value useful discussing next values. If that occurs, the measures and their impacts are discussed in a conditional sequence: any measure should be seen within boundary conditions of preceding measures. So, one can not miss a paragraph: measures on a local level could be understood only within boundary conditions of regional scale and these for their part from those on national level.

Here sometimes fades the boundary between 'measure' and 'given circumstances'. Is the current Dutch coast the consequence of human measures or should one speak of 'given circumstances'? A once performed measure then is a given circumstance, a condition for subsequent measures. To keep this chapter clear and readable anything deviating from a reference situation will be concerned als 'measure'. Every time two states wil be compared: the reference and its deviation by application of the 'measure' concerned. The impacts of that measure are assessed. Though we wil try to formulate the 'measures' as context independent as possible the impact assessment remain context sensitive.To be able to apply such measures in other circumstances succesively added theoretical insights are necessary.

The choice of reference in such a method of 'experimental impact assessment' is important. Choosing 'the average Dutch outskirt, filled with low-rise dwellings' as a reference produces a rather practical image of measures, be it not well applicable for inner cities and high-rise areas. However, we are attached to raise some theoretical insight in aerodynamics. So, we will change references to show impacts that can not be assessed in a standard reference. So, the reference sometimes will have a theoretical character like 'a city in the sea' or 'a sea in the city' to clarify impacts by extremes. In practice after all, a measure lies between these extremes. By attention for extremes not only one specific measure is discussed, but a range of measures with gradually changing impacts.

2.1.6 Measures, targeted impacts per level of scale

The measures discussed in this chapter can be taken on the level of

- national choice of location (100km radius, page 107)
- regional choice of location (30 km radius, page 113)
- arrangement of rural areas, form of conurbations (10 km radius, page 125)
- local choice of location (10 km radius, page 122)
- form of town and town edge (3 km radius, page 131)
- lay-out of districts and district quarters (1 km radius, page 129)
- allotment of neighbourhoods and neighbourhood quarters (300 m radius, page 146)
- allotment and urban details and ensembles divided in 4 hectares (100 m radius, page 141)
- buildings (radius 30m), and
- the micro climate, important for humans, plants and animals (radius 10m).

The conditionality into two directions is self evident. To be able to compare variants on one level a reference on any other level is presupposed. That creates difficulties in comparing measures on different levels of scale, because references have to change to reach more general insight in impacts. Morover, for every several impact (on energy saving, energy production, air pollution and comfort) other characteristics of wind are relevant. For instance for energy saving windstatistics of the winter season are relevant, for other impacts those of the whole year, eventually specified per season. If not otherwise mentioned this chapter counts on wind statistics of the whole year.

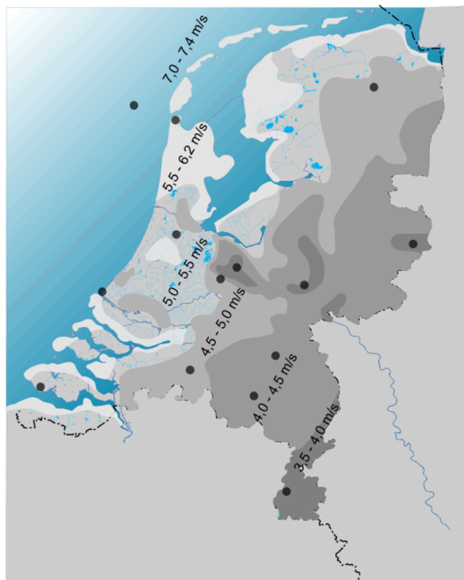
2.2 National choice of location

2.2.1 National distribution of wind velocity

What kind of difference does it make choosing a new housing estate near Amsterdan or Eindhoven concerning energy use, the possibility to extract energy from wind, the dispersion of air pollution and the comfort of outdoor space?
To weigh different building locations concerning these impacts on a national level a simple calculation of wind statistics per location is needed. Here we give a description of such calculations.

On more than 50 locations in The Netherlands wind velocity is regularly measured (Fig. 225).

Selection from Wieringa, Rijkoort et al. (1983) page 28
Fig. 225 *Wind stations in the period 1945-1980*



Selection from Wieringa, Rijkoort et al. (1983) page 84
Fig. 226 *Year average potential wind velocity*[70]
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Wind stations register gusts of more than 5 seconds duration. All measurements are averaged for one hour resulting in the 'hour average wind velocity'[71]. From these hour averages a year average can be calculated, the 'year average wind velocity'[72]. Obstacles around the wind station introduce a deviation by which these data are not immediately applicable in neighbouring locations. The correction into a 'standard ground roughness 3' (grass land) and a standard height of 10 metre produces the 'year average potential wind velocity' given in Fig. 226. Using local ground data (roughness classes) from the year average potential wind velocity one can calculate back the year average wind velocity of neighbouring locations on different heights.

2.2.2 Closer specification of wind statistics

However, in the year average wind velocity some data are lost relevant for energy use, potential energy profit, dispersion of air pollution and comfort of outdoor space as impact of different wind velocities.
Firstly we miss a specification of wind direction and a statistical distribution into different wind velocities throughout the year. For that purpose we still have to go back to the sources the 'distributive frequency division of the hour average wind velocity per wind direction, reduced to 10 metre height above open ground' per wind station. In Fig. 227 this frequency division of wind station Schiphol in the years 1951 - 1976 is given in numbers per 10 000 observations.

Velocity Class* m/sec	Still or variable 0	1	2	E** 3	4	5	S 6	7	8	W 9	10	11	N 12	TOTAL
vk	w													
0,5	348	10	8	11	10	12	16	14	16	15	9	13	14	148
1,5	78	39	43	50	51	58	72	53	66	51	36	44	55	618
2,5	15	59	82	98	80	97	132	111	119	84	68	79	102	1111
3,5	2	88	118	133	94	118	155	160	125	106	84	94	107	1382
4,5		86	132	136	86	124	150	170	113	110	77	87	87	1358
5,5		82	110	101	55	86	121	157	113	112	74	76	71	1158
6,5		74	112	82	46	71	100	163	119	109	73	76	66	1091
7,5		46	88	52	22	47	73	113	123	98	58	62	42	824
8,5		38	59	29	8	27	51	92	90	77	48	37	26	582
9,5		21	44	17	5	17	32	68	84	59	40	29	15	431
10,5		13	29	14	3	10	21	52	70	45	30	17	7	311
11,5		8	14	6	1	4	13	32	53	32	19	10	4	196
12,5		4	8	3		2	8	25	45	26	14	7	3	145
13,5		1	3	1		1	4	15	30	17	7	4	2	85
14,5		1	2	1			1	8	20	9	4	3		49
15,5			1				1	6	12	6	3	1		30
16,5								3	8	4	3	1		19
17,5								2	8	4	2			16
18,5								2	5	3	1			11
19,5								1	2	1	1			5
20,5									2	1				3
21,5									1	1				2
22,5									1					1
TOTAL	443	570	853	734	461	674	950	1247	1225	970	651	640	601	10000

* Here the middle of the class ± 0,5 is mentioned only.
** Here the wind direction in 'hours of the clock' are given; 12 hour indicates North.
'12 hour' contains all wind directions between -10 en 10 degrees from North.

