2 Wind

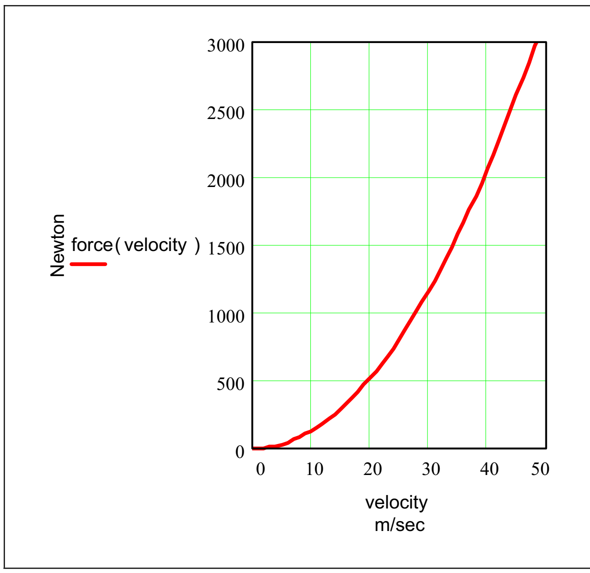
2.1 Global atmosphere

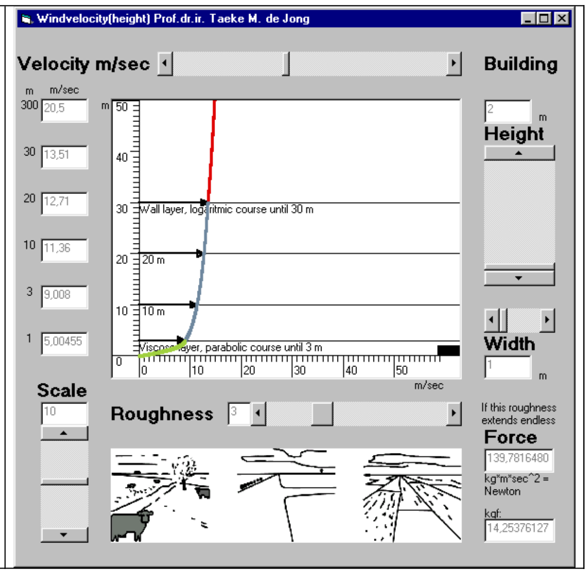
2.1.1 Air, its mass and density

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 10 197.162 kgf/m^2) 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 then a millionth of the Earth's mass (6 x 10^{24}kg). At sea level density ρ of air is 1 290g/m3 (Fig. 195) which equals 3 x 10^{25} particles (Fig. 196).

2.1.2 Wind, its force and power

So, if your own cross section is 1m^2, than 1m^3 air (1.29kg) with a velocity of 1m/sec would hit you in 1sec by a mass of more then 1kg. Happily much of this power immediately starts flowing sideward around you, but to keep calculations simple we do not yet take these leakages into account (see chapter 2.6.4). So, primarily you have to resist a force of 1.29 kg*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 raise to 300N/m^2 (Fig. 193), corresponding to the mass of a child (30kg) hitting you cycling 36km/hour (10m/sec). These figures are valid on 1m height average, where 'storm' in grass land corresponds to 10m/sec, but at 10m and 20m height it corresponds to 24 and 26m/sec at the same time Fig. 194.





Jong (2001)

Fig. 193 *Wind force (= air mass x velocity/sec) on a surface of 1m² ('pressure'). Air mass = density x content and air content = 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. 194 *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.*
www.bk.tudelft.nl/urbanism/team *publications 2003*

Buildings are wider and heigher than you are, taking up many m^2. But you can not simply multiply the surface by the force you have to resist on the ground to get the force a building has to resist. The velocity increases by height. To calculate the pressure (force/m^2) or total force you have to take velocity two times into account. One time you need velocity to calculate the air mass hitting the building in one second and the second time you need velocity to calculate force by multiplying mass and acceleration, which is velocity per second. So, force increases parabollically by square of velocity Fig. 193. Now you have to calculate the wind load on an building on every several layer of its height and sum all these force contributions up to total height Fig. 194. Click on the figure or download the programme (with 8 pictures) and it will calculate the force for you in layers of 1cm neglecting sideward effects. Paragraph 2.4.2 explains how. Mathematically you can calculate it in layers approaching to height zero, called integration. 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 speed and roughness in the programme.

2.1.3 The atmosphere

However, density decreases to 1g/m3 at 50km height (Fig. 195). So, aeroplanes meet less resistance the higher they fly (until 20km), but propellers and wings will work less as well.

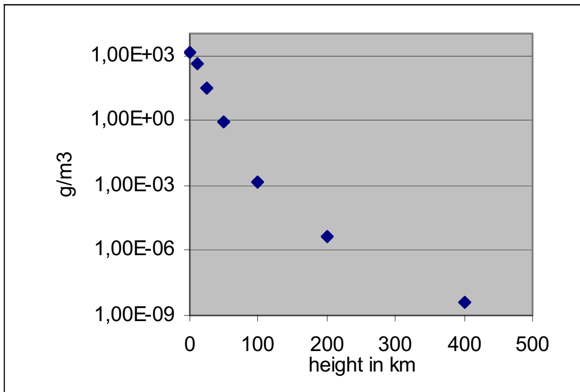


Fig. 195 Density(height)

1,00E+03 in Excel means 10 x 10^3

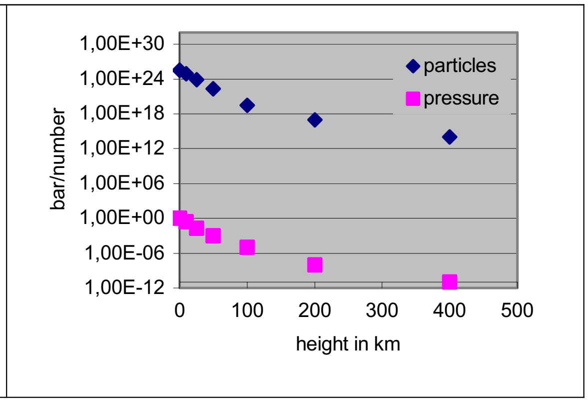


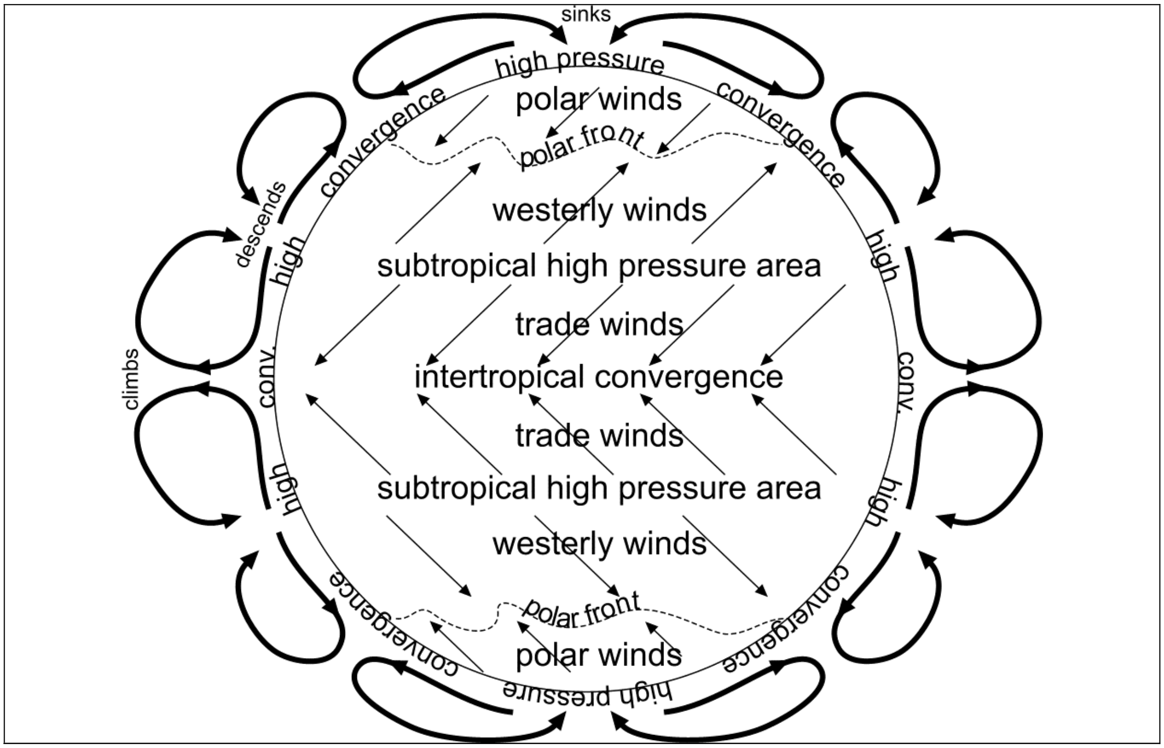
Fig. 196 (Particles/m^3, Pressure)(height)
A bar is 100000N/m2 or 100000Pa or approximatey 1 atmosphere

The smallest wave lengths of ultraviolet sunlight are absorbed above 50km height, heating the thin air above 80km easily until 1000^{o}C at 200km until it equals heat loss by own radiation. The rest of UV light is nearly fully captured by ozone between 50 and 10km. 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 atmosphere by convection from below or radiating it back to universe as invisible infrared light, only captured by CO_2. An air bubble heated by the Earth's surface climbs up 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 resulting in cumulus clouds rising with drying air. They show a flat bottom indicating a temperature boundary of condensation is passed. By condensation solar heat is released, giving the steaming air bubble an extra push upward.

The Earth turns Eastward 360^o in 24 hours. The equator is 40 000km long, as Napoleaon ordered. So, at the equator we have a velocity of 1 670km/hour and we are 3g lighter then 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.

2.1.4 Climate

Equatorial air heated and saturated from moist by tropical temperatures climbs high and fast. Shortages on the ground are supplied by trade winds from South East and North East. Coming from North and South they are not used to equatorial Eastward high speed. Seen from the ground their inertia give them a Westward drift. But they learn fast from rough grounds. Than they climb higher then everywhere else on Earth, because environmental density and temperature decrease slower here with so much competing air bubbles around, stimulated by an extra momentum from condensation causing tropical showers below. But they continue to loose heat by 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 slower Eastward turning subtropic latitude as if they came from South West causing subtropical high pressure and cyclones in struggle with winds departing into tropics as they did themselves in their youth joining them at last or travelling direction pole as South-Western winds we know so well in The Netherlands.



After Bucknell (1967)

Fig. 197 *Gobal wind circulations*

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 boiled water in a very regular and stable pan 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 - 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. What is cause? However, in the long term we find some regularities 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. 193 we already showed the parabolic course of impact 1.
In Fig. 198 up to Fig. 201 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.

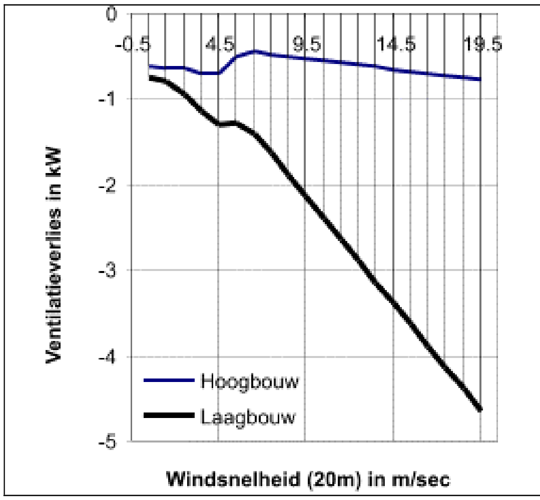


Fig. 198 *Ventilation characteristic*
Ventilation losses from dwellings increase according to the velocity of wind particulary in non airtight houses. However, from 4 m/sec people close their windows. So, in this interval more wind *decreases* ventilation losses.

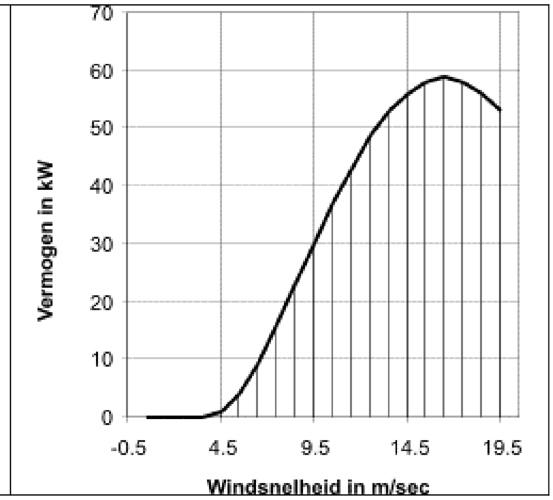


Fig. 199 *Powercharacteristic*
The produced power of this standard wind turbine increases up to 60 kW on a wind velocity of 16 m/sec. Most wind turbines brake on higher velocities to avoid damage.

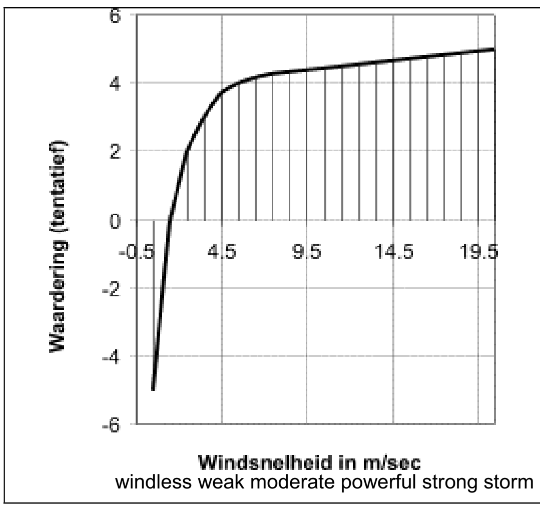


Fig. 200 *Air dispersion characteristic*
This tentative diagram represents air pollution disperses best by storm, but that impact is already reached on moderate wind.

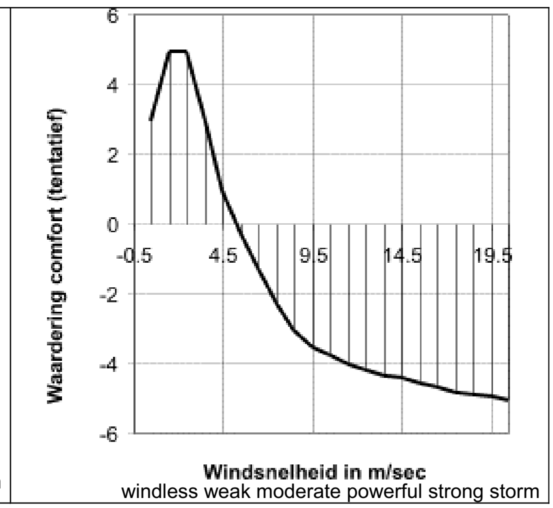


Fig. 201 *Comfort characteristic*
In this tentative diagram is supposed that a weak wind with an average velocity of 1-3m/sec is appreciated most.

Fig. 198 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. 198 and Fig. 201) 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 token on the level of

- national choice of location (100km radius, page 91)
- regional choice of location (30 km radius, page 96)
- arrangement of rural areas, form of conurbations (10 km radius, page 108)
- local choice of location (10 km radius, page 105)
- form of town and town edge (3 km radius, page 113)
- lay-out of districts and district quarters (1 km radius, page 111)
- allotment of neighbourhoods and neighbourhood quarters (300 m radius, page 129)
- allotment and urban details and ensembles divided in 4 hectares (100 m radius, page 124)
- 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.

2.1.7 References to Global atmosphere

Bucknell, J. (1967) "Klimatologie" Prisma-Compendia

Jong, T. M. d. (2001) Standaardverkaveling 11.exe.

Vermeulen, P. E. J. (1986) Experimenteel onderzoek ten behoeve van de modelbeschrijving van drie-dimensionale ruwheidsovergangen MT-TNO.

Vermeulen, P. E. J. and T. M. d. Jong (1985) Wind vangen en wind weren. Een verkennende studie naar de energetische consequenties van windafschermende maatregelen. (Delft) MT-TNO.

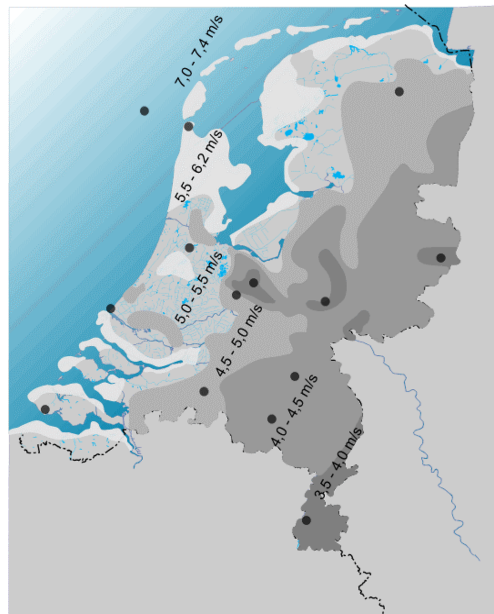
2.2 National choice of location

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. 202).

Selection from Wieringa, Rijkoort et al. (1983) page 28
Fig. 202 *Wind stations in the period 1945-1980*



Selection from Wieringa, Rijkoort et al. (1983) page 84
Fig. 203 *Year average potential wind velocity.*

Wind stations register gusts of more than 5 seconds duration. All measurements are averaged for one hour resulting in the 'hour average wind velocity'. From these hour averages a year average can be calculated, the 'year average wind velocity'. 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. 203. 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. 204 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. 204 *Frequency division w of wind velocity per class vk Schiphol 1951 until 1976 per 10 000*.

Frequency divisions like Fig. 204 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. 204 as

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

fits in the velocity class 5 – 5.5 m/s of location Schiphol indicated in Fig. 203.

In the last row of Fig. 204 all observations are specified by wind direction (Fig. 205).

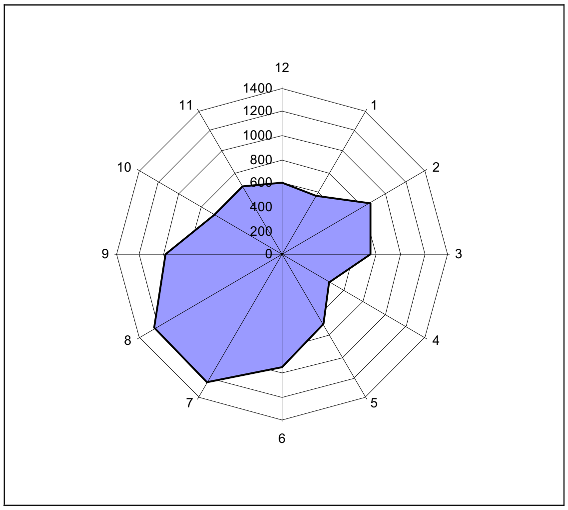
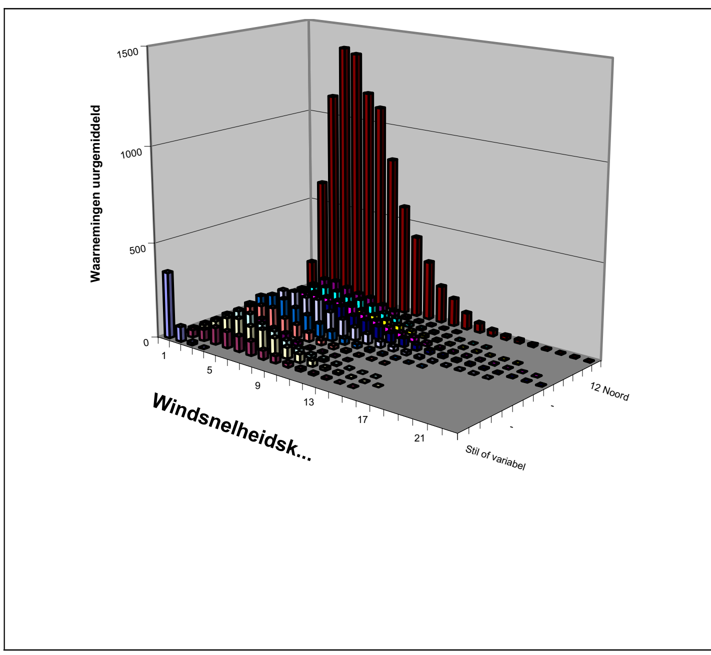


Fig. 205 C*ompass card, per 10 000 observations*

Because there are 10 000 observations, one can direcly read from Fig. 205 that 12% of the wind in Schiphol comes from directions 7 and 8. Together that is roughly 25% from South – East.

Fig. 206 shows Fig. 204 as a diagram of frequency divisions of wind velocity per class in total and per direction.



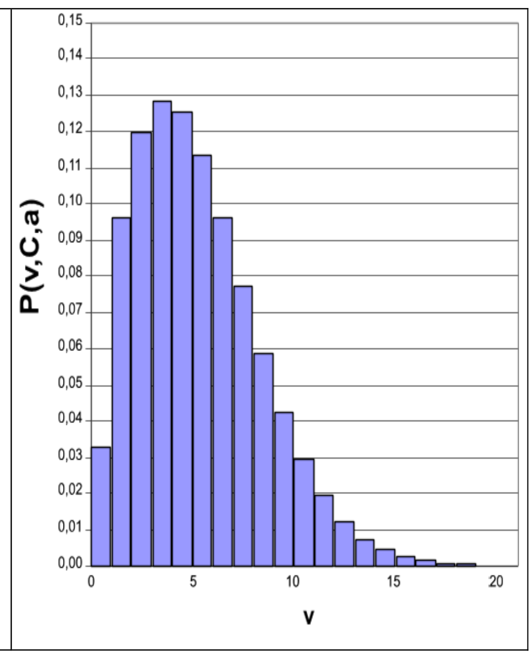


Fig. 206 *A diagram of* Fig. 204

Fig. 207 *Weilbull-distribution*

The form of the graphs is higly similar to the mathematical graph of a Weilbull probability distribution like

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

represented in Fig. 207 with C and a as form and scale parameters specific for every location (Fig. 208).

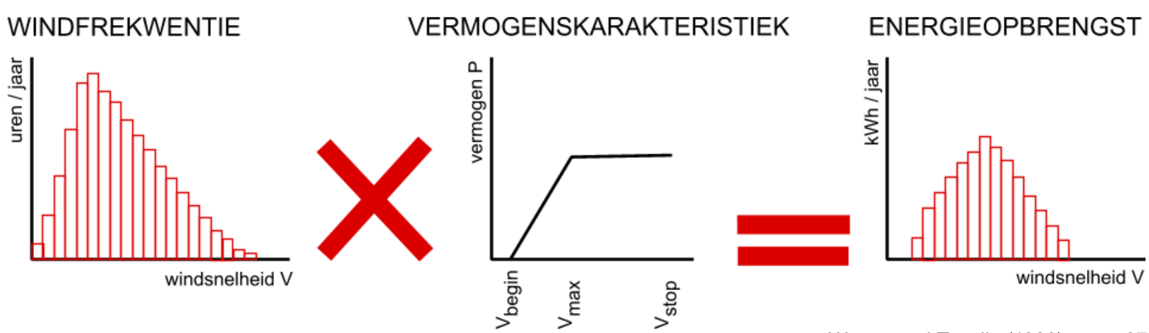
	form	schale	% from direction ('hours' from North, 0 is calm or variable):												
						E			**S**			**W**			**N**
	C	**a**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Beek	2,01	0,042	2	7	9	7	3	4	10	20	17	8	4	4	4
Den Helder	2,00	0,014	1	6	7	8	6	5	10	13	12	10	8	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. 208 *Weilbull parameters en contribution per wind direction for 6 stations.*

By this formula with tables like Fig. 208 we can avoid long tables like Fig. 204 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 94. Later on we will show how per direction local landscape characteristics other then 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. 204 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. 199) you can find the profit by multiplying the number of expected hours that velocity will occur in an environment of grass land (Fig. 209).



Westra and Tossijn (1980), page 37

Fig. 209 *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. 210 left the velocity frequences per direction of wind from Fig. 204 and Fig. 206 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.

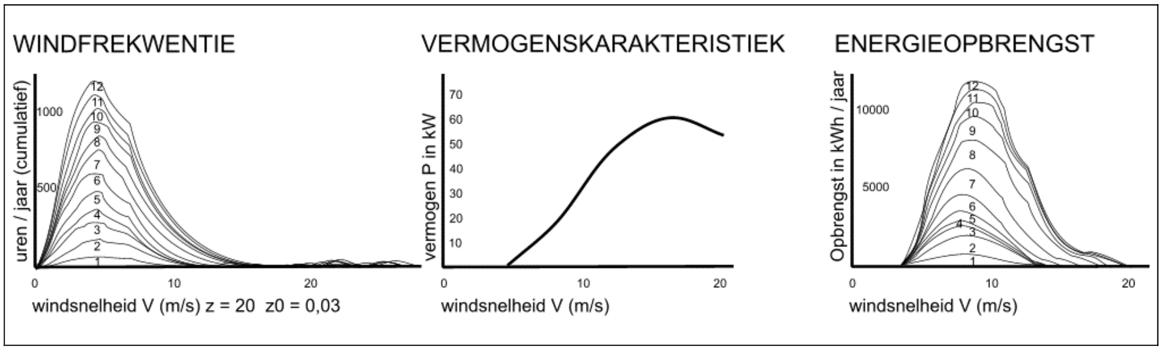


Fig. 210 *Calculating the energy profit of a specific wind turbine in the environment of Schiphol*

Left in Fig. 210 the expected number of hours per verlocity is given. The power characteristic of the wind turbine per velocity in the middle of Fig. 210 is equivalent to Fig. 199. Multiplying the number of hours of every subsequent velocity by the corresponding power produces the energy profit right in Fig. 210.
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:

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

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

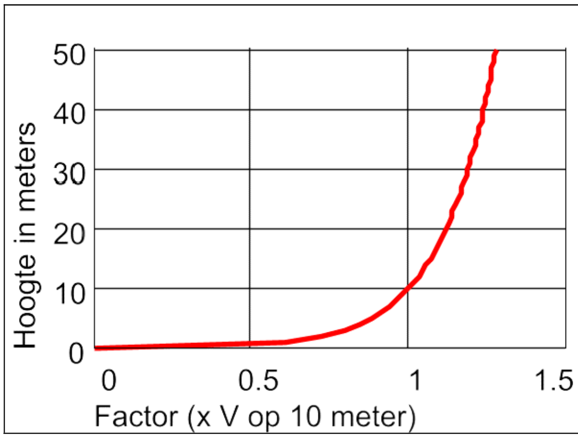
In Fig. 211 the energy profits presupposing a height of 10m in open grass land near Schiphol and Eindhoven are compared this way.

Schiphol:	2*5,4³ = 315 kWh/ m²	x 340 m² = 107 000 kWh
Eindhoven:	2*4,25³ = 154 kWh/ m²	x 340 m² = 522 000 kWh

Fig. 211 *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. 212 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.



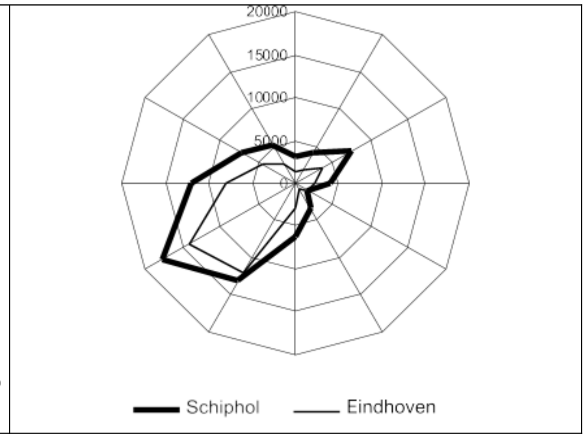


Fig. 212 *Wind velocity factor for height*

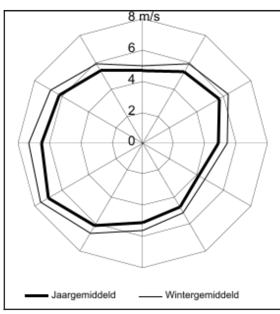
Fig. 213 *Contribution per wind direction 10m height*

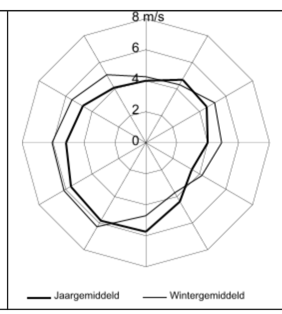
Because the energy profit of wind turbines increases proportional to the third power of wind velocity (see rule of thumb on page 100) you can adapt the average wind velocity vg by this factor to the third power. The wind velocity on 20m according to Fig. 212 is x 1,13 higher then on 10m. To the third 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. 213).

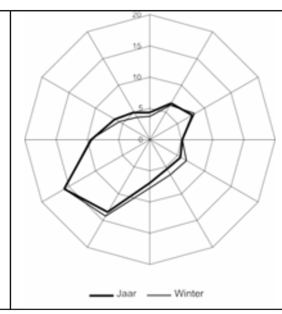
2.2.4 Energy losses from buildings

The Fig. 209 way of calculation 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 94.

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. 214 and Fig. 215).







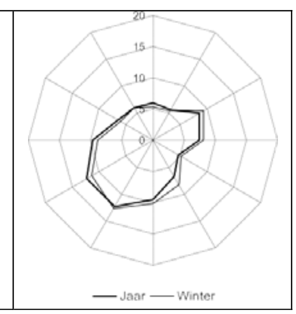


Fig. 214 *Winter half year velocities Schiphol*

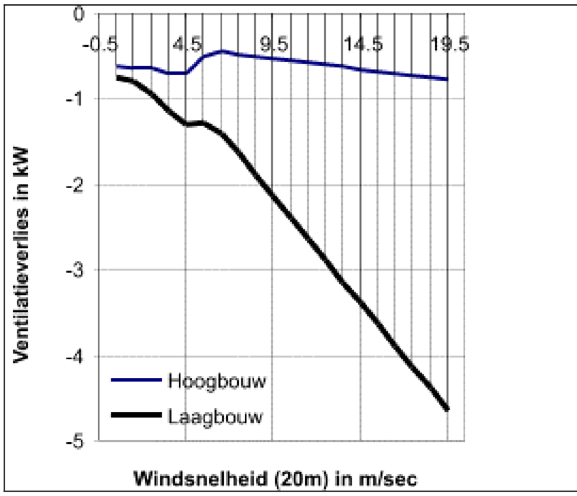
Fig. 215 *Winter half year velocities Eindhoven*

Fig. 216 Winter *probabilities Schiphol*

Fig. 217 *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. 216 and Fig. 217).
In Fig. 218, Fig. 198 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.



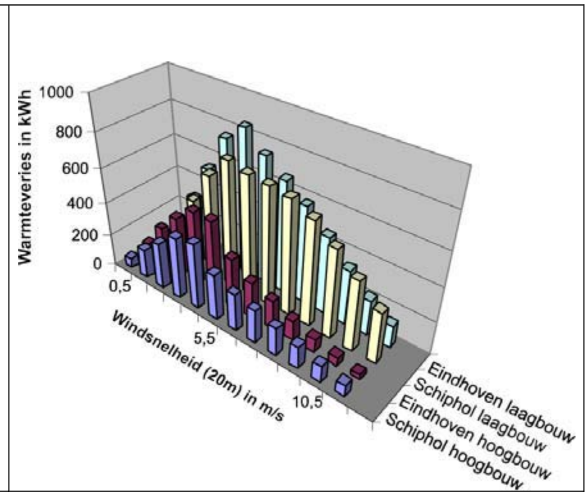


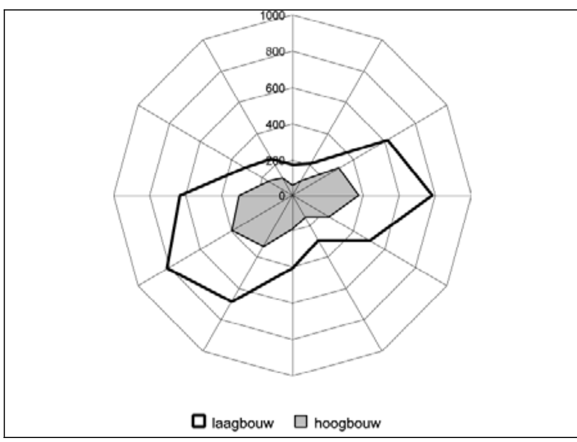
Fig. 218 *Ventilation characteristic*

Fig. 219 *Ventilation losses per dwelling*

As expected Fig. 219 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) then 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. 220 and Fig. 221.



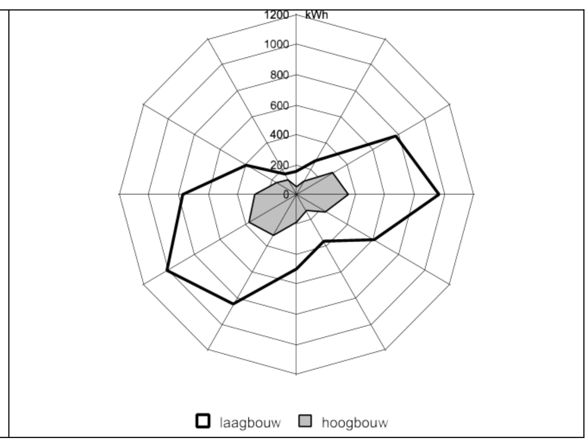


Fig. 220 *Ventilation losses weighting temperature per wind direction Schiphol*

Fig. 221 *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.

2.2.6 Comfort of outdoor space

The same approach without temperature impacts, this time using the tentative graph Fig. 201 reproduced in Fig. 222 would produce Fig. 223.

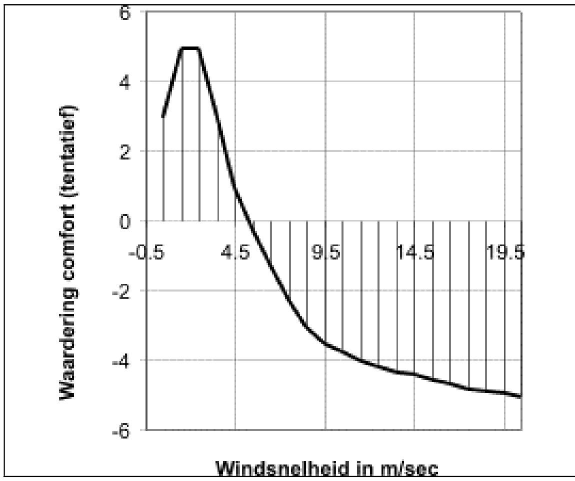


Fig. 222 *Tentative comfort characteristic*

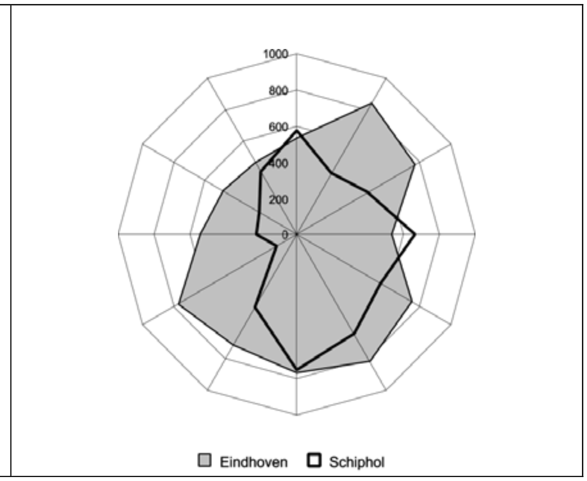


Fig. 223 *Tentative appreciation comfort*

In Fig. 223 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’).

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. 200 repeated in Fig. 222.

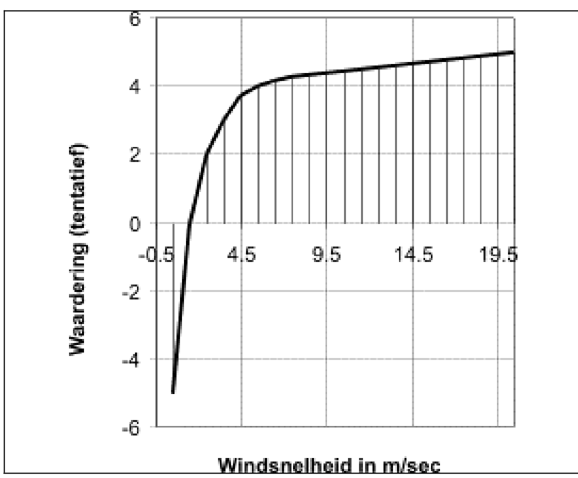


Fig. 224 *Tentative air pollution characteristic*

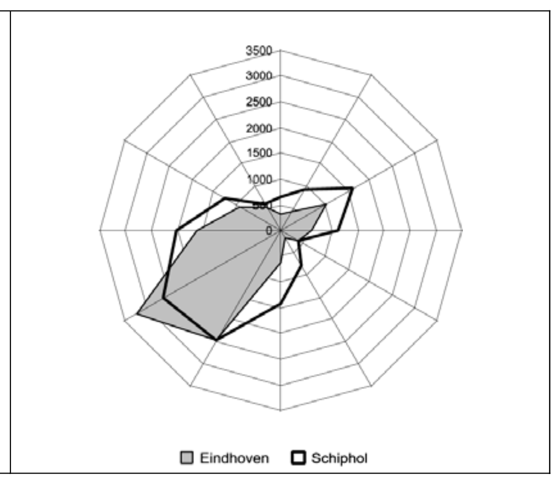


Fig. 225 *Tentative air pollution dispersion*

The impact having an overall positive relation to wind velocity, it shows pronounced similarity with the compass chard of Fig. 205. 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. 226 shows which location scores best.

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. 226 *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.

2.2.9 References to National choice of location

Gids, W. F. d. (1986) Wind/temperatuur statistiek MT-TNO.

Vermeulen, P. E. J., Hoogeveen, et al. (1983) Energie-opbrengsten van windturbines: een boek voor berekeningen MT-TNO.

Westra, C. and H. Tossijn (1980) Windwerkboek. Wat mogelijk is met windenergie ISBN 90 62 1025 9.

Wieringa, J., P. J. Rijkoort, et al. (1983) Windklimaat van Nederland (Den Haag) Staatsuitgeverij ISBN 90-12-04466-9.

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 Weilbull approach (Fig. 207) we do not need tables with all occuring velocities like Fig. 204. We can use the average velocity (like Fig. 214) and its probability (Fig. 216) per direction, summarized again in Fig. 227.