Vermeulen, Hoogeveen et al. (1983) Enclosure 4.27

Fig. 227 *Frequency division w of wind velocity per class vk Schiphol 1951 until 1976 per 10 000*.

Frequency divisions like Fig. 227 are available from every wind station mostly specified per summer (may – october) and winter (november – april) half year and sometimes even per month.
Calculating the average wind velocity in Schiphol from Fig. 227 as

$$vg = \frac{\sum w * vk}{\sum w} = \frac{54420}{10000} = 5.442 \frac{m}{sec}$$

fits in the velocity class 5 – 5.5 m/s of location Schiphol indicated in Fig. 226.

In the last row of Fig. 227 all observations are specified by wind direction (Fig. 228).

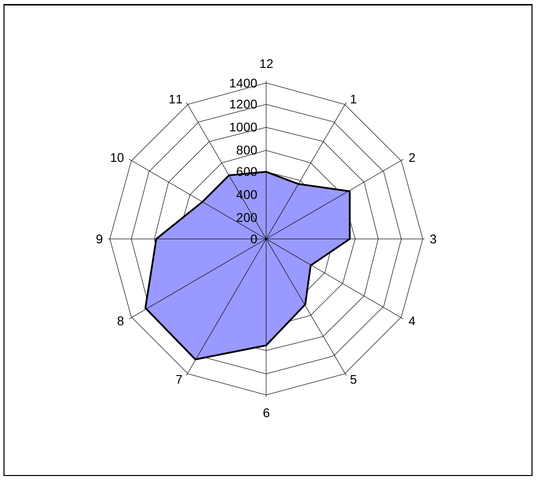
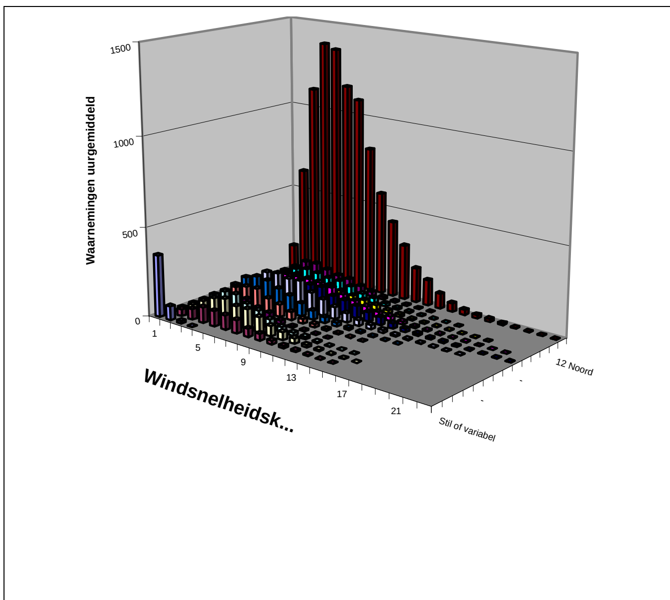


Fig. 228 C*ompass card, per 10 000 observations*

Because there are 10 000 observations, one can direcly read from Fig. 228 that 12% of the wind in Schiphol comes from directions 7 and 8. Together that is roughly 25% from South – West.

Fig. 229 shows Fig. 227 as a diagram of frequency divisions of wind velocity per class in total and per direction.



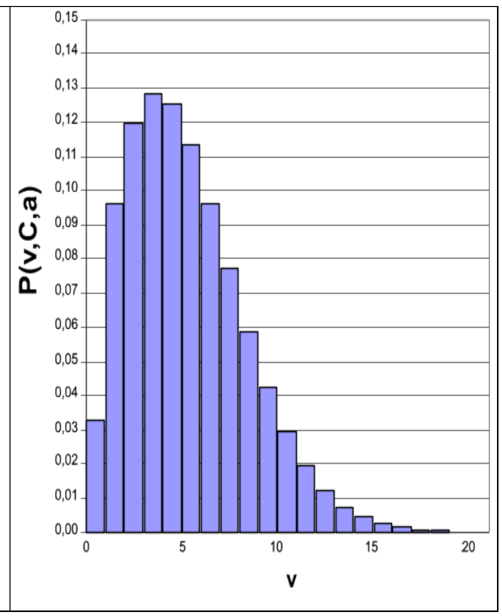


Fig. 229 *A diagram of* Fig. 227

Fig. 230 *Weibull-distribution*

The form of the graphs is higly similar to the mathematical graph of a *Weibull* probability distribution[73] like

$$P(v, C, a) := a \cdot C \cdot v^{C-1} \cdot e^{-a \cdot v^{C}}$$

represented in Fig. 230 with C and a as form and scale parameters specific for every location (Fig. 231).

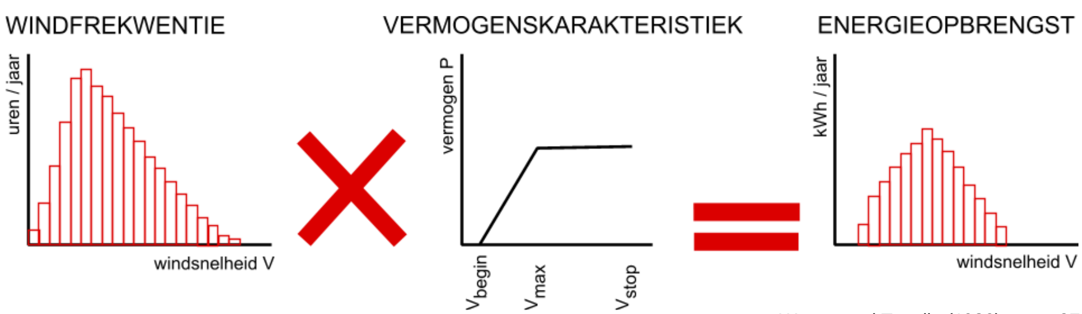
	form	schale	% from direction ('hours' from North, 0 is calm or variable):												
						E			**S**			**W**			**N**
	C	**a**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Beek	2,01	0,042	2	7	9	7	3	4	10	20	17	8	4	4	4
Den Helder	2,00	0,014	1	6	7	8	6	5	10	13	12	10	8	8	7
Eelde	1,74	0,059	3	6	8	8	7	5	9	14	14	10	7	5	4
Eindhoven	1,86	0,052	8	7	8	5	6	6	7	13	16	9	6	5	4
Schiphol	1,86	0,032	4	6	9	7	5	7	10	12	12	10	7	6	6
Vlissingen	1,95	0,025	1	9	9	6	4	5	9	13	13	11	6	7	7

Fig. 231 *Weibull parameters en contribution per wind direction for 6 stations.*

By this formula with tables like Fig. 231 we can avoid long tables like Fig. 227 and calculate back a stepless distribution of wind velocities in 12 directions on any location with the roughness of grassland. That represents local wind characteristics we need to connect to the impact characteristics from page 111. Later on we will show how per direction local landscape characteristics other than grassland are calculated in.