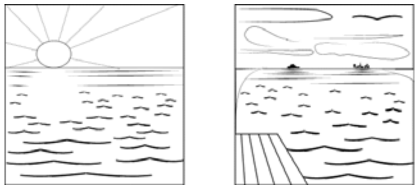
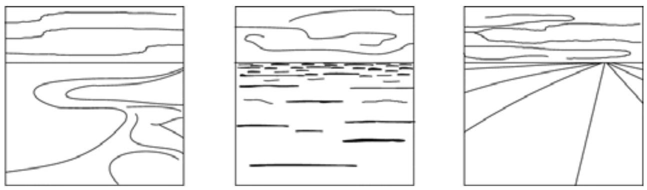
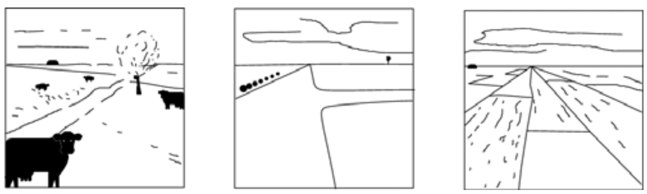
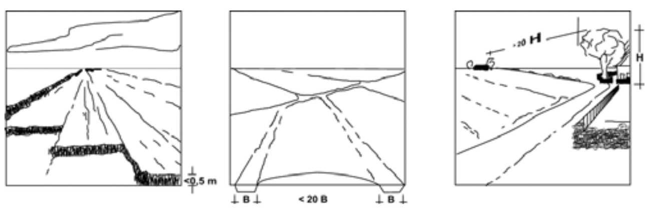
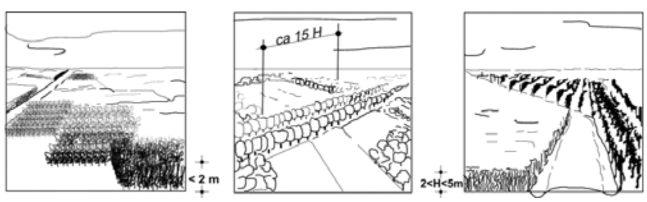
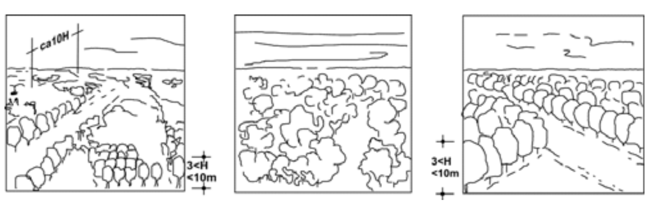
WIND DIRECTION :	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*TOT**
in degrees from North :	30	60	90	120	150	180	210	240	270	300	330	0	
			O			Z			W			N	
whole year													
m/sec average	5,30	5,68	4,89	4,19	4,71	5,08	6,14	6,97	6,51	6,14	5,44	4,67	5,43
hours/ year	500	747	643	404	519	832	1074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

Fig. 227 *Potential wind velocities and their probabilities Schiphol*

In this paragraph we consider wind velocities in winter to be 10% the year average from Fig. 227 (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. 227.

2.3.1 Roughness of surrounding grounds

In wind surveys classes of roughness are distinguished (Fig. 228

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

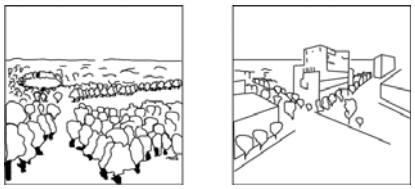
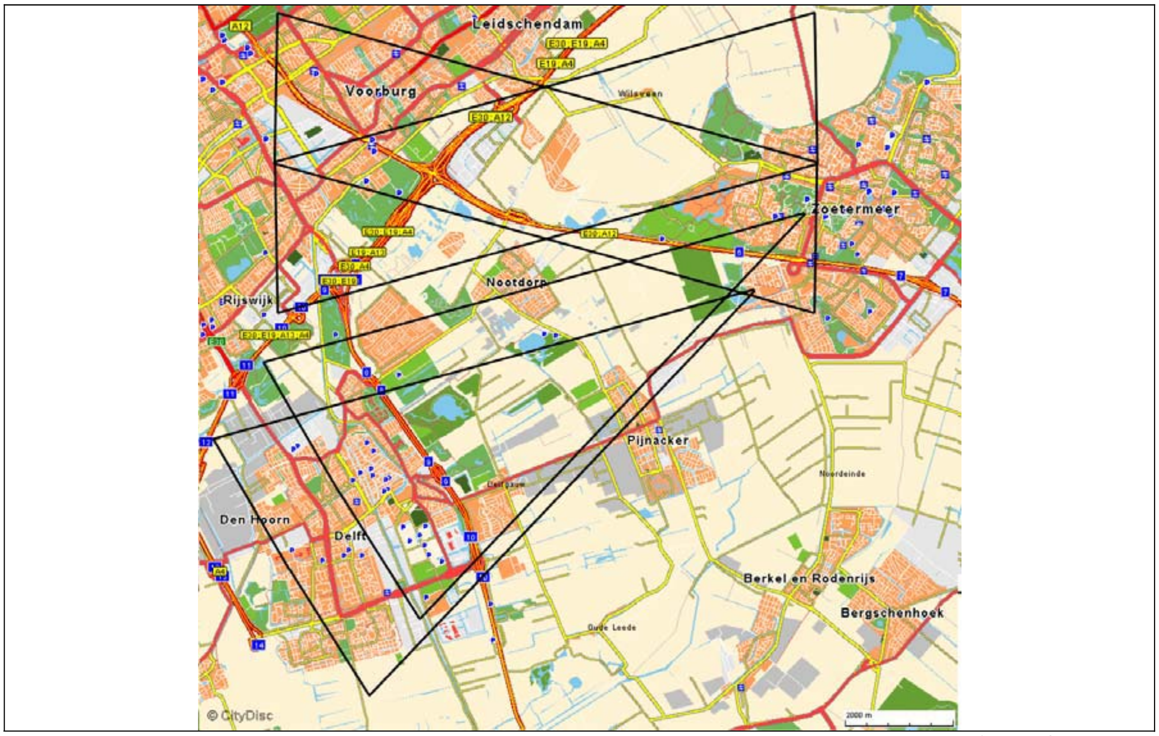
Classes of roughness		
7		10m < H < 15m: • bottom regularly and fully covered by rather large obstacles with mutual distance not larger then 2x their height: ○ regular forests ○ low rise buildings in villages ○ suburbs
8		H > 10m • centre of a large city with alternating high rise and low rise buildings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

Fig. 228 *Classes of roughness*

We wil now concentrate on a location of a residential area (class of roughness 7) Leidscheveen between Zoetermeer and Voorburg - Leidschendam. 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. 229 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. 230 shows a 30° cutout from 'zero point' in Zoetermeer direction West ('9 hour'). Fig. 231 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. 228. Such calculations utilise the parameters from the last two columns of Fig. 228.

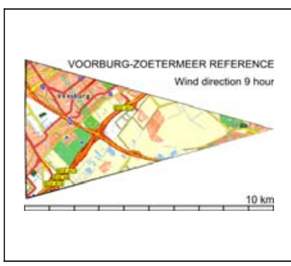


Fig. 230 *Voorburg -> Zoetermeer reference*

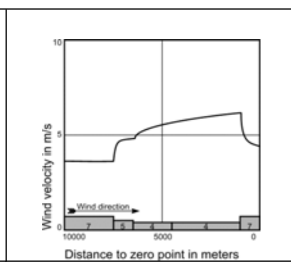


Fig. 231 A*verage wind velocity* Fig. 230

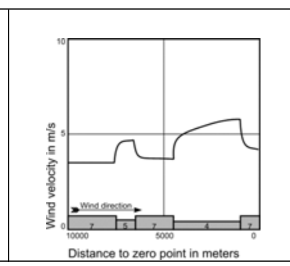


Fig. 232 *Voorburg with Leidscheveen lose*

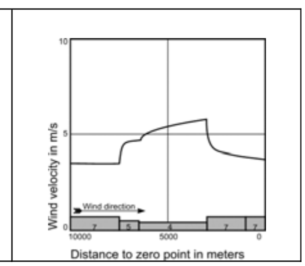


Fig. 233 *Zoetermeer with VoZo adjacent*

Fig. 232 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. 233 shows an imaginary variant with VoZo adjacent to Zoetermeer. In Fig. 231 (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. 232 they decrease by 760 and 20; in Fig. 233 by 3 010 and 170 kWh/year.

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

Fig. 234 to Fig. 237 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.

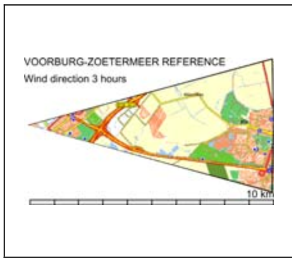


Fig. 234 *Zoetermeer -> Voorburg reference*

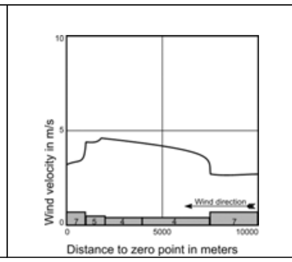


Fig. 235 A*verage wind velocity* Fig. 234

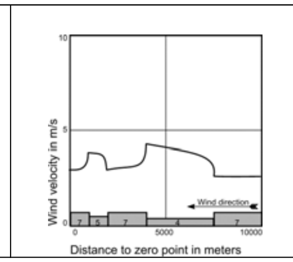


Fig. 236 *Zoetermeer –> Voorburg with Leidscheveen*

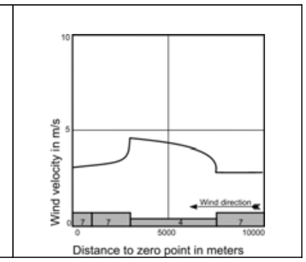


Fig. 237 *Zoetermeer –> Voorburg variant*

Fig. 235 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. 236 they decrease by 1000 and 23 in Fig. 237 by 710 and 60 kWh/year.

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

Fig. 238 shows the impacts of regional alternatives behind the Westerly edge of Zoetermeer. They decrease fast within 100m. Fig. 239 shows the same behind the Easterly edge of Voorburg. They are smaller because Westerly wind blows more often and stronger (see page 101) and the foreland of Voorburg already had a higher roughness then Zoetermeer, but lower temperatures neglected here could increase the impact.

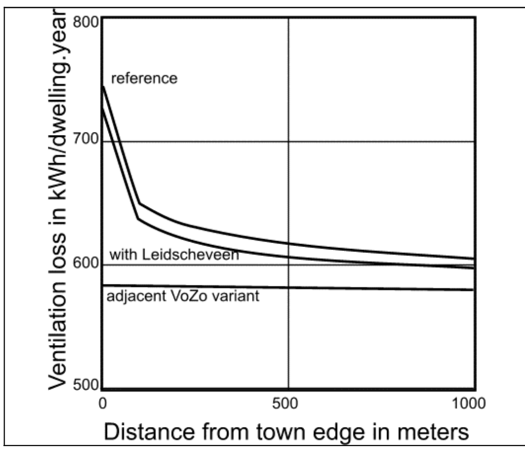


Fig. 238 *Impact Westerly wind on Zoetermeer*

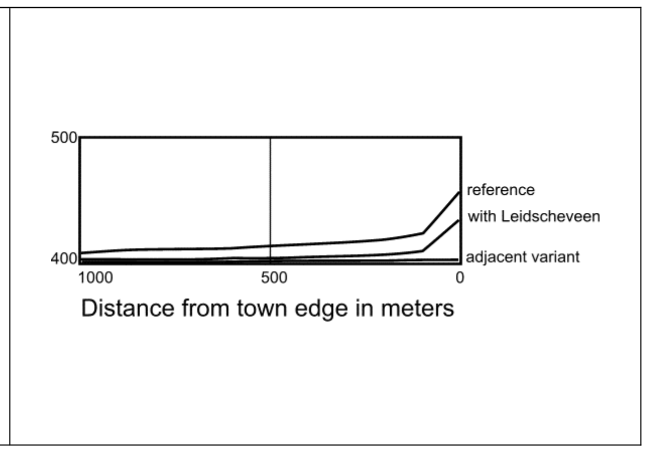


Fig. 239 *Impact Easterly wind Voorburg*

So, the total impact on ventilation losses are 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 113. 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. 240 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. 241.

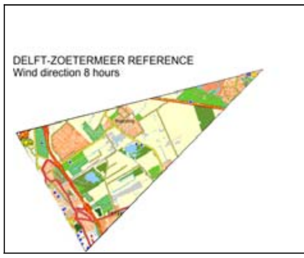


Fig. 240 *Delft -> Zoetermeer reference*

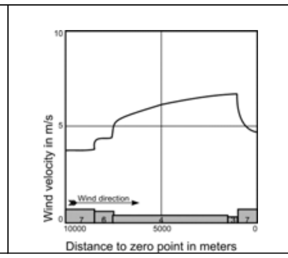


Fig. 241 *Average wind velocity in reference of* Fig. 240

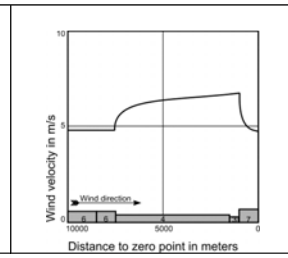


Fig. 242 *Delft -> Zoetermeer simplified reference*

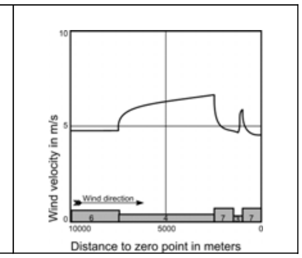


Fig. 243 *Delft -> Zoetermeer with Rokkeveen*

Fig. 242 simplifies Fig. 241 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. 241 to 6,74 m/sec in Fig. 242. Such differences at more then 5km distance apparently do not matter much. So, Fig. 242 becomes our reference. In Fig. 243 Rokkeveen is added. Though this residential area has a great impact on the wind velocity profile, for the town edge of Zoetermeer the impact is surprisingly less then 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. 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. 244 before Rokkeveen a green structure replaces farm land (roughness 6 see page 106).

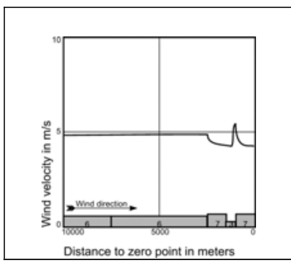


Fig. 244 *Delft -> Zoetermeer with green structure*

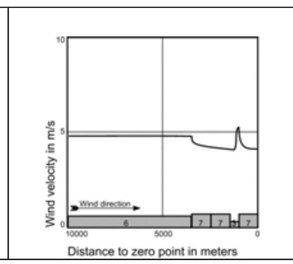


Fig. 245 *Delft -> Zoetermeer 1km regular forest added*

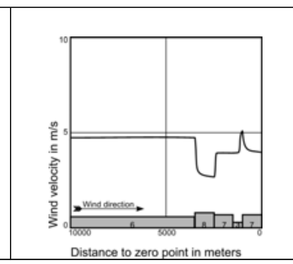


Fig. 246 *Delft -> Zoetmeer 1km heavy forest added*

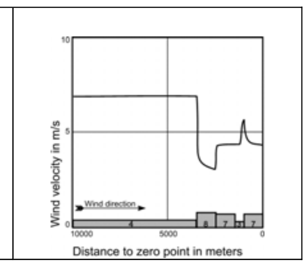


Fig. 247 *The same, with farm land instead of green structure*

In Fig. 245 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. 246 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. 247 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.

2.4 Local measures

2.4.1 Local shelter of residential areas

From Chapter 2.2 we learned that the impact of relatively small linear open spaces as railways and highways perpendicular on wind is substantial. Wind sheltering action has to be taken as close to the residential area as possible. That is why we shift our attention some kilometres into a cutout with its zero point in Rokkeveen itself (8 ‘hour’ South West see Fig. 229). This residential area is not separated from its foreland by a highway or wide water. So, shelter can adjoin immediately to residential area.

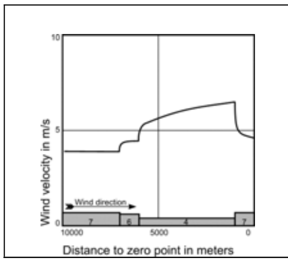


Fig. 248 *Reference windvelocity*

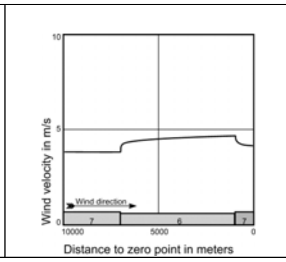


Fig. 249 *Delft -> Rokkeveen with 6km green structure*

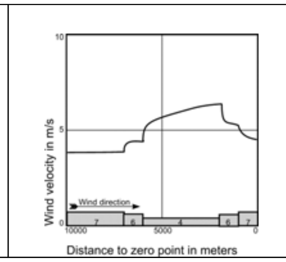


Fig. 250 *Delft -> Rokkeveen with 1km regular forest*

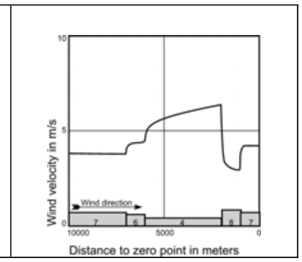
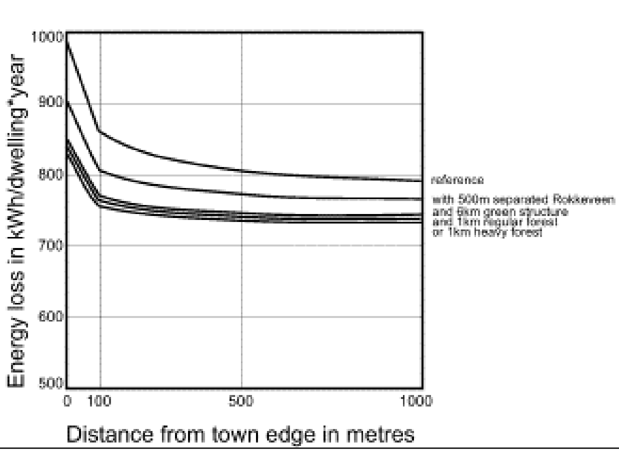


Fig. 251 *Delft -> Rokkeveen with 1km heavy forest*

In Fig. 248 we suppose above Delft a stable velocity of less then 4 m/sec. Above 1km Delftse Hout it climbs up and stabilises on 4.5 m/sec in a few hundred metres. Then above 5 km farmland it starts to climb up fast continuing to increase more slowly to 6,52 m/sec. Then above Rokkeveen it slows down fastly to 4,61 m/sec and outside the graph slowly to 4.2 km/sec above above suburban built up area.
In Fig. 249 farmland is replaced by green structure (rougness 6). Then wind velocity at the edge of Rokkeveen decreases substantially from 6.52 to 4.73 m/sec. Energy loss per non airtight dwelling per year as far as due to wind from this direction decreases 190 kWh only (from 987 kWh to 797 kWh).
If the last km before Rokkeveen would have been replaced by green structure only, velocity would reduce to 5.23 m/sec. Ventilation loss would still reduce by 141 kWh.
Would 1km roughness higher than 6 have more impact?

In Fig. 250 and Fig. 251 only the last km before Rokkeveen farmland (roughness 4) is replaced by regular forest (roughness 7) and heavy forest (roughness 8). From these thought experiments we conclude 1km regular forest has approximately the same impact as 6km green structure. However, 1km heavy forest with rather high trees (15m) reduces wind velocity substantially to 2.90 m/sec at the edge of town. Energy loss per non airtight dwelling per year as far as due to wind from this direction there decreases 324 kWh from 987 kWh to 663 kWh. However, above suburban built up area wind velocity increases again fastly stabelising on approximately 4.2 m/sec.

Fig. 252 and Fig. 253 compare regional remote (see 2.3.5) and locall adjacent (see above) impacts.



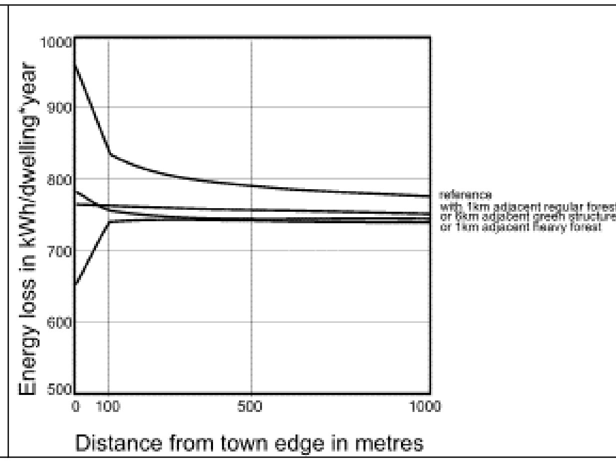


Fig. 252 *Impact regional layout on Zoetermeer separated by railways and highway*

Fig. 253 *Impact locally adjacent shelter on Rokkeveen*

Representated impacts are restriced to 1 of 12 wind directions. Figures may be multiplied by a factor 3 to 5 if more directions are sheltered. The impact is decreasing fastly up to 100m in the urban area.

2.4.2 Increase of wind velocity by height

Preceding calculations are tacitly restricted to velocity differences in direction of wind itself (x-direction) and not perpendicular on x (in witdth y and height z). In Fig. 212 we casually mentioned the importance of velocity differences in height (z-direction), but then the view restricted to a height of 10m (international standard measuring wind) and passing chapter 2.2 to 20m (where wind is not disturbed substantially by single buildings).
On differences in wind velocity perpendicular to wind direction in witdh (lateral differences in wind velocity) we did not say more then mention them (2.3.4). Tacitly we supposed styled roughesses and velocities to be continued endlessly perpendicular to the surface of drawing.

However, on this level of scale we can not maintain these simplifications. A separated built up area ('roughness island') ondergoes substantial impacts from wind parallel to its edges. Wind survey yielded experimental results by which we can estimate these lateral impacts. However, that requires some insight in increase of wind velocity by heigth.

To calculate wind velocity v as a working of height z (v(z), wind profile, see Fig. 194, Fig. 255 and Fig. 256) we divide the atmosphere from the largest height $z=d_3$ where wind still is influenced by Earth's surface to the ground in tree layers:
90% 'boundary layer' from d_3 to $0.1 \times d_3$;
9% 'wall layer' from $d_2 = 0.1 \times d_3$ to $d_1 = 0.01 \times d_3$;
1% 'viscose layer' from d_1 to ground level.

The wind velocity of these layers can be approximated by three different formulas (Voorden 1982, Appendix B):

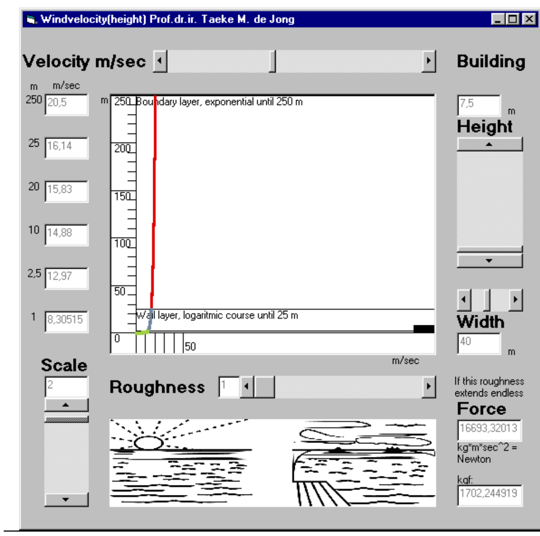
(1) where $d_3 > z > d_2$: $v_3(z) = v_{d3} * (z/d_3)^{\alpha}$;
(2) where $d_2 \geq z \geq d_1$: $v_2(z) = (v_{d3} * 0.4 / (Sqr(25 + (\ln(d_3 / d_0))^2)) / 0.4) * \ln(z / d_0)$;
(3) where $d_1 > z > 0$: $v_1(z) = v_2(d_1) * ((2 * z / d_1) - (z^2 / d_1^2))$.

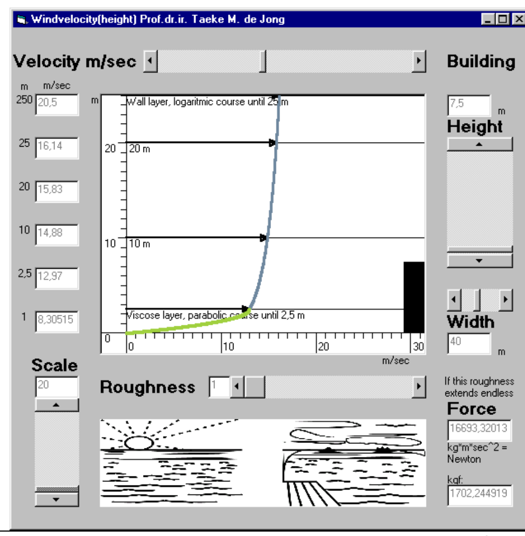
If we know velocity v at d_3 (v_{d3}) the exponential formula (1) produces a velocity for every z in boundary layer below d_3 supposed we know d_3 and exponent α. Exponent α and d_3 are parameters dependent on roughness, we can take them from Fig. 254. For the wall layer the logaritmic formula (2) needs an other parameter d_0 different for every roughness as well (Fig. 254). In an urban environment with much local turbulence the lowest viscose layer has theoretical value only. But for roughesses lower then 5 we can approximate wind velocities by parabolic formula (3). Within formula (3), formula (2) is used to calculate $v_2(d_1)$.

Rough-ness class	α	d_3	d_2	d_1	d_0	parameters used elsewhere	
						D(h)	β
		m	m	m	m		
1	0.104	250	25.0	2.50	0.0002	0	0.07
2	0.144	275	27.5	2.75	0.005	0	0.08
3	0.181	300	30.0	3.00	0.03	0	0.09
4	0.213	350	35.0	3.50	0.1	0	0.11
5	0.245	400	40.0	4.00	0.25	0.3 0.7	0.14
6	0.273	450	45.0	4.50	0.5	0.7	0.16
7	0.313	475	47.5	4.75	1	0.8	0.18
8	0.363	500	50.0	5.00	2	0.8	0.20

Fig. 254 *parameters dependent from roughness in formulas used in wind surveys.*

If we do not know v_{d3}, but we know v_{10m} or v_{20m}, we can vary the upper scroll bar of the computer programme Windvelocity(height), - downloadable from www.bk.tudelft.nl/urbanism/team publications 2003 - to get the right profile.





Jong (2001)

Fig. 255 *Exponential $v_3(z)$ and Logaritmic $v_2(z)$ increase of wind velocity by height*

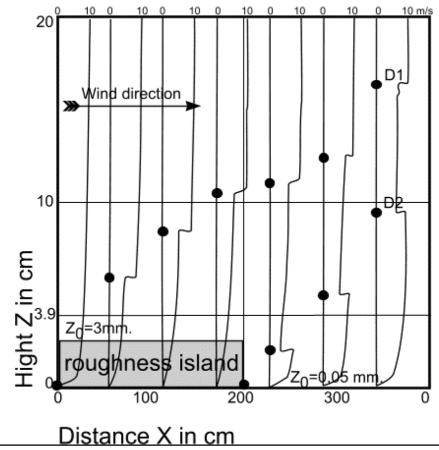
Fig. 256 *Logaritmic $v_2(z)$ and Parabolic $v_1(z)$ increase of wind velocity by height*

In the logaritmic formula (3) factor v_{d3} * 0.4 / (Sqr(25 + $(\ln(d_3 / d_0))^2$) is known as 'wall shearing stress velocity'.

2.4.3 The form of a town

Fig. 257 shows the result of a wind tunnel experiment described in Vermeulen (1986). This experiment serves as a reference for thought experiments to follow.

Above a roughness island in a smooth environment discontinuities in wind velocity appear. The wind meets the edge of the roughness island for the first time (x = 0) still having a regular velocity profile like described on page 113. Above the roughness island a specific velocity profile is estabished with lower velocities than the surrounding smooth surface. However, on some height above the roughness island the old profile remains. The height up to where the new profile establishes its impact is called 'internal boundary layer thickness (Δi). The development of this boundary layer is drawn by dots in Fig. 257. Behind the roughness isand the old profile recovers up to a second boundary layer height. In the used model x=300cm from the first change of roughness, the first boundary layer height (D_1) amounts 16,5 cm , the second (D_2) 9,5 cm.



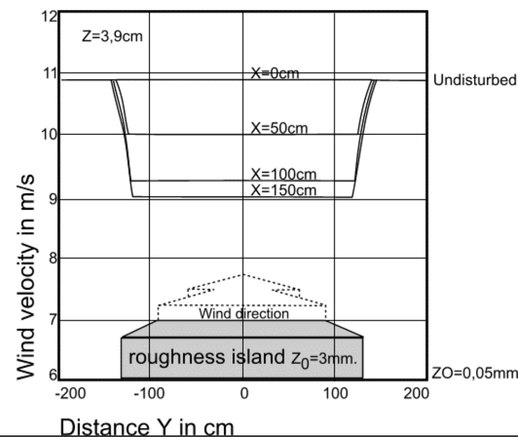


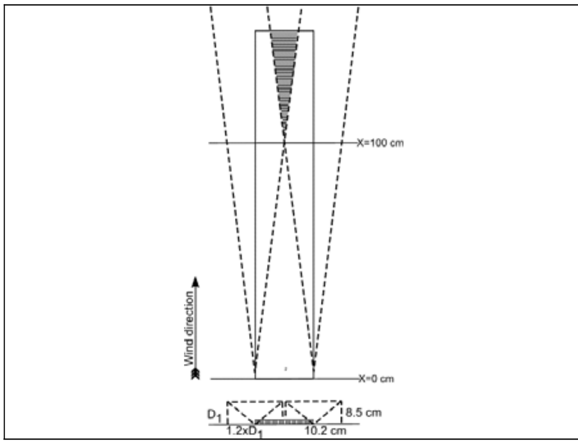
Fig. 257 *Wind velocity profiles in height*

Fig. 258 *Wind velocity profiles in width*

Fig. 257 shows wind profiles from the beginning (x=0) above and behind (up to x=300) the roughness island in cross section in case that island would extend endlessly perpendicular to the surface of drawing. Fig. 258 shows wind profiles 3.9cm above the roughness island in front view limited on two sides on a distance of x={0, 50, 100, 150cm) from the front edge. At x = 0 wind still behaves undisturbed like above a smooth surface. After 50cm above the rough surface wind velocity has slowed down, but on both sides the velocity of the smooth surface remains. Between both velocities a lateral transitional zone develops. In the experiment the width of the transitional zone appears to be 1.2 times the internal boundary layer thickness D_1.

Fig. 257 shows, the thickness of the internal boundary layer D_1 is approximately 1/10 times the distance to frontal edge x.
So, behind x=1000m (where D_1 is approximately 100m) a transitional zone can penetrate the air above the roughness island already 120m from the side edges. When the island is 240m width the transitional zones meet eachother. So, the wind velocity from this point on could increase by interacting lateral impacts to the back of the island in spite of the underlying roughness.
For example, above an elongated separated urban area with its narrow front to South, Southerly wind not only slows down in its own direction, but produces on the Westerly and Easterly edges a side effect. This increases wind velocity by interaction above the Northern part of the area.

To examine this interaction in more detail a windtunnel experiment on a narrow roughness island is carried out. Fig. 259 shows a map of the model with hypotheses concerning the transition zone, and Fig. 260 a front view with the result of measurements.



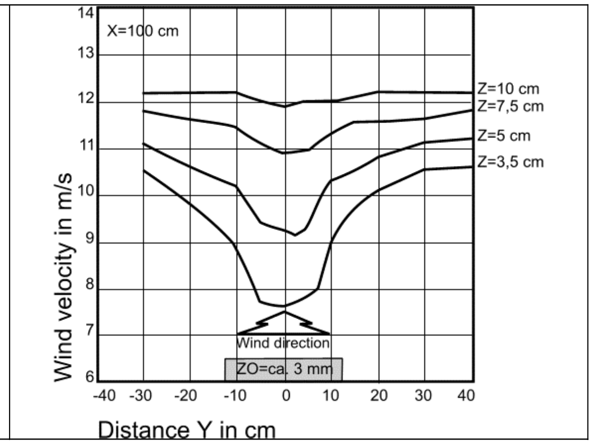


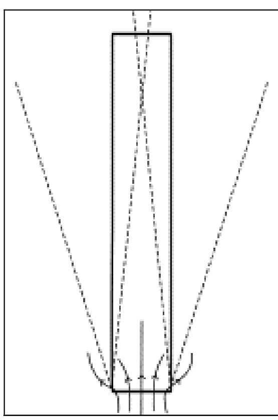
Fig. 259 *Hypothetical interaction above an elongated roughness island.*

Fig. 260 *Measurements above an elongated roughness island x=100cm.*

Fig. 260 shows results of measurement near the point where interaction hypothetically should begin (x=100cm). Behind this point (shaded area in Fig. 259) wind velocity should increase anew. Examining these results next deviantions draw attention:

1 wind velocity decreases more then expected (8,6 m/sec instead of 9,25 m/sec);
2 transition zone outside the roughness island is wider then 1,2 * D1 = 10,2 cm;
3 transition zone inside the roughness island is narrower then 10,2 cm.

We can explain these deviations concerning the possibility wind swerves out meeting a narrow roughness island (initial interaction). Fig. 261 represents this additional supposition. As a result of the crooked flow and the material used in the experiment in the very start wind meets a higher roughness then on perpendicular flow. That may explain the first effect. The other effects are caused by a slightly outward initial change of direction of the transition zone as a whole.



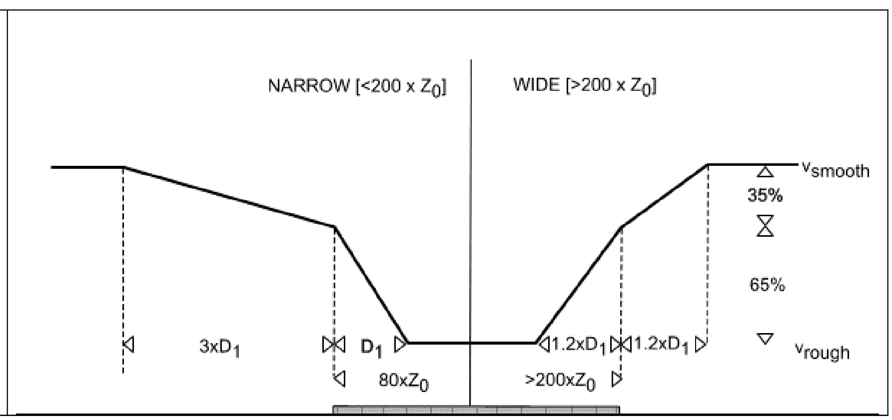


Fig. 261 *Supposed initial interaction*

Fig. 262 *Arithmatical approach of lateral interaction with and without initial interaction*

Fig. 262 shows how to calculate wind velocity in transition zones. Starting points are undisturbed velocities above smooth (v_{smooth}) and rough (v_{rough}) surfaces and their internal boundary layer thicknesses d_3. The difference between both velocities has to be bridged. Above the island already 65 % is bridged , the remaining 35 % is bridged above the smooth surface.
A wide roughness island has no initial interaction. The difference is bridged symmetrically in a distance of 1. 2*D_1. A roughness island narrower then 200 x Z0 (roughess length, not the length of the island) causes initial interaction. Wind velocity difference is bridged over a much larger distance outside the island and above the rough surface over a somewhat smaller distance. The island of Fig. 260 was

25 cm wide, 80 times the roughness length z_0 = 0,3 cm, much less then 200. By initial interaction 65 % was bridged above the island over a distance D_1 (8,5 cm), the remaining 35 % over a distance 2*D_1 (17 cm).

Returning to the thought experiment of page 108 concerning Leidscheveen we can put Fig. 232 on top of its background Fig. 231 as shown in Fig. 263.

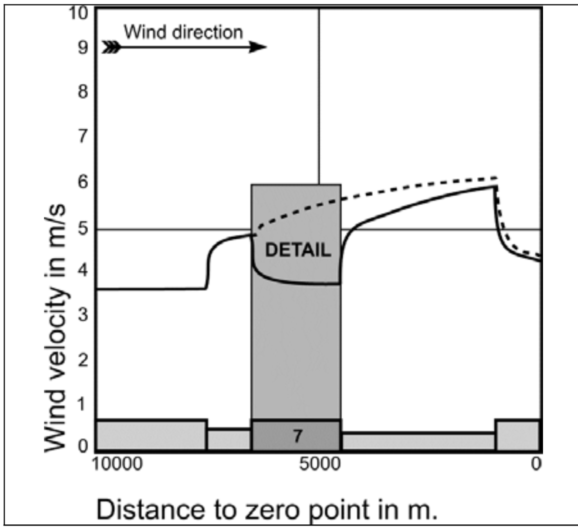


Fig. 263 *Westerly wind in and around Leidscheveen from* Fig. 231 *and* Fig. 232

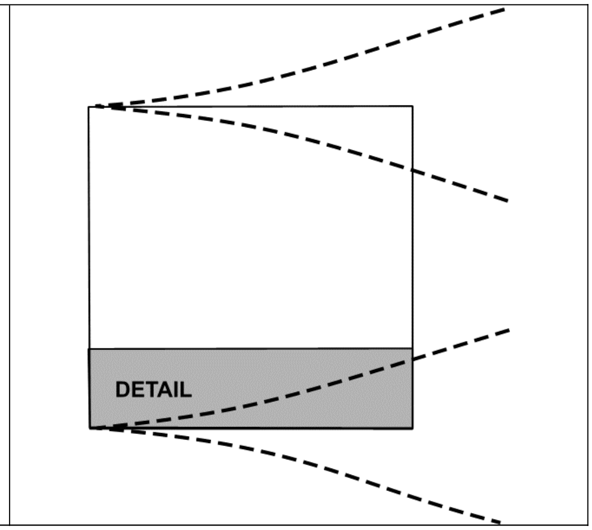
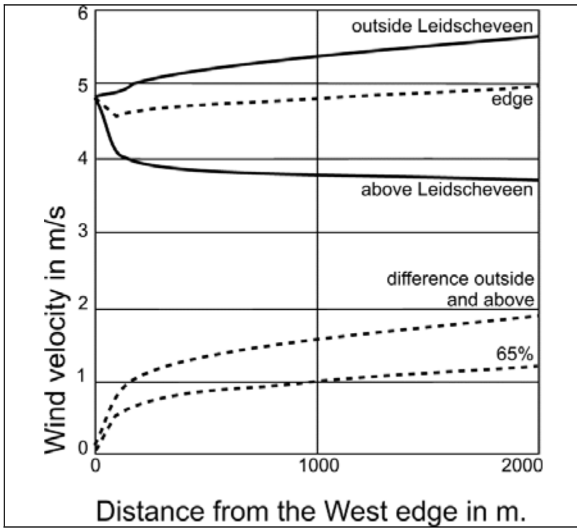


Fig. 264 *Leidscheveen as a rougness island*

Fig. 264 shows Leidscheveen styled as a square of 2x2km.It has no intial interaction because it is wider then 200 times the rougness length Z0 = 1 belonging to class 7. So, the transition zone will penetrate the built up area 1. 2* D_1 m.