2.2.3 The energy profit of wind turbines

The number of observations of wind blowing with a given velocity and direction w(v,d) in Fig. 227 per number of observations 10 000 for many years in the past, is equivalent to its probability P(v,d) for the future. P(v,d) is proportional to the number of hours h(v,d) that kind of wind blowing from the total number of hours in a year. So h(v,d) = 8 766 x P(v,d). That number of hours determines the energy profit of wind turbines in an year. For example, if you know the power a wind turbine delivers on every velocity (power characteristic, see Fig. 222) you can find the profit by multiplying the number of expected hours that velocity will occur in an environment of grass land (Fig. 232).



Westra and Tossijn (1980), page 37

Fig. 232 *The way of calculating energy profit of a wind turbine*

Comparing national locations concerning the profit of wind turbines, direction of wind does not yet play the rôle it does concerning energy losses in buildings or comfort of outdoor space. The turbine after all can turn with the wind where buildings can not. On lower levels of scale we have to make this calculation for every direction seperately reduced by its specific roughness other than grass land.

However, this diagram of calculation can be used to estimate the impact of national choice of location on energy use of buildings, the comfort of outdoor space and the dispersion of air pollution as well. So, we will elaborate it for the difference in energy profit of wind turbines in the environment of Schiphol and Eindhoven.

In Fig. 233 left the velocity frequences per direction of wind from Fig. 227 and Fig. 229 are summarised into a total frequency division while the contribution of every separate direction remains (cumulatively) recognisable. Point of departure still is a standard height of 10 metres and a ground roughness comparable to open grass land. On lower levels of scale we will vary them as well.

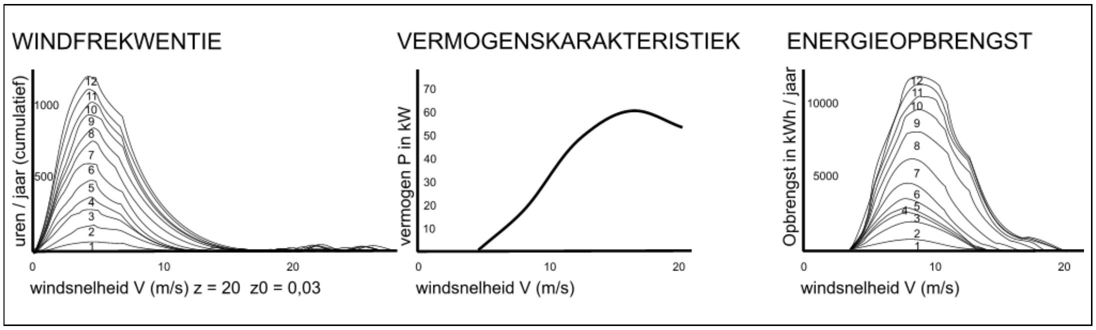


Fig. 233 *Calculating the energy profit of a specific wind turbine in the environment of Schiphol*

Left in Fig. 233 the expected number of hours per verlocity is given. The power characteristic of the wind turbine per velocity in the middle of Fig. 233 is equivalent to Fig. 222. Multiplying the number of hours of every subsequent velocity by the corresponding power produces the energy profit right in Fig. 233.

Apparently the wind turbine delivers most energy on directions 6, 7, 8 and 9 'hour'. So in that directions we have to keep the site open. However situating a wind turbine South East of town shields the turbine from an also considerable contribution from North West (1, 2 and 3 'hour'). So you can situate it better somewhat above West of town.

Comparing national locations can be done more simple by a rule of thumb for the energy profit of wind turbines with a height of 10m surrounded by open grass land[74]:

$$E = 2 \cdot vg^3 \cdot O$$

E = total yearly energy production in kWh/ m²·year
vg = year average wind velocity averaged per hour
O = surface of rotor

In Fig. 234 the energy profits presupposing a height of 10m in open grass land near Schiphol and Eindhoven are compared this way.

Schiphol:	$2 \cdot 5{,}4^3$ = 315 kWh/ m²	x 340 m² = 107 000 kWh
Eindhoven:	$2 \cdot 4{,}25^3$ = 154 kWh/ m²	x 340 m² = 522 000 kWh

Fig. 234 *The energy profit of wind turbines in Schiphol and Eindhoven by rule of thumb*

The total profit of a reference turbine of 340m2 of 10m height in all directions surrounded by grass land is in the environment of Schiphol approximately 100 000 kWh per year and in Eindhoven approximately 50 000 kWh.

We neglected amongst others height and wind direction differentiating velocity and local roughness. Wind supply is reduced from different directions, but most wind turbines are erected higher, reducing this impact. In Fig. 235 is indicated how wind velocity in open grass land (the international standard for local wind velocity measures) increases by height z. We will discuss this factor more precisely in paragraph 2.4.2.