Fig. 265 and Fig. 266 are distorted details of Fig. 263 and Fig. 264.
Fig. 265 shows velocities outside and above Leidscheveen in more detail. Below their difference is represented. 65 % of the difference is bridged above rough urban area (Fig. 265). That is the way you find wind velocity on the edge inbetween the curves above. In the South East corner of Leidscheveen wind velocity is increased up to 5 m/sec by lateral impacts, while earlier calculations (Fig. 263) indicated there 3,7 m/sec. This velocity is not reached on the East edge until 300 meter (1. 2*D1) from the South edge (Fig. 266).



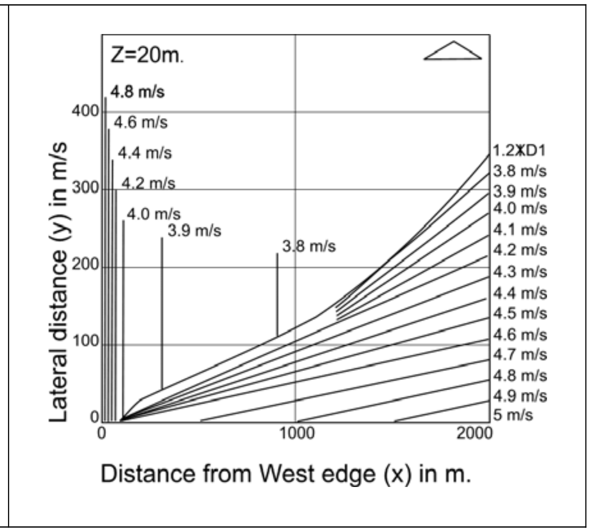


Fig. 265 *Given (continues lines) and calculated (dotted) wind velocities outside and above Leidscheveen as distorted detail from* Fig. 263

Fig. 266 *Transition zone penetrating from South in normal decrease of Westerly wind velocity above Leidscheveen as distorted detail from* Fig. 264

From Fig. 257 we learned D_1 (the height where the undisturbed wind velocity meets the disturbed one) is approximately 1/10 of x. So, we can approximate the distance from the South edge (Fig. 262) 1.2 x D_1 in Fig. 266 by drawing a straight line into the South West corner of the island, but here it is calculated according to a method by {Vermeulen, 1983 #5711}. From Fig. 265 we know the velocity above Leidscheveen without lateral effect at the East edge (3.7m/sec) and the penetrating velocity in the South East corner (5m/sec). Inbetween the velocity increases proportional (Fig. 262) to the distance from the South edge. The velocities on the South edge we know from Fig. 265 as well. Connecting points of equal wind velocity at the East an South edge we get 'altitude' lines of equal wind velocity.

The below left quadrant of Fig. 267 is a copy from Fig. 266 mirrored 1km above and extrapolated 4km into the East. Width (1km) and length (4km) are not proportionally drawn. Now interaction appears behind the point where 1,2*D1-lines cross. According to Vermeulen (1986) the 'altitude' lines within the interaction area you can simply connect.

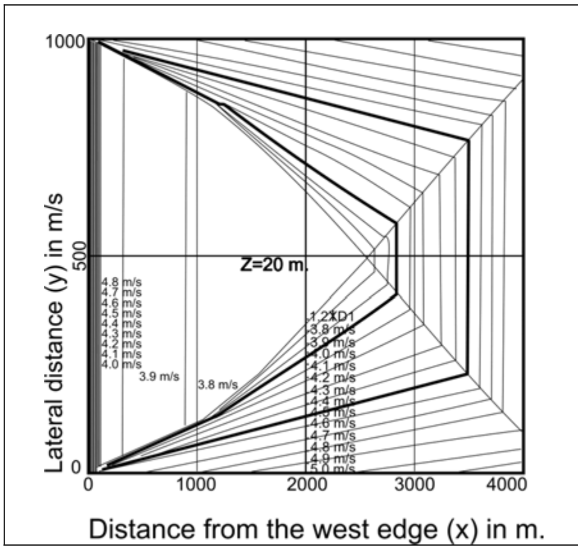


Fig. 267 *Elongated island head in wind (length drawn shortened)*

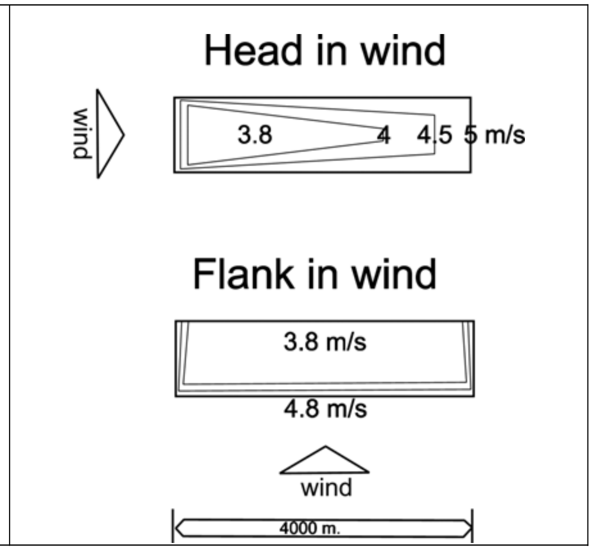


Fig. 268 *Head and flank in wind (proportionally drawn)*

Fig. 268 'head in wind' shows the same model in true proportions: an elongated island with 'altitude lines' 4, 4,5 en 5m/sec adopted from Fig. 267. Wind velocity in heart line primarily drops from 4.8 to 3.8m/sec, but then increases up to 5m/sec on the East edge due to lateral impacts. Drawing the case 'flank in wind' the first left km from Fig. 267 is used only extrapolating the middle parts. In that case the urban area is surprisingly exposed to lower wind velocities because lateral impacts play practically no rôle. That conclusion is controversial to the usual intuition that elongated urban areas should be located with 'head in wind'. 'Flank in wind' appears to be better from a viewpoint of shelter. However, the question is how much this measure yields. Fig. 269 compares them by a grid of hectares.

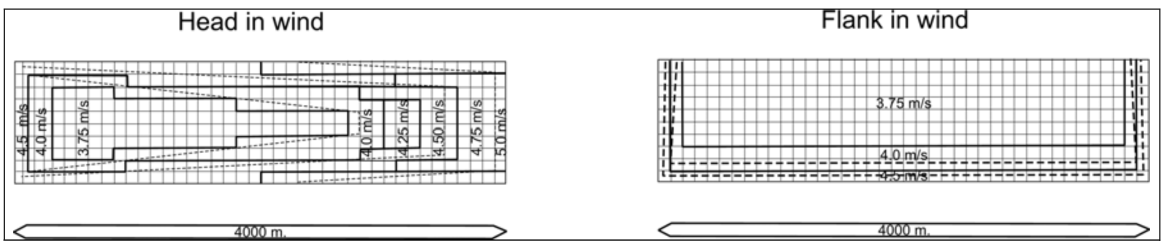


Fig. 269 *Windvelocities per hectare*

Suppose there are 40 dwelling per hectare. From ventilation losses of non airtight dwellings due to Westerly wind we now can calculate the total difference.

Windvelocity	head	flank	Ventilatilion loss in kWh due to Westerly wind			
m/sec	ha	ha	Per dwelling	Per ha.	Total head	Totaal flank
3,75	88	252	504	20160	1774080	5080320
4,00	98	90	521	20840	2042320	1875600
4,25	12		539	21560	258720	
4,50	120	58	557	22280	2673600	1292240
4,75	34		577	23080	784720	
5,00	48		597	23880	1146240	
Totaal	400	400			8679680	8248160

Fig. 270 *Difference in ventilatiion loss head and flank in wind*

The difference due to western wind amounts 431 520 kWh per year (approximately 27 kWh average per dwelling). However, this amount can not be charged as profit by giving an elongated urban area a turn by 90^o. On every orientation after all, the impact of at least four wind directions have to be analysed. Then the profit is the difference in impact from two wind directions head and two flank.

2.4.4 Dispersion of urban area

Is a non elongated ('compact') town better then a whether or not favourably oriented elongated or dispersed one? This question can not be answered for all cases because elongatedness is substantially dependent from orientation. Anyway, for Westerly wind in case of Leidscheveen the following is valid. Fig. 271 and Fig. 272 show three classes of wind velocity on a hectare grid.

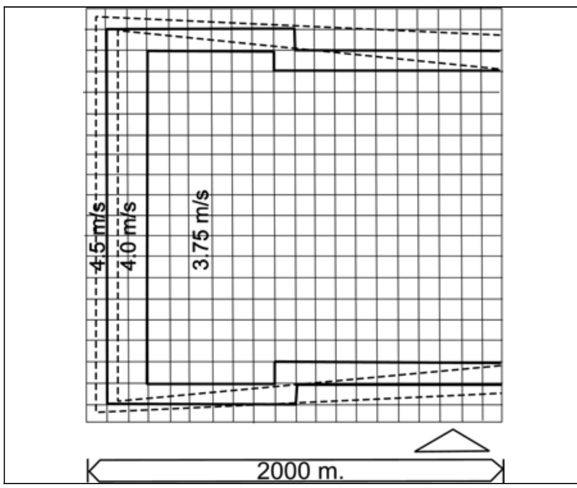


Fig. 271 *Compact town*

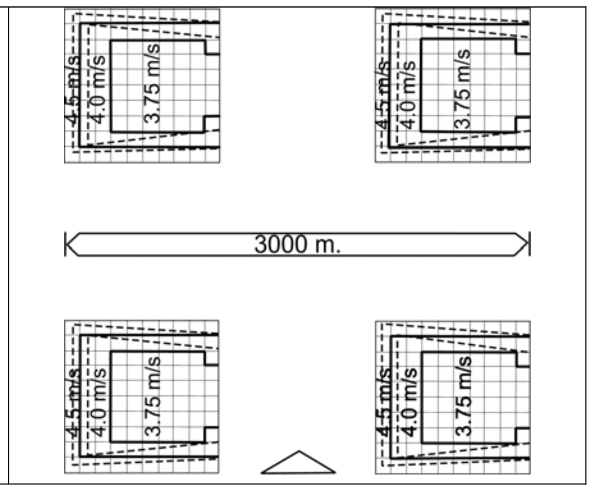


Fig. 272 *Dispersed town*

From the ventilation loss per dwelling due to Westerly wind of 3,75, 4 en 4,50 m/sec we can calculate a difference (Fig. 273).

Windvelocity	Compact	Gespreid	Ventilatieverlies in kWh bij westenwind			
m/sec	ha	ha	per woning	per ha	totaal compact	totaal gespreid
3,75	250	160	504	20160	5040000	3225600
4,00	72	128	521	20840	1500480	2667520
4,50	78	112	557	22280	1737840	2495360
Totaal	400				8278320	8388480

Fig. 273 *Difference in ventilation loss in compact and dispersed towns*

The difference in favour of building compact towns amounts 110 160 kWh per year only (approximately 7 kWh average per dwelling). Velocity and probability of Western wind amounts a little above the average. So, you can multiply this figure by approximately 10 to estimate the total profit. Comparison with elongated forms is more difficult by orientation sensitivity. A fast method of multiplying the profit of westerly wind does not make sense then. For every several case the calculation has to be repeated for all 12 wind directions. We will not elaborate that.
The intended profit of this paragraph to be used in next paragraphs is insight in the importance of lateral wind effects as such.

2.4.5 The form of town edge

The acquired insights make rough study of town edge design possible. By doing that in the same time we reach the lowest level of scale roughness based calculations can be useful. On lower levels of scale the average image of roughness is disturbed too much by local form variations essential for urban design. However, they remain indispensable as input for predictions on lower levels of scale. The next chapter will examine levels of district and neigbourhood further by carefully designed wind tunnel experiments. They will link up connections between urban design and wind behaviour in more detail.

However, on the level of town edge design the roughness approach (grain approximately 100m radius) still makes sense for rough conclusions. We restrict to the impacts of large gaps in the city edge. They occur by large access roads with noise zones or green lobes penetrating the city.
Fig. 274 shows a model of a small town (approximately 50 duizend inwoners) with lobes like that.

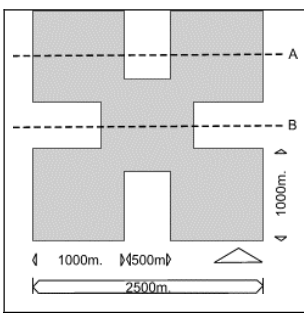


Fig. 274 *Small town with green lobes*

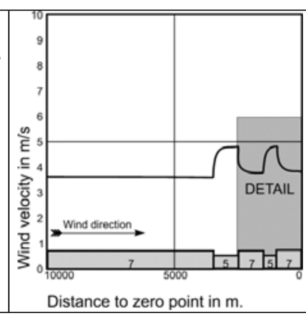


Fig. 275 *Wind velocity profile cross section A*

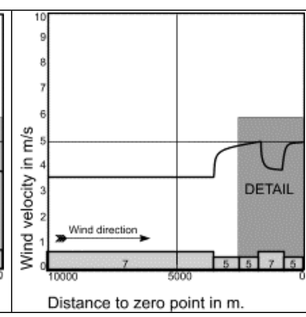


Fig. 276 *Windvelocity profiel doorsnede B*

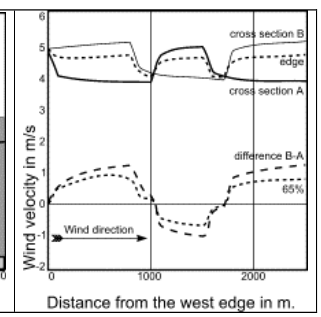
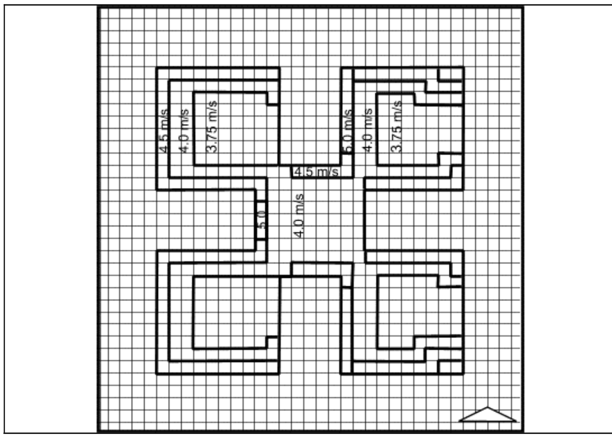


Fig. 277 *Difference profile A en B*

Fig. 275 and Fig. 276 show the windvelocity profiles of cross section A and B in case it would be Leidscheveen blown by Western wind. Fig. 277 shows above the last 3000m of both profiles projected on top of eachother. Below the difference between both profiles is represented; 65% has to be bridged laterally above urban area over a distance 1,2 * D_1. This determines wind velocity on the edge.

From these data we estimate again an average wind velocity per hectare.



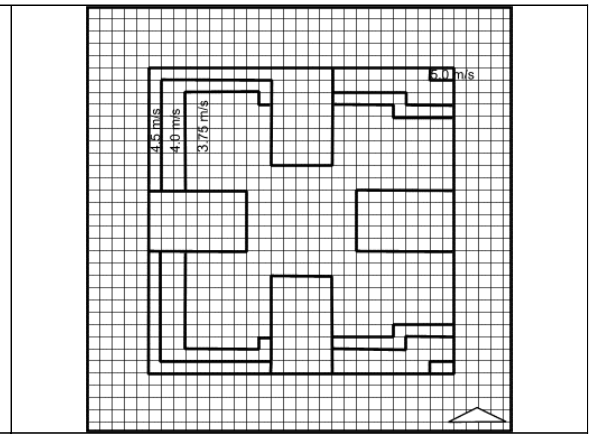


Fig. 278 *'Open' Stadsrand* Fig. 279 *'Gesloten' stadsrand*

Fig. 278 shows lobes penetrating from four directions. In Fig. 279 the lobes are filled with forest of the same roughness as the urban area keeping the urban surface equal.
From the ventilation losses belonging to wind velocity 3,75, 4, 4,5 and 5m/sec due to westerly wind, Fig. 280 calculates the difference.

Windvelocity	Open	Gesloten	Ventilatieverlies in kWh bij westenwind			
m/sec	ha	ha	per woning	per ha	totaal open	totaal gesloten
2,75	154	305	504	20160	3104640	6148800
4,00	184	74	521	20840	3834560	1542160
4,50	106	82	557	22280	2361680	1826960
5,00	21	4	597	23880	501480	95520
Totaal	465	465			9802360	9613440

Fig. 280 *Difference in ventilation loss by 'open' and 'closed' town edge*

The difference is 188 920 kWh per year (Approximately 10 kWh per dwelling). Multiplying Westerly wind impact by 10 the total average profit is approximately 100 kWh x 1860 dwellings.

2.4.6 Wind directions, temperature and built form

In chapter 2.2 we restricted our thought experiments to two wind directions and in this chapter even to one (Westerly wind). Assuming an average temperature for all wind directions we reported virtual ventilation losses of non airtight, low rise buildings due to Westerly wind as an indicator. Their *differences* clarified an impact of environmental roughness useful for other impacts as well. We exclusively varied regional and local environment applying different roughnesses, keeping the rest constant. Otherwise the impact of environmental roughness on itself could not be clarified. It would be mixed up with other causes (possible measures). To clarify other causes the reverse we have to keep environmental rougness constant. If we take one layout of roughnesses in the environment – the one we will use in next chapters for experiments in the wind tunnel (Fig. 285) – we can compare the contribution of every several wind direction and their temperature properly (Fig. 281). We calculated energy losses by ventilation for every wind direction in the same way we did above (column A and B) and for airtight dwellings (column C and D).

		without temperature influence				temperature influence		with temperature influence			
		non airtight		airtight		non airtight	airtight	non airtight		airtight	
wind direction		A	B	C	D	E	F	A x E	B x E	C x F	D x F
'hours'	degrees	kWh		kWh				kWh		kWh	
1	30	322	6%	154	6%	70%	66%	227	4%	101	4%
2	60	492	9%	228	9%	116%	111%	570	10%	254	10%
East 3	90	405	7%	201	8%	168%	151%	681	12%	304	12%
4	120	246	4%	129	5%	205%	174%	504	9%	225	9%
5	150	369	7%	186	8%	64%	57%	238	4%	106	4%
South 6	180	530	10%	259	10%	71%	65%	377	7%	168	7%
7	210	729	13%	232	9%	100%	141%	731	13%	326	13%
8	240	769	14%	315	13%	107%	116%	819	15%	365	15%
West 9	270	591	11%	253	10%	107%	111%	631	11%	281	11%
10	300	389	7%	172	7%	90%	91%	349	6%	156	6%
11	330	366	7%	173	7%	71%	67%	260	5%	116	5%
North 12	0	329	6%	167	7%	45%	40%	149	3%	67	3%
	Total	5537	100%	2469	100%			5536	100%	2469	100%

Fig. 281 *Contributions per wind direction to total energy loss by ventilation*

In the lowest row 'Total', column A shows we can multiply the loss of Westerly wind by 10 to have an idea of total loss from all directions indeed. The totals without temperature influence are the same as those including temperature influence, because in columns A, B, C and D we assumed an average temperature of all directions.
Columns E and G show tentative weight factors for temperature, based on Visser (1986). Multiplying A, B, C and D by these factors produces the necessary correction to get a better idea about the real losses per direction. They are used in next chapters as well.