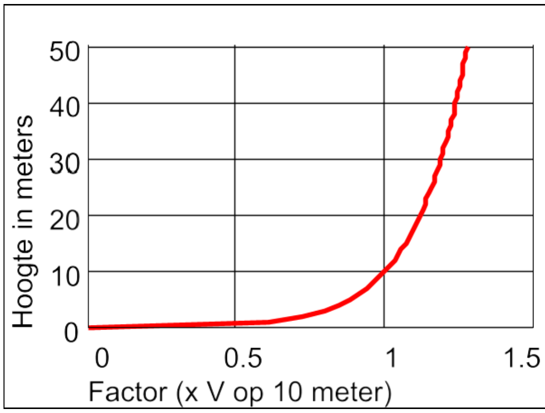


Fig. 235 *Wind velocity factor for height*

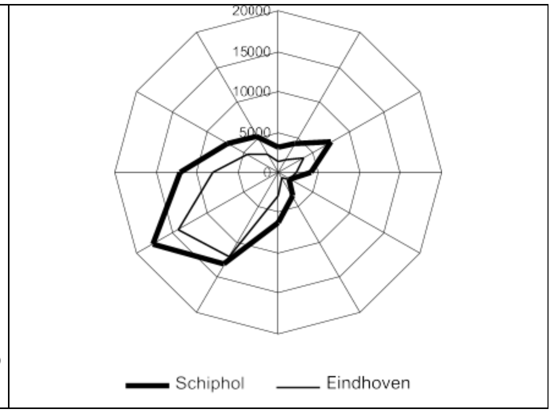


Fig. 236 *Contribution per wind direction 10m height*

Because the energy profit of wind turbines increases proportional to the third power of wind velocity (see rule of thumb on page 117) you can adapt the average wind velocity vg by this factor to the third power. The wind velocity on 20m according to Fig. 235 is x 1,13 higher than on 10m. To the third power this factor becomes 1,44. By this factor you can mulitply the profit on 10m to get the profit on 20m (for Schiphol and Eindhoven approximately 155 000 kWh and 75 000 kWh per year respectively). The absolute differences of both locations increase, as well as the contributions of different wind directions (Fig. 236).

2.2.4 Energy losses from buildings

The way of calculation in Fig. 232 can be applied to energy losses of buidings, the distribution of air pollution and the comfort of outdoor space as well. In that case you do not multiply the expected occurences of wind velocities by those in the power characteristic of wind turbines, but by those of the respective other characteristics mentioned on page 111.

Energy losses from buildings by wind not only consist of ventilation losses, but we will neglect other ones (convention, precitipation) as less important (see Vermeulen and Jong, 1985). For ventilation losses form dwellings we will restrict ourselves to wind data form the heating season, not importantly differing from better accessible data concerning the winter half year. The average wind velocity in a winter half year is approximately 10% higher than throughout the year (Fig. 237 and Fig. 238).

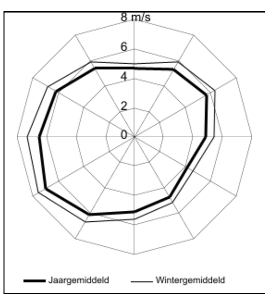


Fig. 237 *Winter half year velocities Schiphol*

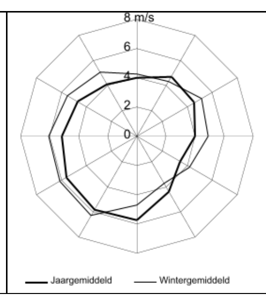


Fig. 238 *Winter half year velocities Eindhoven*

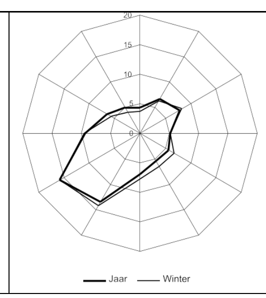


Fig. 239 Winter *probabilities Schiphol*

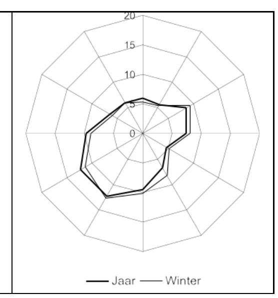


Fig. 240 *Winter probabilities Eindhoven*

The probability (number of hours) of wind from all directions is approximately the same in winter as throughout the year for all directions (Fig. 239 and Fig. 240).
In Fig. 241, Fig. 221 is repeated: the ventilation characteristic of an average one family low rise dwelling and an average more airtight one family high rise appartment. In this graph the average

occupant's behaviour to open windows at wind velocities lower than approximately 5 m/s is recognisable. This behaviour sometimes makes wind suppressing measures decreasing wind velocity less than 5 m/sec useless.

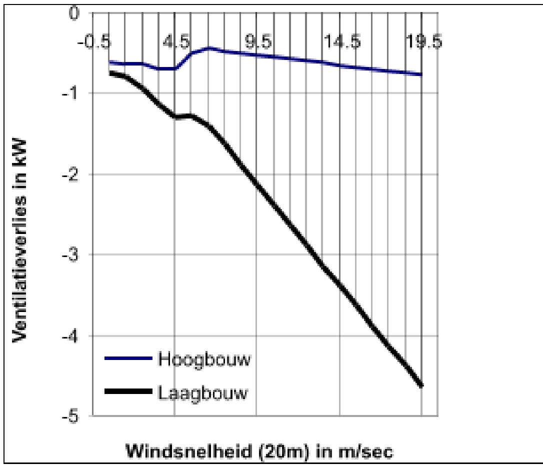


Fig. 241 *Ventilation characteristic*

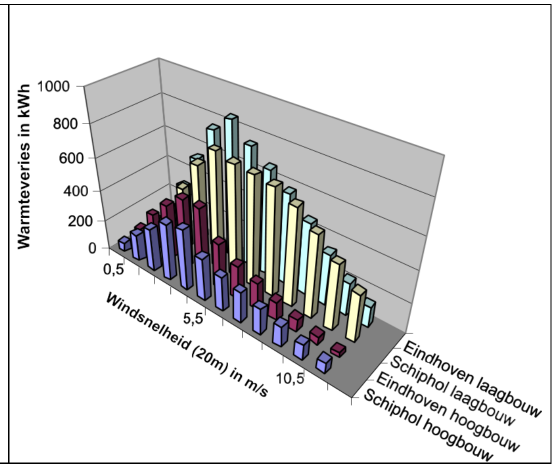


Fig. 242 *Ventilation losses per dwelling*

As expected Fig. 242 shows low rise familiy dwellings lose more in Schiphol (6861 kWh) than in Eindhoven (5557 kWh, 1300 kWh less). However, high rise dwellings lose *less* in Schiphol (2516 kWh) than in Eindhoven (2626 kWh, 110 kWh more). In Eindhoven with lower wind velocities people open up their windows more often and that counts negative in high rise buildings.

2.2.5 Temperature impacts

On which side you can shelter a dwelling best: the side of the coldest Easterly wind or the South-West side where most wind is coming from?
Answering this question requires input of temperature data. We choose an approach based on wind and temperature data Gids (1986) from wind station Eelde (with a wind characteristic between that of Schiphol and Eindhoven). We consider a period of the year between beginning December and the end of February. This approach gives a weight factor spreading heat losses by ventilation over 12 wind directions. Multiplied by the earlier mentioned figure for total energy losses of two dwellings in Schiphol en Eindhoven this produces contributions per wind direction as represented in Fig. 243 and Fig. 244.

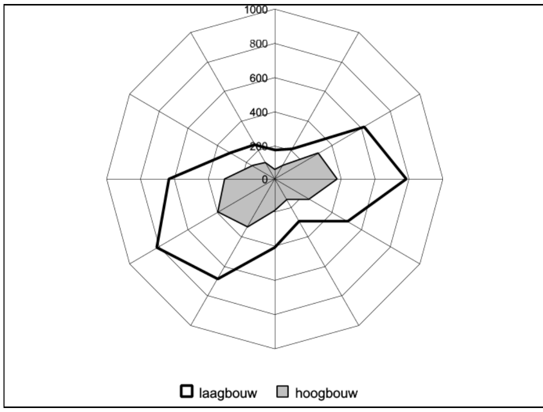


Fig. 243 *Ventilation losses weighting temperature per wind direction Schiphol*

Fig. 244 *Ventilation losses weighting temperature per wind direction Eindhoven*

Sheltering on East (3 "hour" or 90°) appears to be nearly as effective as sheltering West South West (8 "hour" or 240°), though highest velocities come from South West[75].

2.2.6 Comfort of outdoor space

The same approach without temperature impacts, this time using the tentative graph Fig. 224 reproduced in Fig. 245 would produce Fig. 246.

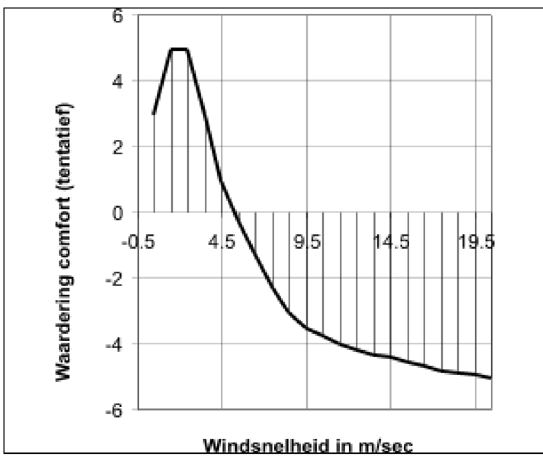


Fig. 245 *Tentative comfort characteristic*

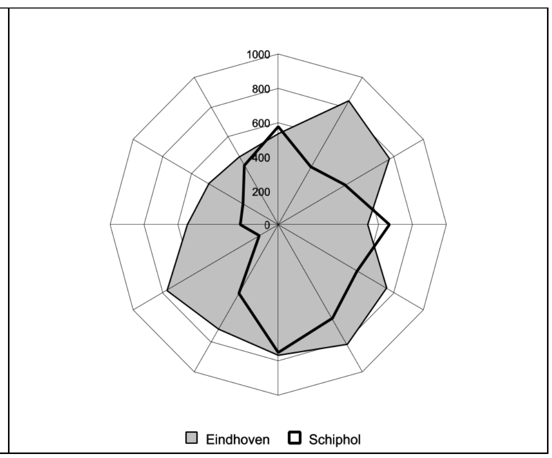


Fig. 246 *Tentative appreciation comfort*

In Fig. 246 the appreciation of every velocity is multiplied again by the respective probable velocity per direction. For all directions together Schiphol would get 11 000, Eindhoven 16 000 points. Schiphol would probably like shelter in directions with a Westerly component. Eindhoven probably does not need any shelter but eventual complaints are most probably caused by wind from North West (10 or 11 'hour')[76].

2.2.7 Dispersion of air pollution

The higher the wind velocity the better air pollution is dispersed, though increasing velocities have diminishing returns. This impact is tentatively represented in Fig. 223 repeated in Fig. 245.

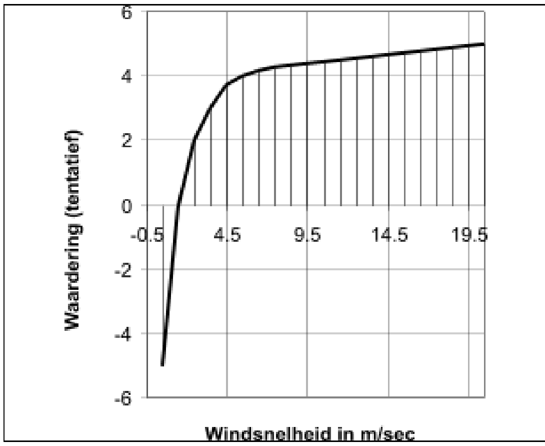


Fig. 247 *Tentative air pollution characteristic*

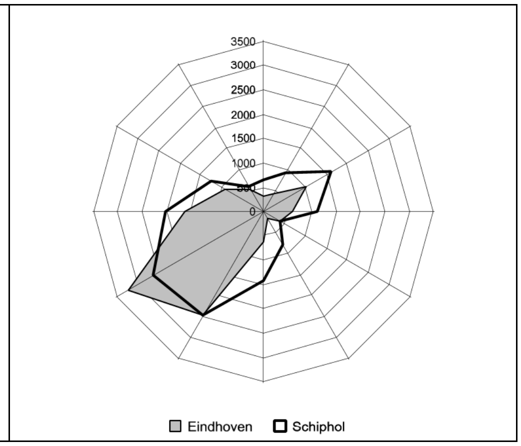


Fig. 248 *Tentative air pollution dispersion*

The impact having an overall positive relation to wind velocity, it shows pronounced similarity with the compass chard of Fig. 228. In Schiphol air pollution is better dispersed. The multiplication produces approximately 16 000 in Schiphol and 12 500 in Eindhoven.

2.2.8 Summary national comparison

Comparing Schiphol and Eindhoven on these criteria with most reservations concering the tentative ones, Fig. 249 shows which location scores best[77].

CRITERION	*WIND DIRECTION*	*1 2 3 4 5 6*	*7 8 9 10*	*11 12 TOT*
1 minimise	ventilation loss	E E E E E E	E E E E	E E E
2 maximise	wind energy	S S S S S S	S S S S	S S S
3 maximise	dispersion of air pollution	S S S S S S	X E S S	S S S
4 optimise	outdoor space comfort	E E E E E E	E E E E	E E E
		S: Schiphol better E: Eindhoven better X: No difference		

Fig. 249 *Comparison Schiphol and Eindhoven on 4 criteria*

Temperature impacts are neglected. The evaluation of dispersion of air pollution is highly similar to the energy profit of wind turbines and the evaluation of outdoor space comfort is similar to that of ventilation losses from non airtight buildings. The difference for such buildings is substantial (1 300 kWh/year in favour of Eindhoven), but in the case of airtight buildings the much lower difference (110 kWh/year) is paradoxically in favour of Schiphol by the behaviour of inhabitants (more closed windows). In the next paragraphs we will restrict to energy profits of wind turbines and ventilation loss in airthigt and non airtight buildings. In case of non airtight buildings we can use the conclusions mostly for outdoor comfort as well and in case of energy profits of wind turbines in the same time we can think of dispersion of air pollution.