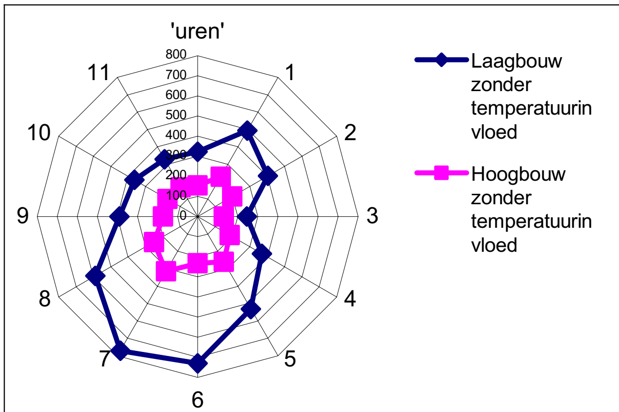


Fig. 282 *Contributions per wind direction to total energy loss by ventilation without temperature influence (A and C in* Fig. 281*)*

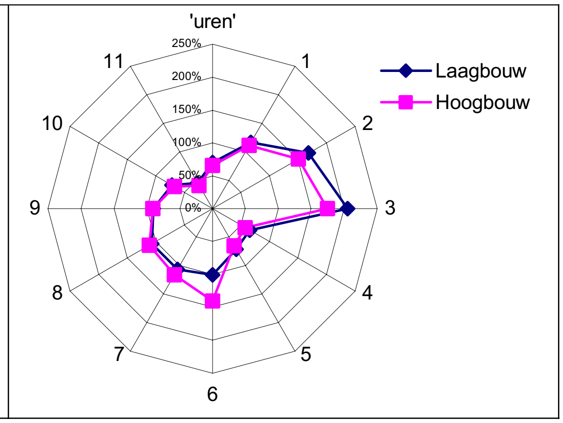


Fig. 283 Tentative correction factors for temperature influence *(E and F in* Fig. 281*)*

Fig. 282 and Fig. 283 show Easterly winds being less probable but colder have a larger impact on energy losses by ventilation then South Westerly winds. To understand why Southerly winds contribute more in airtight buildings (Hoogbouw in Fig. 283) then in non airtight ones (Laagbouw) you have to look at **Fig. 198**.

2.4.7 References to local measures

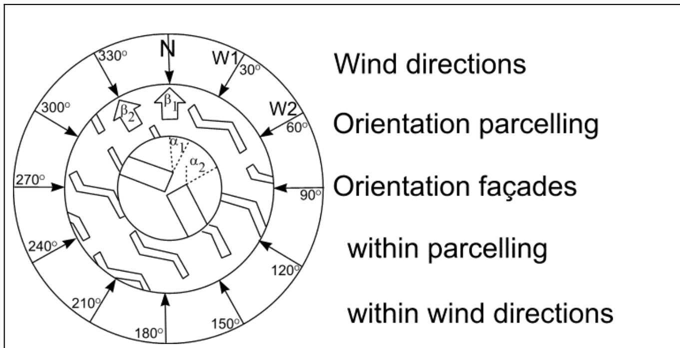
Jong, T. M. d. (2001) Standaardverkaveling 11.exe.
Vermeulen, P. E. J. (1986) Experimenteel onderzoek ten behoeve van de modelbeschrijving van drie-dimensionale ruwheidsovergangen MT-TNO.

Visser, G. T. (1986) Winddrukverschillen over woningen bij een viertal configuraties op wijkniveau MT-TNO.

2.5 District and neighbourhood variants

2.5.1 From calculable 'rough surface' into allotments in a wind tunnel

Changing location and size of a homogenuous undirected roughness, influences every external wind direction in the same way. However, changing form on a lower level of scale introduces internal directions within that field of roughness behaving differently even for one single external wind direction. And design can vary form within form. This complication you can imagine as 3 potter's wheels turning around the same centre. If we consider 12 directions, there are 12 x 12 x 12 combinations (Fig. 284).



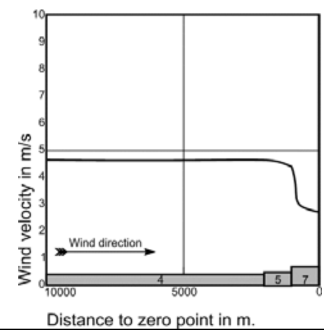


Fig. 284 *Three levels of schale where orientation has to be token into account*

Fig. 285 *Supposed wind tunnel context by standard Northerly wind*

The external wheel represents 12 local wind statistics (W1, W2, W3 … concerning probability, velocity and temperature) as it applies outside and at the edge of the urban fragment we consider. The second wheel represents the considered fragment with its own arrow indicating North (β_1). In this chapter the direction of the allotment as a whole (β_1, β_2, β_3 ...) is variable. The middle wheel represents façades within the allotment having variable orientations (α_1, α_2, α_3 ...), causing different ventilation losses locally. In previous paragraphs α and β were neglected. Ventilation losses were averaged over all directions of allotments and façades.

In this chapter α and β are varied by interpreting tests of 18 different allotments in the wind tunnel of Visser (1986) from 7 different angles (0^o – 90^o by steps of 15^o) with a standarised W and foreland roughness (Fig. 285). From these 7 measured angles, 4 (0^o – 90^o by steps of 30^o) appeared to be sufficient to draw conclusions about all directions of allotment.

2.5.2 Wind tunnel experiments

On the level of districts and neighbourhoods 4 configurations 1 x 1 km Jong (1986) - fully elaborated in models 1:500 - are tested by Visser (1986). In each of the four models 30 x 2 measuring points were installed at front and back side of different building blocks to measure pressure differences (Fig. 286).

Right above in each configuration (Fig. 286) each time you find a quarter of a district centre. So, any configuration could be thought mirrored twice around this centre into a full district 2x2km consisting of 4 district quarters. Each configuration consists of 9 neighbourhood quarters 300x300m (one central, 8 peripheral). Each neighbourhood quarter consists of 9 ensemble quarters (hectares 100x100m one central, 8 peripheral). District roads are planted with trees; neighbourhood and ensemble roads are not.

The configuration is outside blown along from North to East (90o from North). At South and West side the configuration as a district quarter is part of an imaginary district filled up with equal roughness.
In this paragraph we study the differences between the four configurations not trying to develop calculation models.

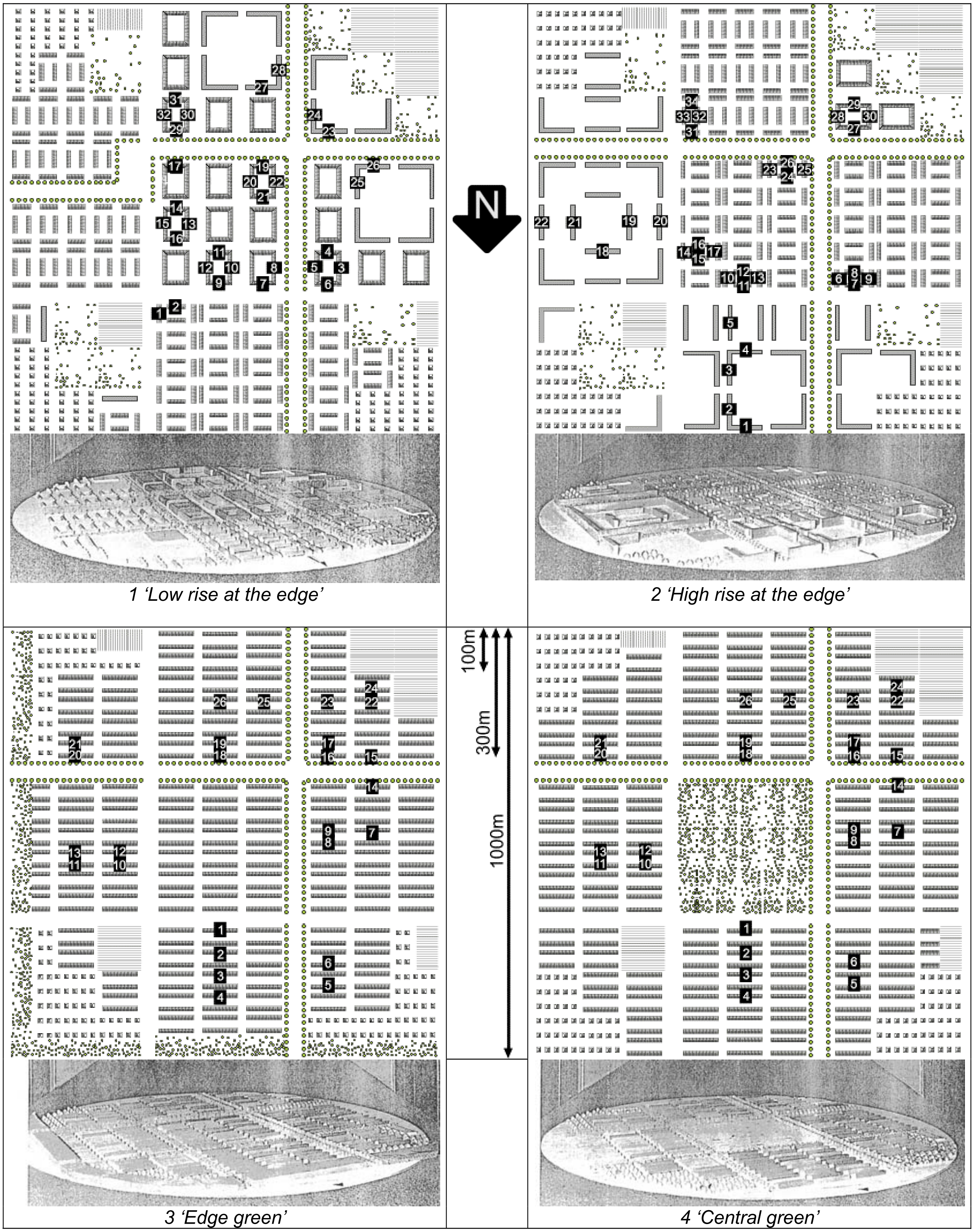


Fig. 286 *District configurations in wind tunnel with measuring points indicated*

Concerning the average result of all measuring points the differences between the configurations are remarkably small. However, there are substantial differences between locations within configurations. (Fig. 293and Fig. 296). Fig. 287 shows hectare allotments applied in the tested configurations.

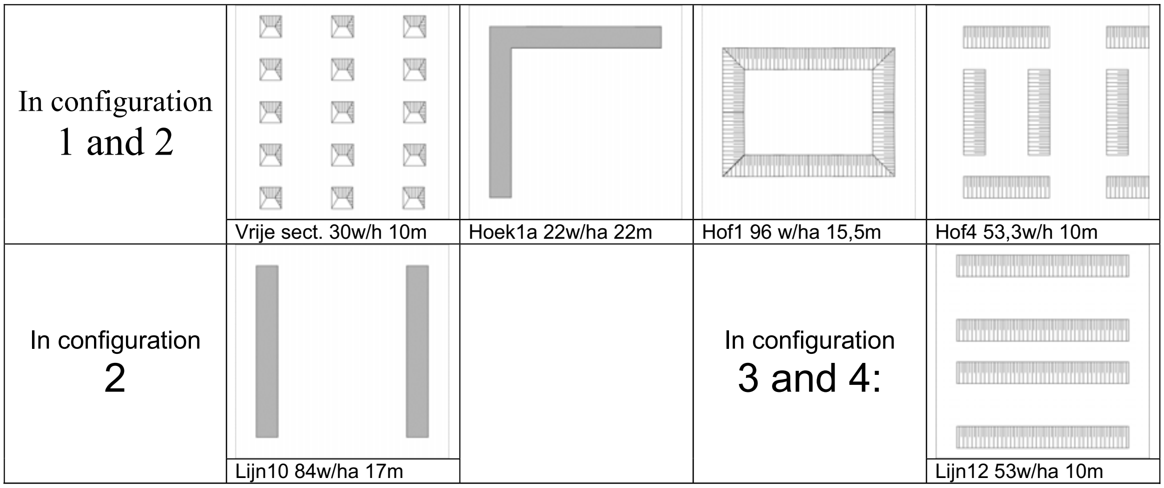


Fig. 287 *Hectare allotments applied in the tested configurations*

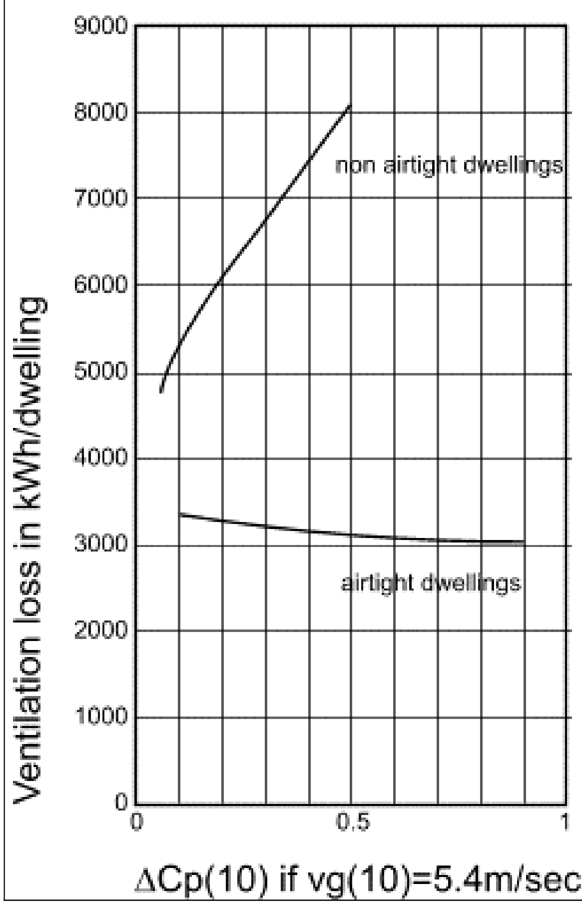
In paragraph 2.6.1 we study the results of 14 wind tunnel experiments by Visser (1986) on hectare level; 7 with green and 7 without. In these experiments a number of theoretical repeating point, line, corner and courtyard allotments 500x500m elaborated in models 1:250 are tested. The force these allotments ondergo by standard wind is measured. From these tests TNO developed a calculation method for allotments repeating in two dimensions. By this method more types of allotment are calculated.

2.5.3 Pressure differences between front and back façades

Ventilation loss of a dwelling not only depends on wind statistics derived from year average wind velocity vg on z=10m height in the nearest wind measuring station (vg(10), for example 5,4m/sec near Schiphol). It depends also on the environment and orientation of the building block. On these more local factors pressure differences between front and back façades follow determining ventilation losses at last.

Pressure differences are proportional to driving pressure of wind: $0,5 \times \rho \times vg(10)^2$. In this formula ρ ('ro') is the density of air. Pressure differences between front and back façades determining ventilation are measured in wind tunnel. Dividing such pressure differences by the local driving pressure of wind produces a factor $\Delta Cp(10)$ representing the resistance of an allotment independent from wind velocity. The result of wind tunnel tests are expressed in $\Delta Cp(10)$. Fig. 288 shows the relation between ventilation loss near Schiphol and $\Delta Cp(10)$ in any wind direction Visser (1986). Airtight buildings in vg(10) lose less energy by increasing pressure because inhabitants close windows they opened in less pressure!

Inside urban areas energy yield of wind turbines is less relevant. However, pressure difference is important as well for comfort of outdoor space, dispersion of air pollution and wind loads. But we have measured ventilation losses and will use it as an indicator.



	Degrees from y-axis				
Point	0	30	60	90	av.
1	0,00	0,18	0,32	0,32	0,21
2	0,10	0,16	0,07	0,04	0,09
3	0,10	0,02	0,10	0,02	0,06
4	0,02	0,14	0,24	0,05	0,11
5	0,12	0,08	0,11	0,11	0,11
6	0,34	0,38	0,02	0,04	0,20
7	0,34	0,26	0,10	0,04	0,19
8	0,08	0,05	0,12	0,16	0,10
9	0,35	0,28	0,11	0,05	0,20
10	0,10	0,00	0,10	0,12	0,08
11	0,11	0,12	0,02	0,05	0,08
12	0,10	0,19	0,24	0,19	0,18
13	0,01	0,10	0,12	0,01	0,06
14	0,18	0,08	0,04	0,05	0,09
15	0,02	0,13	0,25	0,38	0,20
16	0,10	0,19	0,14	0,13	0,14
17	0,02	0,12	0,22	0,30	0,17
18	0,18	0,11	0,01	0,16	0,12
19	0,19	0,16	0,01	0,06	0,11
20	0,02	0,08	0,19	0,07	0,09
21	0,04	0,10	0,14	0,01	0,07
22	0,00	0,16	0,12	0,16	0,11
23	0,38	0,36	0,30	0,13	**0,29**
24	0,14	0,32	0,35	0,35	**0,29**
25	0,17	0,06	0,28	0,24	0,19
26	0,53	0,28	0,05	0,12	0,25
27	0,23	0,20	0,04	0,22	0,17
28	0,34	0,03	0,22	0,48	0,27
29	0,13	0,08	0,07	0,05	0,08
30	0,06	0,01	0,08	0,02	0,04
31	0,08	0,07	0,02	0,10	0,07
32	0,05	0,07	0,16	0,30	0,15
Gem.	0,14	0,14	0,14	0,14	0,14

Visser (1986)

Fig. 288 *Ventilation loss related to ΔCp(10) if vg(10) = 5,4m/sec*

Fig. 289 *ΔCp(10) in measure points of configuration 1 in 4 directions*

Fig. 289 shows ΔCp(10) measured in every measure point of configuration 1 four times while wind was blowing 0^o to 90^o from y-axis each time turning the model 30^o (any direction could be North). Measuring points 23 and 24 (high rise at a crossing, see Fig. 286 conf. 1) suffer the largest pressure differences, 23 on 0^o, 24 on 60^o and 90^o. This kind of details we study in paragraph 2.5.5. This paragraph studies the averages in lowest row compared with the averages of the onter configurations.

2.5.4 District lay out

The averages in lowest row of Fig. 289 seem to show the direction of wind does not matter but this is only the case in configuration 1. It is explained best because half of the measured blocks there are oriented perpendicular to the other half. So, the minimum ventilation loss of one building block compensates the maximum of the other one. Configuration 2 is less balanced that way and configurations 3 and 4 have only one orientation of building blocks (Fig. 290).