2.3 Regional choice of location

On a regional level you no longer can take grassland in all directions as a standard of comparison. Wind is hampered by vegetation and buildings. On a regional level we not yet see them individually, but roughly as 'roughness'. New buildings are sheltered by vegetation or existing (sometimes less air tight) buildings. However, they shelter other locations themselves. So, locating new buildings sheltered is not always obvious, especially when they are airtight. There are arguments to locate new buildings South West of town as well (sheltering old less airtight ones, comfort of existing outdoor space, dispersion of air pollution, possibilities to yield wind energy at location).

In this paragraph we restrict ourselves to regions comparable to Schiphol as far as wind statistics are concerned. We concentrate on roughness of surrounding grounds. Due to the Weibull approach (Fig. 230) we do not need tables with all occuring velocities like Fig. 227. We can use the average velocity (like Fig. 237) and its probability (Fig. 239) per direction, summarized again in Fig. 250.

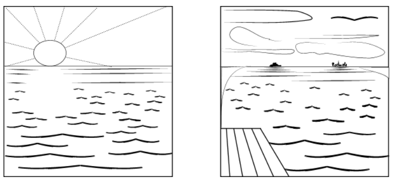
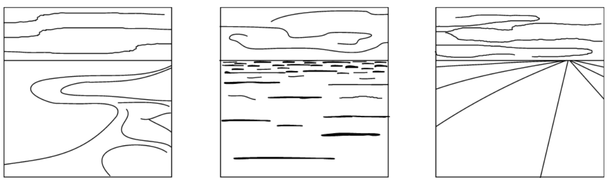
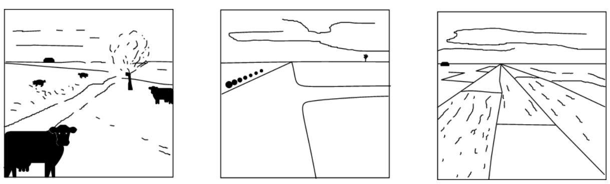
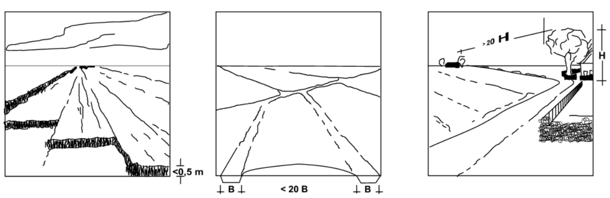
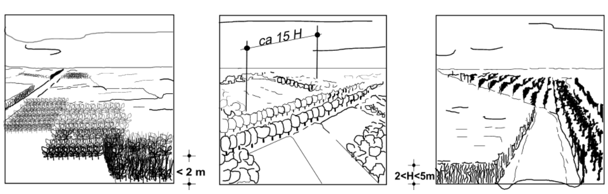
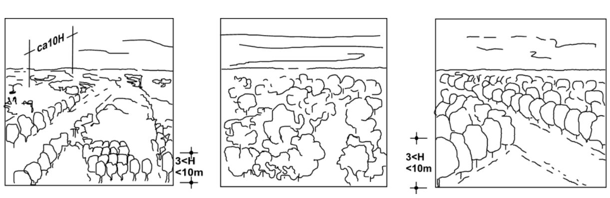
WIND DIRECTION :	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*TOT**
in degrees from North :	30	60	90	120	150	180	210	240	270	300	330	0	
			E			S			W			N	
whole year													
m/sec average	5,30	5,68	4,89	4,19	4,71	5,08	6,14	6,97	6,51	6,14	5,44	4,67	5,43
hours/ year	500	747	643	404	519	832	1074	1072	850	574	563	528	8766
*inclusive periods of calm or variable direction													

Fig. 250 *Potential wind velocities and their probabilities Schiphol*

In this paragraph we consider wind velocities in winter to be 10% the year average from Fig. 250 (important for calculating ventilation losses and comfort of outdoor space). The probability from a specific direction we take equal to half the values from Fig. 250.

2.3.1 Roughness of surrounding grounds

In wind surveys classes of roughness are distinguished (Fig. 251

Classes of roughness		
1		• open sea • pond with free brush length of at least 1km
2		• land surface without obstacles or vegetation o shallow o beach o ice plain o snow landscape without trees • pond with free brush length of approximately 1km
3		• flat land with shallow vegetation (grass) and isolated, rarefied obstacles: o air strip o grassland without trees o fallow fields
4		• farm land with regular low (<0,5 m) crops • grassland with ditches on mutual distance less than 20 x their width • dispersed obstacles on mutual distance of more that 20 x their own height: o low hedges o singuar row trees without leaves o singular farms
5		H < 2 m: • farm land with alternating high and low crops • vineyards, maize fields 2m < H < 5m: • low orchards • influential obstacles with mutual distance 15 x their own height: o rows of trees with leaves
6		3m < H < 10m: • groups of obstacles with a mutual distance of 10x their typical height: o large farmsteads o parcels of forest o dispersed shrubs o young densely planted woods o orchards

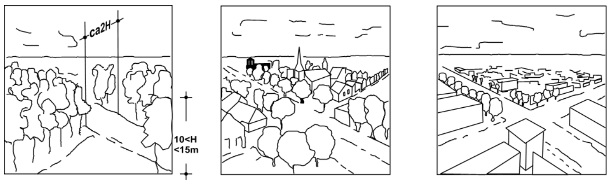
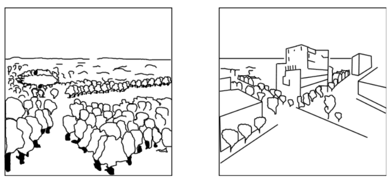
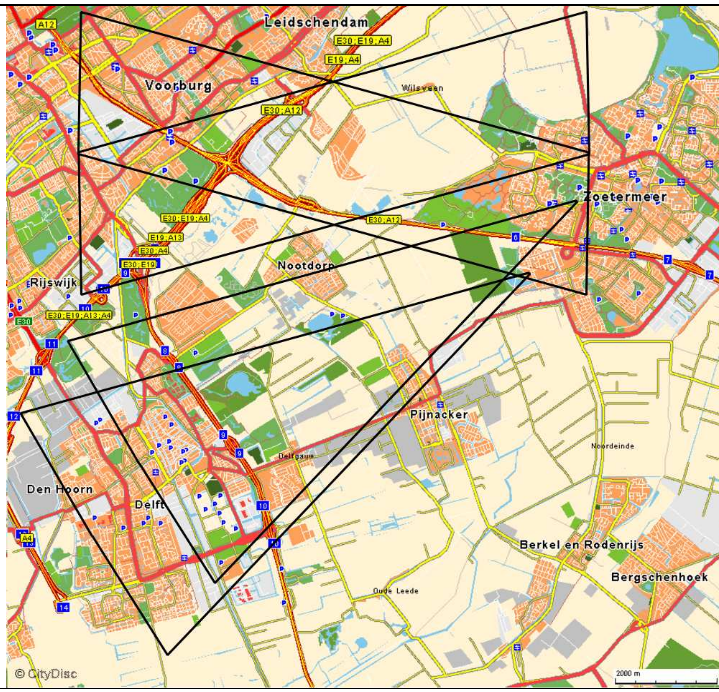
Classes of roughness		
7		10m < H < 15m: • bottom regularly and fully covered by rather large obstacles with mutual distance not larger than 2x their height: o regular forests o low rise buildings in villages o suburbs
8		H > 10m • centre of a large city with alternating high rise and low rise buildings • heavy forests with many irreguar open spaces

Fig. 251 *Classes of roughness*

The standard class supposed in wind data is class 3[78]. Wind characteristics on locations surrounded by other classes of roughness are derived mathematically from the data provided in class 3.
We wil now concentrate on a location of a residential area (class of roughness 7) Leidscheveen between Zoetermeer and Voorburg - Leidschendam[79]. The experimental question is, to compare wind climate without Leidscheveen, with Leidscheveen and when Leidscheveen would have been built adjacent to Zoetermeer ('VoZo'). In paragraph 2.3.5 we will compare several arrangements of green and buildings (roughness 6, 7 and 8) between Zoetermeer and Delft with or without a residential area Rokkeveen adjacent to Zoetermeer.



Citydisc/Top.Dienst

Fig. 252 Study area *Den Haag – Zoetermeer – Delft*

2.3.2 Impact of new urban area lose from or adjacent to town in case of Westerly wind

Fig. 253 shows a 30° cutout from 'zero point' in Zoetermeer direction West ('9 hour'). *Fig. 254* shows the calculated average wind velocity on 20m height in the reference. Below the graph the reference is styled as sequence of different roughnesses. The numbers refer to the classes of roughness in Fig. 251. Such calculations utilise the parameters from the last two columns of Fig. 251.

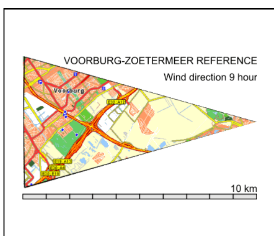


Fig. 253 Voorburg -> Zoetermeer reference

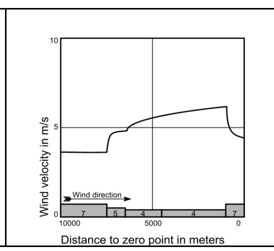


Fig. 254 Average wind velocity Fig. 253

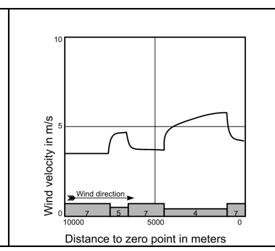


Fig. 255 Voorburg with Leidscheveen lose

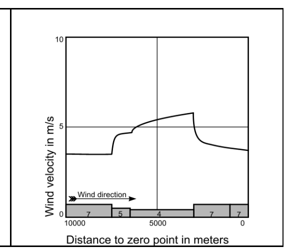


Fig. 256 Zoetermeer with VoZo adjacent

Fig. 255 shows Leidscheveen 1km lose from Voorburg. This urban area with approximately 8 500 dwellings slows down wind on 20m height roughly from 5 to 4 m/sec, but it has little impact on the built up area of Zoetermeer 3,5 km further on without obstacles inbetween. *Fig. 256* shows an imaginary variant with VoZo adjacent to Zoetermeer. In *Fig. 254* (reference) on zero point (right) an imaginary wind turbine has 10 530 kWh/year energy profit due to Westerly wind only; equivalent energy losses from a non airtight dwelling are 750 kWh/year. In *Fig. 255* they decrease by 760 and 20; in *Fig. 256* by 3 010 and 170 kWh/year.

2.3.3 Impact of new urban area lose or adjacent in case of Easterly wind

Fig. 257 to *Fig. 260* show reference and experiments to clarify the impact in case of Easterly wind on 'zero point' Voorburg. They are less realistic to remain comparable with the previous experiment.

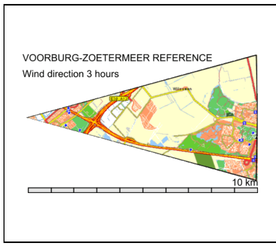


Fig. 257 Zoetermeer -> Voorburg reference

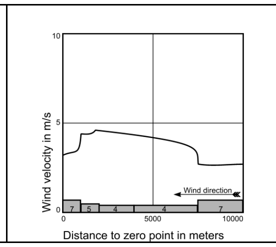


Fig. 258 Average wind velocity Fig. 257

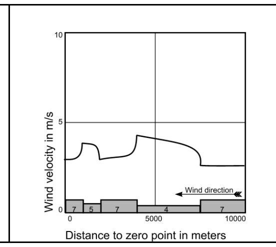


Fig. 259 Zoetermeer –> Voorburg with Leidscheveen

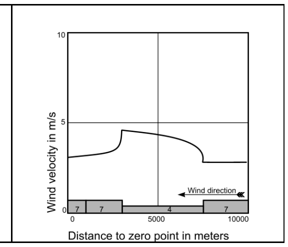
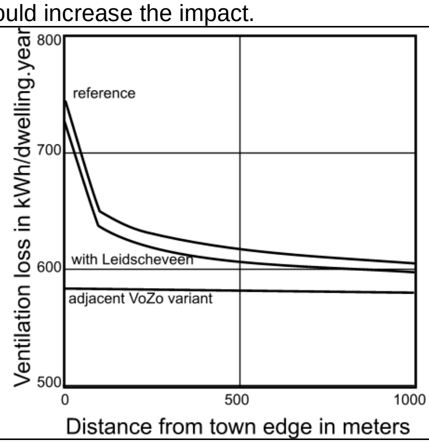


Fig. 260 Zoetermeer –> Voorburg variant

Fig. 258 immediately shows the lower average wind velocity from East compared with West. So, the impact is less as well. On the new zero point an imaginary wind turbine has 3070 kWh/year energy profit due to Easterly wind only; equivalent energy losses from a non airtight dwelling are 460. In *Fig. 259* they decrease by 1000 and 23 in *Fig. 260* by 710 and 60 kWh/year.