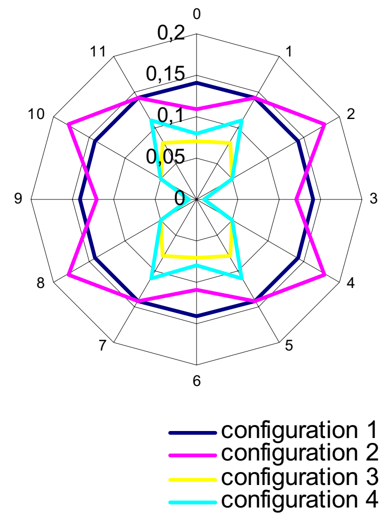


Fig. 290 *Average ΔCp(10) in different configurations two times mirrored around the centre.*

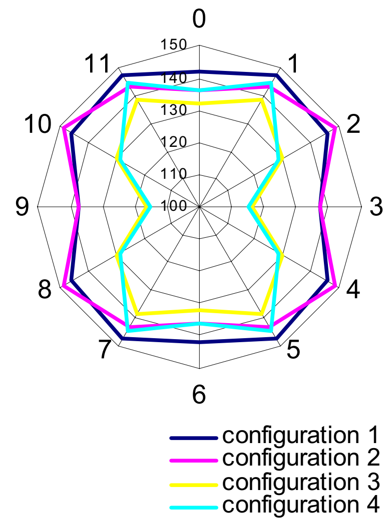


Fig. 291 *Average ventilation loss of a non airtight dwelling in kWh per allotment direction if standard Northerly wind would blow from all directions*

Comparing the impact of locations and allotment directions we should use an equal standard wind (here Northerly wind, representing approximately 2.69% of the virtual total ventilation loss per allotment direction) for every allotment direction (Fig. 291).The virtual total ventilation loss then is 100%. Fig. 292 shows averages multiplied into such a virtual total.In configuration 1 it is 5 344kWh for non airtight dwellings. That is less then we calculated by roughness 7 in Fig. 281 (5 536kWh in column A X E), and for airtight dwellings it is more (3 266 kWh instead of 2 469 in column C x F). Perhaps the roughness class of configurations is closer to 8 then class 7 we used in paragraph 2.4.6 and supposed in Fig. 285.

	Configuration 1			Configuration 2		Configuration 3		Configuration 4	
	calculated								
	roughness	average	virtual	average	virtual	average	virtual	average	virtual
	100%	2,69%	100%	2,69%	100%	2,69%	100%	2,69%	100%
non airtight	5536	144	5344	141	5233	129	4787	131	4862
airtight	2469	88	3266	89	3303				
ΔCp(10)		0,14		0,14		0,05		0,06	

Fig. 292 *Estimating average ventilation losses from 4 allotment directions multiplied into a virtual total.*

Average pressure difference in configuration 2 (high rise on the edge) is the same (ΔCp(10)=0.14) as in configuration 1 (low rise on the edge). But there are differences per *allotment direction*. So, you can not yet conclude both configurations should have the same ventilation loss. *Wind directions* deliver different contributions and their reduction depends on the North direction arrow of the allotment in the compass card of *wind directions*. Because configuration 3 (edge green) and configuration 4 (central green) have lower pressure differences in *all* directions (Fig. 291) we can conclude they will have less ventilation loss then configurations 1 and 2 indeed. However, the difference between a lay out with green on the edge or within the centre is negligible!

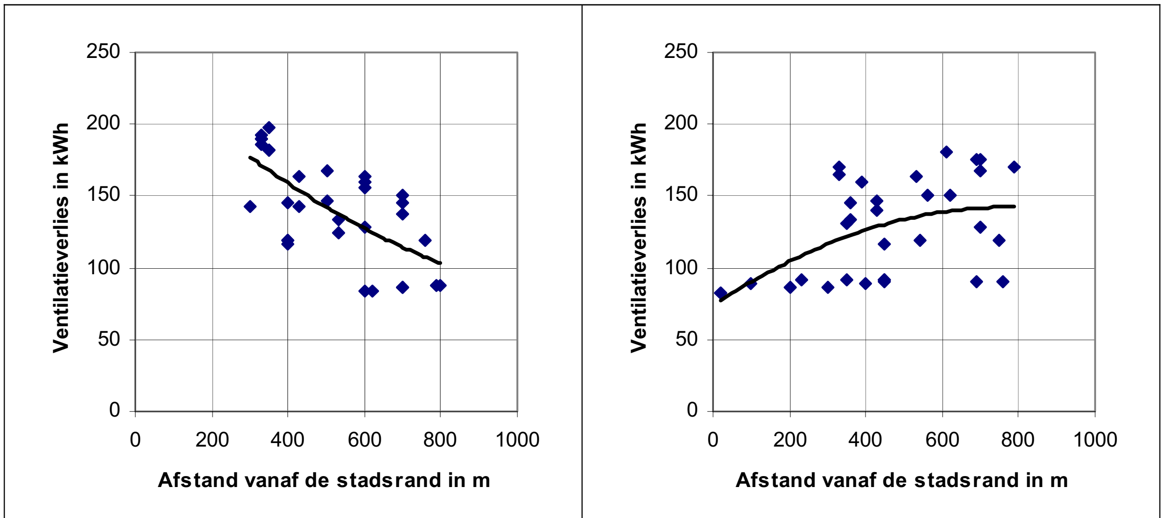
Configuration 1 (low rise on the edge) has more ventilation losses from non airtight low rise dwellings and less from airtight high rise ones then configuration 2 (high rise on the edge). Fig. 288 shows airtight highrise has less ventilation loss by more wind pressure. Inhabitants close their windows earlier.

Slant flow along (30^{o} of 60^{o}) causes in all cases maximum loss (Fig. 290). Perhaps we should orientate allotments with two perpendicular directions East or South West sheltering one of them best

and the othe not at all. This yields more than both half. We tested that hypothesis by calculating perpendicular and slant flowing along for 12 North direction arrows but the result disappointed because adjacent wind directions score high as well by slant flow. They dim the aimed impact into a negligible result.
That is of course not the case in parallel blocked configurations 3 and 4.
So, measures on the level of district or neighbourhood have more local then general impacts. Big local impacts level out in the district as a whole in such a way that differences in its lay out become marginal.

2.5.5 Neighbourhoods

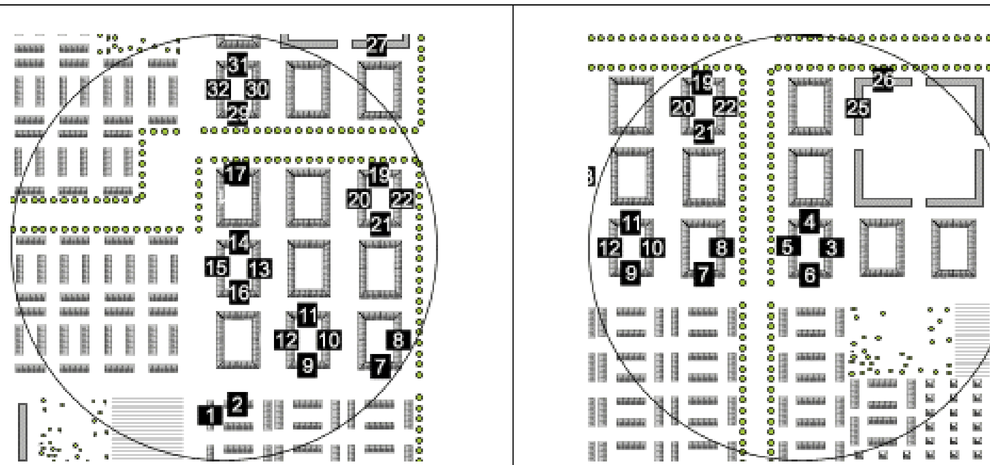
We restrict ourselves to perpendicular flow with Northerly wind character (2.7%) from 0^{o} and 90^{o} out of y-axis. In both cases wind meets on 300m from town edge a 30m wide neighbourhood road and on 600m a 70m wide district road with trees.
A roughness approach (paragraph 2.4.6) would show decreasing loss until 100m from town edge stabilising on approx. 150kWh for non airtight low rise and for airtight high rise increasing stabilising on 75 kWh. Fig. 293 shows wind tunnel results elaborated into kWh (paragraph 2.4) from configurations 1 (low rise on the edge) and 2 (high rise on the edge) as a working of distance to town edge.



configuration 1 (low rise on the edge) configuration 2 (high rise on the edge)

Fig. 293 *Ventilation losses of non airtight low rise and iartight high rise dwellings by standard Northerly wind (2.7% of virtual total) as a function of distance to town edge in configurations 1 and 2*

Wind tunnel experiments now specified to location give a clearer distinction between low rise and high rise on the edge then leveled out over the district. The largest low rise loss in configuration 1 appears in measure point 15 (197kWh), a 15.5m high building located on a 15m wide road without trees and a foreland of 10m high dwellings. The smallest appears in measure point 13 (116kWh), a courtyard dwelling. The difference is approx. 80 or virtually 3000kWh.

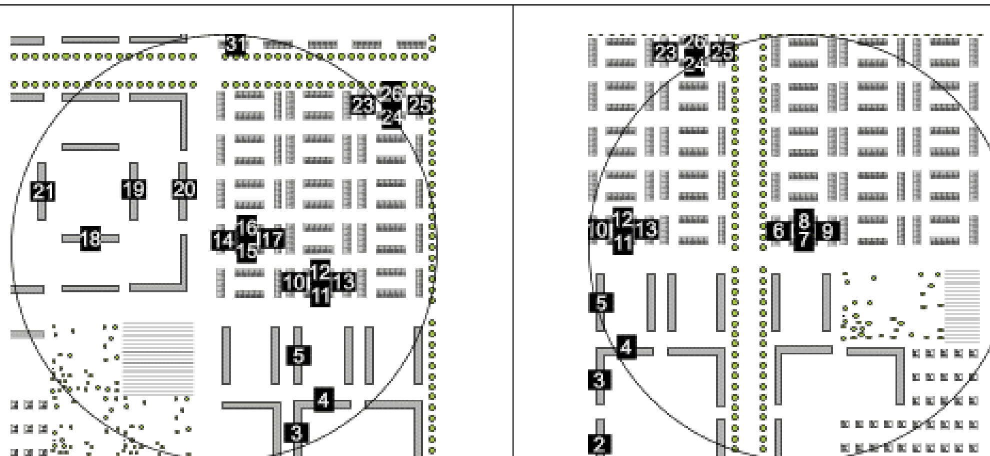


Measure points 1, 9, 15, 29, 32 | *Measure points 5, 6, 7, 9*

Fig. 294 *Measure points in configuration 1 in a radius of 300m*

Measure points 1(186kWh), 6(190kWh), 7(190kWh), 9(163kWh), 15(197kWh) and 32(182kWh) score high by wind over a 40m neighbourhood road without trees. Measure points 5(145kWh), 17(143kWh) and 29(150kWh) get wind over a much wider district road (80 to 100m) with 6m heigh trees. The local importance of trees in large urban spaces is indicated here. The difference is approx. 40 or virtually 1500kWh.

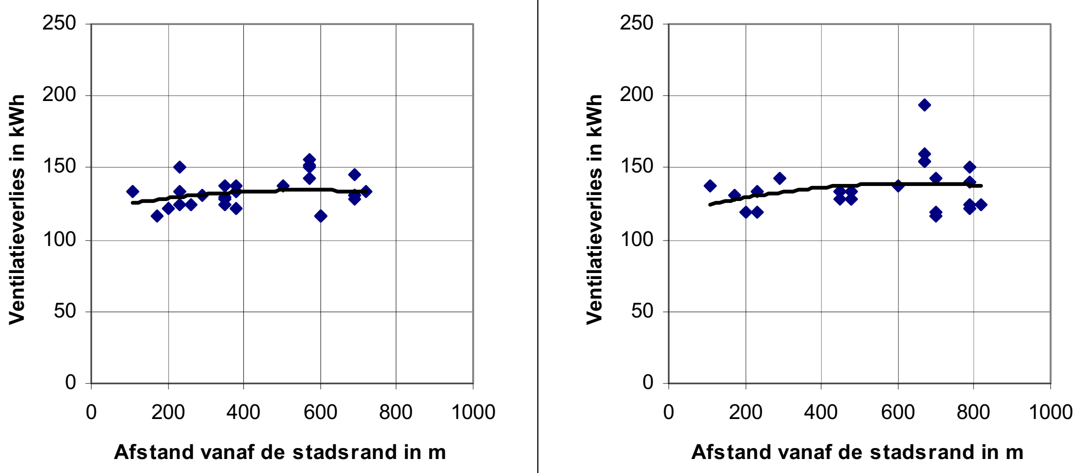
In configuration 2 measure points 7(147kWh), 11(170kWh) en 14(131kWh) lie on a 40m wide neighbourhood road without trees. Measure point 14 scores low because it is shelterd by 22m high high rise buildings on the other side of the road. The low rise minimum measure point 10(116kWh) lies on 10m wide ensemble streets. The maximum in measure point 25(180kWh) is most likely explained by its position on the edge of the used model.



Measure points 10, 14, 25 | *Mearusre points 7, 11*

Fig. 295 *Measure points in configuration 2 in a radius of 300m*

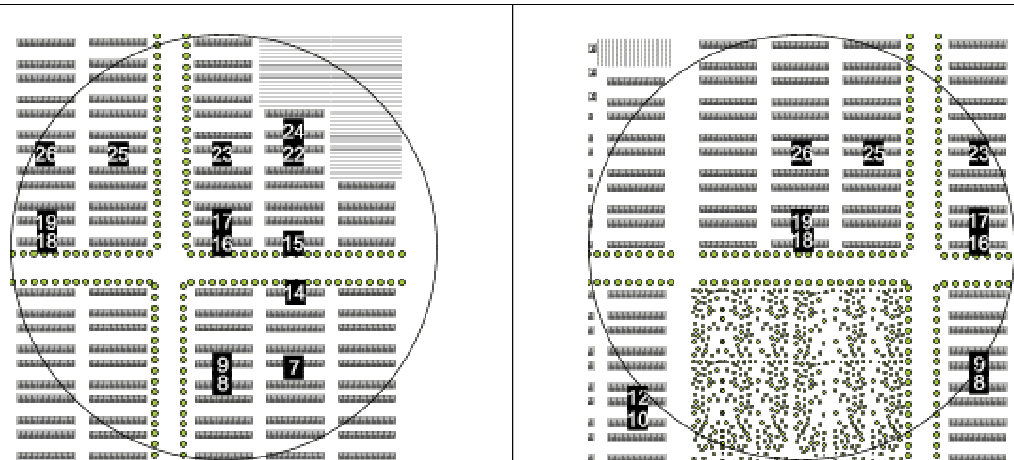
Fig. 296 shows the same figures as Fig. 293 for configuration 3 en 4 without high rise.



configuration 3 (green on the edge) | *configuration 4 (central green)*

Fig. 296 *Ventilation losses of non airtight low rise dwellings by standard Northerly wind (2.7% of virtual total) as a function of distance to town edge in configurations 3 and 4*

In configuration 3 measure point 27(150kWh) ies on a 40m wide neighbourhood road without trees. Measure points 20(156kWh), 18(152kWh), 15(150kWh) and 16(143kWh) score approximately equaly high ying on a 70m wide district road with trees. Minima 2(116kWh), 17(116kWh), 19(116kWh) and 21(116kWh) get wind from a backyard lying on 10m wide ensemlbe roads.



Measure points 15, 17, 18, 19, 22 in Configuration 3 | *Measure points 17, 18, 19 in Configuration 4*

Fig. 297 *Measure points in configuration 3 and 4 in a radius of 300m*

In configuration 4 measure point 18(194kWh) scores extremely high. It gets wind from 300m wide open green area in the centre of district quarter. Even district road trees do not help much on this location. Minima 21(116kWh), 6(119kWh), 5(119kWh) and 17(119kWh) again lie on small ensemble streets. Measure point 19(143kWh) lies on a small street as well, but that is the first street behind the green behind measure point 18(194kWh), and that is still apparent there.

2.5.6 References to District and neighbourhood variants

Jong, T. M. d. (1986) Configuratiekeuze op buurt- en wijkniveau (Den Haag) MESO.
Visser, G. T. (1986) Winddrukverschillen over woningen bij een viertal configuraties op wijkniveau MT-TNO.

2.6 Allotment of hectares

2.6.1 From wind tunnel experiments into methods of calculation

From the results of 14 wind tunnel experiments on repeating theoretical point, line, corner and courtyard allotments with and without green a calculation method is developed Visser (1987; Visser (1987) predicting average pressure differences between front and back façades of dwellings ΔCp(z) (ΔCp on heigth z). The reference height z is 2.5 times the average building height.

The calculation is restricted to allotments with two main directions at most. For two directions we have to determine the value of ΔCp perpendiculary blown along by wind (ΔCp_0). Façades may bend 30° from main direction at most. Within that margin measuring a second main direction is not necessary. The expected ΔCp per flow direction is calculated for 100 x 100m allotment types in Fig. 298.

Visser (1987; Visser (1987)

Fig. 298 *Allotment types 100x100m with different height Visser (1987) calculated ΔCp(z) for*

Fig. 299 shows the result of these calculations.

	height	vert.surf.	without green					with green 6m high					with green 10m high				
	m	F/O	N	+30	+60	+90	av.	N	+30	+60	+90	gem.	N	+30	+60	+90	av.
Punt01	10	0,24	0,14	0,13	0,09	0,00	0,09	0,13	0,12	0,09	0,00	0,09	0,12	0,11	0,08	0,00	0,08
Punt02	10	0,24	0,14	0,13	0,09	0,00	0,09	0,13	0,12	0,09	0,00	0,09	0,12	0,11	0,08	0,00	0,08
Punt03	10	0,24	0,19	0,17	0,13	0,00	0,12	0,18	0,17	0,12	0,00	0,12	0,12	0,19	0,11	0,00	0,11
Punt05	10	0,16	0,19	0,17	0,12	0,00	0,12	0,18	0,17	0,12	0,00	0,12	0,12	0,19	0,11	0,00	0,11
Punt06	10	0,30	0,14	0,13	0,10	0,00	0,09	0,14	0,13	0,09	0,00	0,09	0,13	0,12	0,08	0,00	0,08
Punt07	15,5	0,14	0,23	0,21	0,15	0,00	0,15	0,22	0,20	0,14	0,00	0,14	0,20	0,19	0,13	0,00	0,13
Punt08	15,5	0,21	0,16	0,15	0,11	0,00	0,11	0,16	0,14	0,10	0,00	0,10	0,14	0,13	0,03	0,00	0,08
Punt09	22	0,09	0,20	0,19	0,13	0,00	0,13	0,20	0,10	0,10	0,00	0,10	0,20	0,19	0,13	0,00	0,13
Punt10	22	0,18	0,19	0,18	0,13	0,00	0,13	0,19	0,18	0,10	0,00	0,12	0,18	0,12	0,12	0,00	0,11
Lijn01	10	0,24	0,21	0,19	0,14	0,00	0,14	0,20	0,18	0,13	0,00	0,13	0,18	0,12	0,12	0,00	0,11
Lijn02	10	0,24	0,21	0,19	0,14	0,00	0,14	0,20	0,19	0,13	0,00	0,13	0,18	0,17	0,12	0,00	0,12
Lijn05	10	0,32	0,14	0,13	0,03	0,00	0,08	0,13	0,12	0,08	0,00	0,08	0,12	0,11	0,09	0,00	0,08
Lijn06	15,5	0,25	0,20	0,19	0,13	0,00	0,13	0,19	0,18	0,10	0,00	0,12	0,18	0,16	0,12	0,00	0,12
Lijn07	11	0,18	0,28	0,26	0,18	0,00	0,18	0,27	0,24	0,18	0,00	0,17	0,24	0,22	0,16	0,00	0,16
Lijn08	22	0,35	0,12	0,11	0,08	0,00	0,08	0,12	0,11	0,08	0,00	0,08	0,11	0,10	0,07	0,00	0,07
Lijn09	22	0,35	0,12	0,11	0,08	0,00	0,08	0,12	0,11	0,08	0,00	0,08	0,11	0,10	0,07	0,00	0,07
Hoek01	22	0,18	0,28	0,26	0,18	0,00	0,18	0,28	0,26	0,18	0,00	0,18	0,27	0,24	0,19	0,00	0,18
Hoek02	22	0,35	0,28	0,26	0,18	0,00	0,18	0,28	0,26	0,18	0,00	0,18	0,27	0,24	0,18	0,00	0,17
Hof01	15,5	0,25	0,14	0,13	0,09	0,00	0,09	0,13	0,12	0,09	0,00	0,09	0,12	0,11	0,08	0,00	0,08
Hof01>	15,5	0,19	0,25	0,23	0,17	0,00	0,16	0,24	0,22	0,16	0,00	0,16	0,22	0,20	0,15	0,00	0,14
Hof02	10	0,16	0,22	0,20	0,14	0,00	0,14	0,21	0,19	0,14	0,00	0,14	0,19	0,18	0,17	0,00	0,14
Hof02>	15,5	0,19	0,25	0,23	0,17	0,00	0,16	0,24	0,20	0,16	0,00	0,15	0,22	0,20	0,15	0,00	0,14
Hof03	10	0,16	0,22	0,20	0,14	0,00	0,14	0,21	0,19	0,14	0,00	0,14	0,19	0,18	0,10	0,00	0,12
Hof03>	10	0,12	0,33	0,30	0,21	0,00	0,21	0,31	0,28	0,20	0,00	0,20	0,28	0,26	0,10	0,00	0,16
Hof04	10	0,24	0,26	0,24	0,17	0,00	0,17	0,25	0,23	0,16	0,00	0,16	0,23	0,21	0,15	0,00	0,15
Hof05	15,5	0,37	0,19	0,18	0,13	0,00	0,13	0,18	0,17	0,12	0,00	0,12	0,17	0,15	0,11	0,00	0,11
average			0,20	0,19	0,13	0,00	0,13	0,20	0,18	0,13	0,00	0,12	0,08	0.17	0,12	0,00	0,12

Fig. 299 *$\Delta Cp(z)$ for 4 flow along directions in 23 allotment types (> second measurement perpendicular)*

Hof01, Hof02 and Hof03 have two main directions of front-back façades. So, ΔCp had to be measured two times. Hoek01, Hoek04, Hof04 and Hof05 have two directions with the same characteristics perpendicular. So, the same measurement can be used the reverse (90^o is 0^o, 60^o is 30^o and so on) for the perpendicular part. Averaging the impact of both directions proportional to the number of dwellings you get numbers for corner and courtyard allotments caomparable with point and line alotments.