2.3.4 Impacts on energy losses by ventilation behind the edge in the interior of town

Fig. 261 shows the impacts of regional alternatives behind the Westerly edge of Zoetermeer. They decrease fast within 100m. Fig. 262 shows the same behind the Easterly edge of Voorburg. They are smaller because Westerly wind blows more often and stronger (see page 118) and the foreland of Voorburg already had a higher roughness than Zoetermeer, but lower temperatures neglected here could increase the impact.



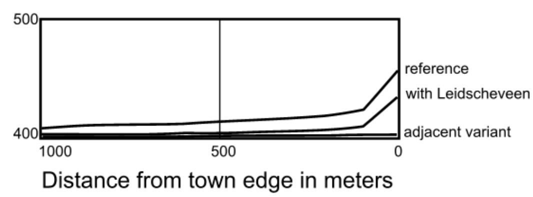


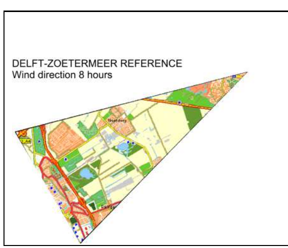
Fig. 261 *Impact Westerly wind on Zoetermeer*

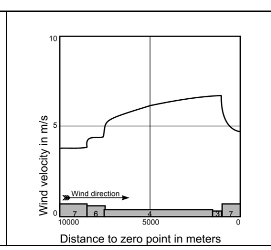
Fig. 262 *Impact Easterly wind Voorburg*

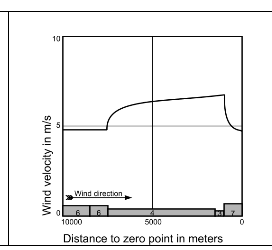
So, the total impact on ventilation losses is small, though they have some significance for comfort of outdoor space. That is why we pay not much intention to calculating these impacts more precise now, but they are point of departure and give insight for calculating measures on lower levels of scale. Not only temperature could affect the outcome, but also impacts perpendicular on the direction of wind. These 'lateral impacts' depend on the total form of the conurbation. They will be studied closer in 2.4.3 page 131. Furtermore we have to realise that these calculations are based on average roughnesses. Wide ways, open allotment and lay-out of the edge could increase wind loads inside of town locally substantially. We should conclude that in calculating the impact of measures on lower levels of scale the regional lay-out adjacent to towns are most important. So, we have to examine them in more detail.

2.3.5 Highways, railways, green areas and forests

Fig. 263 shows a 10km long cutout of 30^o this time seen from zero point Zoetermeer in wind direction '8 hour' to Delft. The largest zone is farm land (roughness 4) increasing wind velocity up to 6.67 m/sec on the edge of town Zoetermeer in Fig. 264.







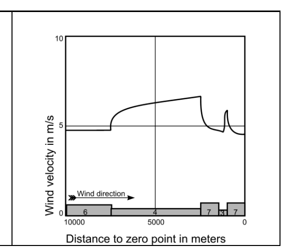


Fig. 263 *Delft -> Zoetermeer reference*

Fig. 264 *Average wind velocity in reference of* Fig. 263

Fig. 265 *Delft -> Zoetermeer simplified reference*

Fig. 266 *Delft -> Zoetermeer with Rokkeveen*

Fig. 265 simplifies Fig. 264 by gathering Delft and Delftse Hout as a zone with roughness 6. This simplification increases wind velocity at the edge of town Zoetermeer from 6,67 m/sec in Fig. 264 to

6,74 m/sec in Fig. 265. Such differences at more than 5km distance apparently do not matter much. So, Fig. 265 becomes our reference. In Fig. 266 Rokkeveen is added[80]. Though this residential area has a great impact on the wind velocity profile, for the town edge of Zoetermeer the impact is surprisingly less than we would expect because after slowing down above Rokkeveen the wind accelerates within 500m very fast above railways and highway A12 between Rokkeveen and existing Zoetermeer[81]. So, the impact of Rokkeveen reduces wind velocity from 6,74 to 5,92 m/s, reducing ventilation loss on the edge of town Zoetermeer by only 90 kWh/dwelling·year (1 m3 natural gas).

In Fig. 267 before Rokkeveen a green structure replaces farm land (roughness 6 see page 123).

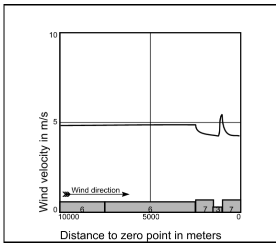


Fig. 267 *Delft -> Zoetermeer with green structure*

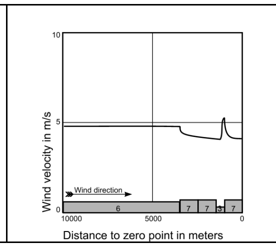


Fig. 268 *Delft -> Zoetermeer 1km regular forest added*

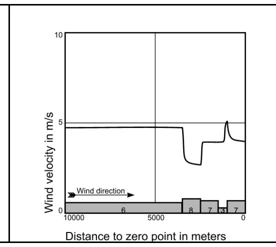


Fig. 269 *Delft -> Zoetmeer 1km heavy forest added*

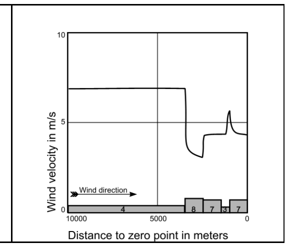


Fig. 270 *The same, with farm land instead of green structure*

In Fig. 268 except this green structure 1km forest (roughness 7) is added as well. Both cases do not make much difference on the old town edge. The impact is more than undone by railways and highway. Wind velocity is compared to the reference decreased from 6,74 to respectively 5,45 and 5,35 m/sec, but the largest amount was already caused by Rokkeveen. At the old town edge ventilation losses caused by this direction of wind are decreased by approximately 150 kWh/dwelling·year and for adjacent directions something comparable but smaller.
In Fig. 269 regular forest is replaced by heavy forest (roughness 8). Wind velocity at the old town edge then decreases somewhat (5,25 m/sec), but not significant though the wind profile changes substantially. The fast increase above Rokkeveen is remarkable.
In Fig. 270 the impact of a lower roughess on larger distance is studied by replacing Delft, Delftse Hout and green structure by farm land. By these measures wind velocity at the old town edge still increases from 5,25 to 5,71 m/sec.