Then we have to take other windstatistics than Northerly into account. The quarter we calculated is only very exceptionally equal to a quarter of all ventilation losses as well. This is for instance the case if that quarter (0^o to 90^o from y-axis) coincides with wind directions West to North. For every other North indicating arrow the calcuated quarter will contribute more or less then 25% of the ventilation loss, dependent from the wind statistics exposed. This contribution is calculated for 12 North indicating arrows and completed into a 100% virtual total loss. The supposition that a dwelling surrounded by repeating allotments is equally sheltered into the other quarters is better justified then in previous paragraphs.

2.6.2 Impact of trees

Fig. 300 shows the result of this calculation on the average of Fig. 299 itemized for airtight high rise allotments and low rise ones supposed to be non airtight.

	without green					with green 6m height					with green 10m height				
main direction	0	30	60	90	virt.	0	30	60	90	virt.	0	30	60	90	virt.
average															
low rise	162	249	599	507	**5162**	161	247	594	506	**5130**	158	244	585	505	**5075**
high rise	90	136	343	414	**3343**	90	136	343	414	**3343**	90	136	343	414	**3347**

Fig. 300 *Ventilation loss as a consequence of standard Northerly wind.*

The impact of 6m high (young) trees is negigible. However, when for instance after 10 years trees reach a height of 10m there is some impact. However, locally the impact may be substantial (page 130).

2.6.3 Comparing repeated allotments 100x100m

Fig. 301 and Fig. 302 show some allotment types in seqeunce of virtual ventilation losses.

	loss	height	density	distance
	kWh/won	m	dwell./ha	m
Lijn05	4789	10	64	15
Punt01&02	4795	10	48	15
Punt06	4817	10	48	17
Punt08	4901	15	72	18
Hof01	4906	15	96	40
Punt05	4980	10	36	23
Punt03	4982	10	48	23
Lijn06	5008	15	64	40
Lijn01&02	5025	10	48	23
Punt07	5068	10	64	35
Hof02	5086	14	64	40
Hof03	5130	10	48	40
Lijn07	5187	11	64	40

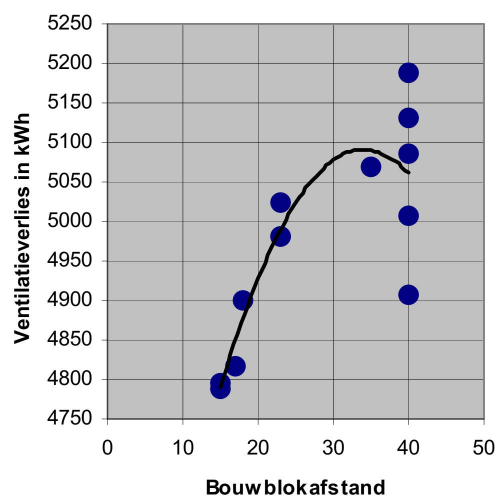


Fig. 301 *Allotment types in sequence of loss*

Fig. 302 *Relation loss and block distance in m*

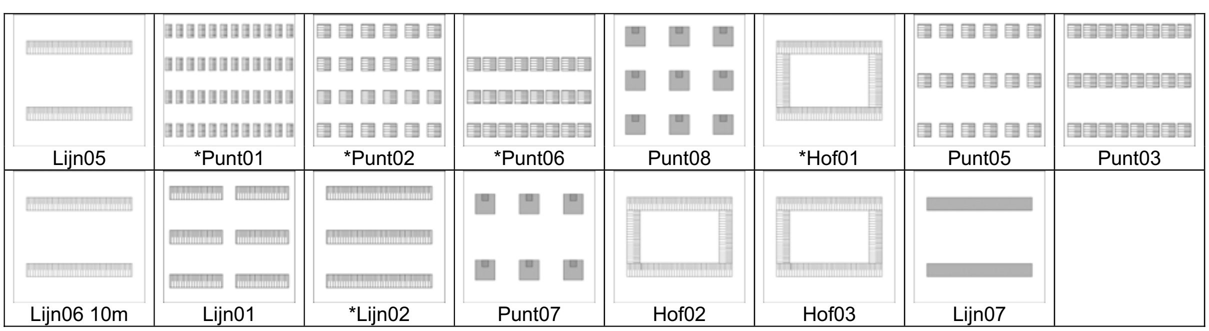


Fig. 303 *Allotment types in sequence of highest to lowest loss*

Remarcably there is nearly no relation with dwelling density. Lijn05 and Lijn07 of equal dwelling density (64 dwellings in the hectare concerned) and nearly the same height (10 and 11m respectively) have lowest and highest loss. However, frontal density F/O (vertical surface F per horizontal surface

O) is determining (see Fig. 299) reasonably related with distance between building blocks (drawn as polynome regression in Fig. 302), but diverging at higher distances.

Fig. 304 and Fig. 305 show the results for point and line allotments on any orientation.

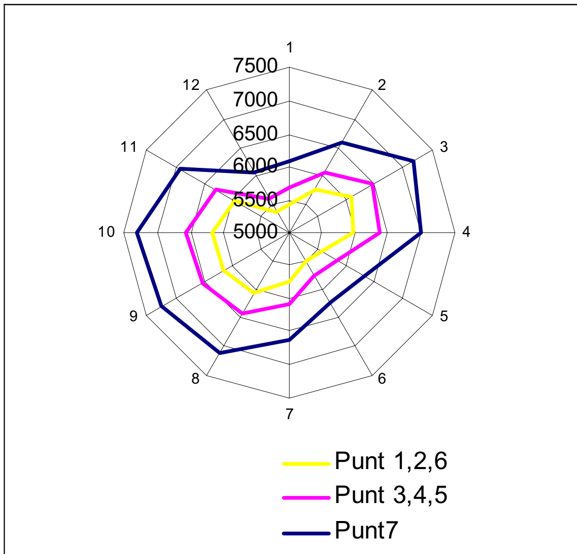


Fig. 304 *Ventilation loss of point allotments*

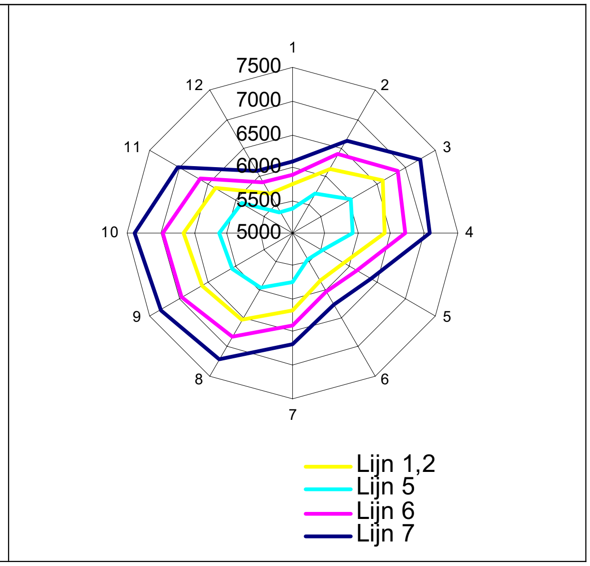


Fig. 305 *Ventilation loss of line allotments*

Biggest loss is reached when you orientate façades of point and line allotments 7 due West. Smallest loss is reached by line allotments 5 or point allotments 1,2 and 6 orientated on North North West (330^{o}). The virtual difference is more then 1000kWh/dwelling.

Fig. 306 shows courtyard allotments. Orientation sensitivity levels out most in hof04 and hof05 because perpendicular blocks have equal length. Higher blocks like hof01 and hof05 (15.5m high) lose less then lower ones like hof03 and hof04 (10m).

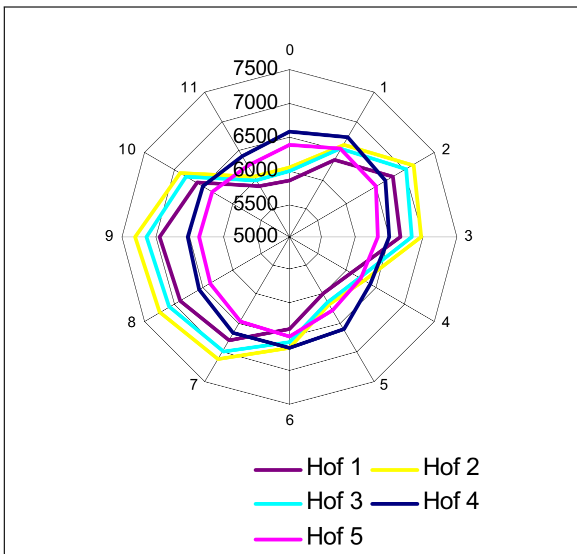


Fig. 306 *Ventilation loss of courtyard allotments*

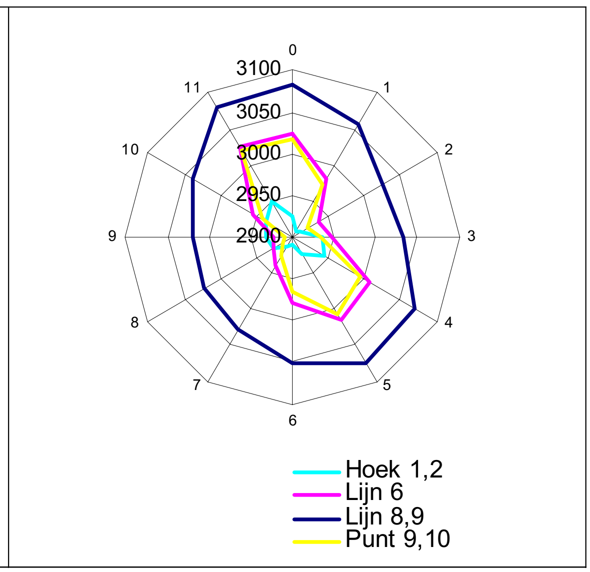


Fig. 307 *Ventilation loss of high rise allotments*

Fig. 307 shows losses of airtight high rise allotments on a much smaller scale. Total variation is less then 100kWh. Inhabitant's behaviour causes maxima where low rise non airtight allotments showed minima.

2.6.4 Wind behaviour around high objects

Wind behaviour on smallest scale is decribed more in detail by Voorden (1990). From that publication we derive some conclusions only. The accidental physical context and size or form of the objects cause unpredictable turbulences. Without windtunnel experiments calculations do not produce much general conclusions. However, scale models of free standing sharp edged buildings higher then 15m above the environment in a frontal flow of wind in the wind tunnel show some regularity in causing whirls windward and leeward recognisable on real scale (Fig. 308).

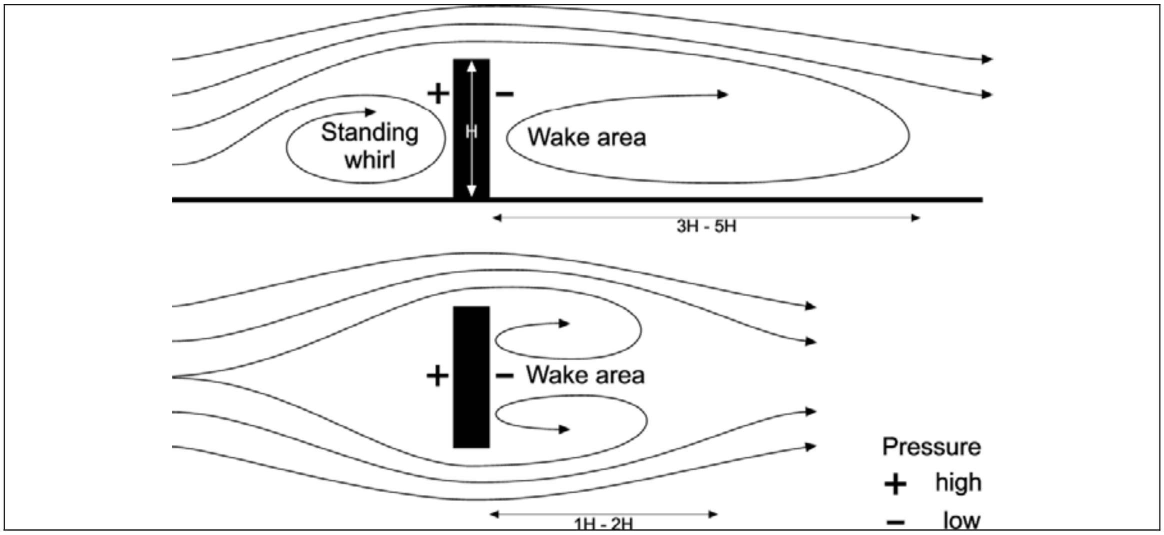


Fig. 308 *Whirls around a free standing building*

Windward and leeward a standing whirl arises causing unexpected wind directions on ground level. Walking or cycling along windward of the building, but especially through the wake area (zog-gebied) leeward you can experience sudden and diametral changes in wind direction. Protecting yourself with an umbrella against the wind from your left side you suddenly get wind from the right side. Fig. 308 (below) shows the same impact horizontally. The density of lines indicates wind velocity. At ground level near the edges of the building (no entrances there!) and 1H to 2H leeward, that velocity could be as high as at the top of the building. The whirls leeward are caused by low pressure on that side; the wind ‘comes back’ to fill the gap caused by high velocities at the edge pulling calm air with them. Openings in the building at ground level may avoid whirls there, but yield new wind velocities at ground level like Fig. 308 (below) now not considered as a plan but as a cross section.

Permeable walls like applied at the entrance of the Faculty of Architecture in Delft or dense shrubs avoid pressure differences causing whirls. They can slow down wind velocity at ground level and protect windy areas, supposed they can resist high wind velocities themselves. Networks of small wind turbines utilise local wind velocity, but they still have to be designed.

2.6.5 References to allotment of hectares

Visser, G. T. (1987) Beoordeling van de mogelijkheden voor theoretische modellering op wijkniveau aan de hand van oriënterende windtunnelmetingen MT-TNO.

Visser, G. T. (1987) Modelontwikkeling voor de berekening van ventilatieverliezen in wijken bestaande uit identieke bouwgroepverkavelingen MT-TNO.

Voorden (1990) Windhinder, stedenbouwfysica gc49 (Delft) Faculteit Bouwkunde.

2.7 Sound and noise

2.7.1 Music

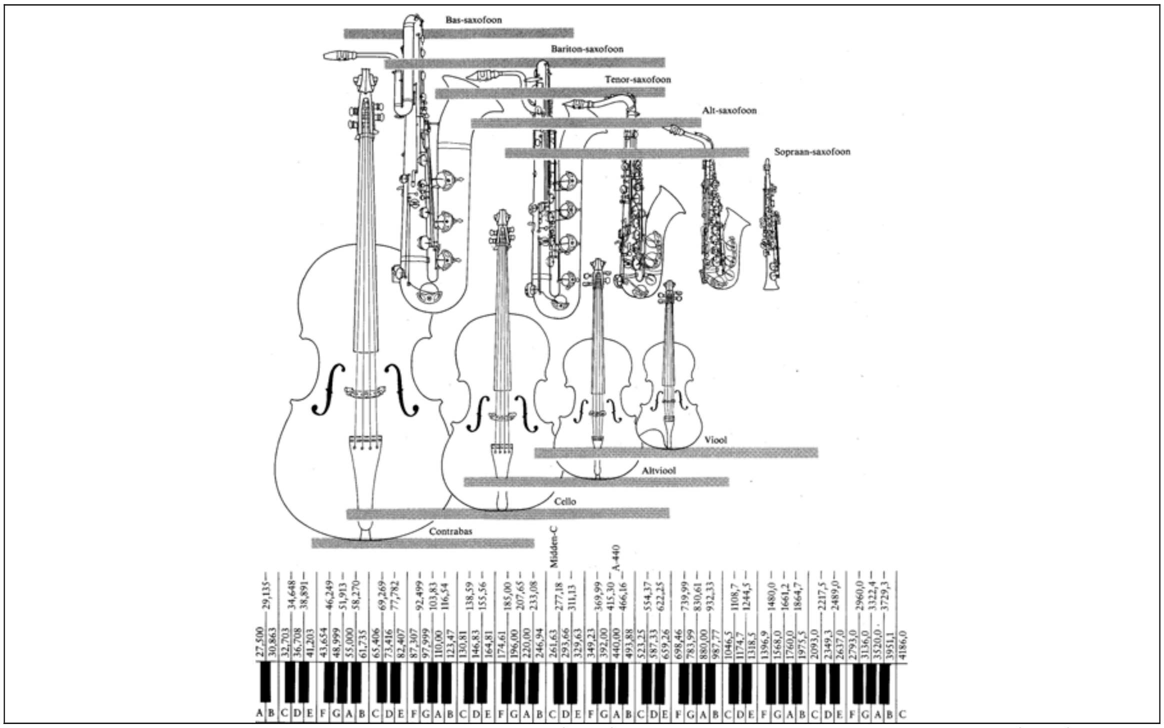
Movement of air is measured as wind when it is moving into one direction longer than 5 seconds (2.2.1). When it is flowing back in the next 5 seconds it is not even counted in wind statistics. But if the wind is blowing at average into one direction more then an hour we count it as wind and we calculate the ‘hour average wind velocity’ we used in chapters above. Wind is caused by slowly increasing temperature differences on the Earth’s surface causing differences in air pressure. Sometimes these differences are leveled out by wind in an hour, sometimes in weeks and seldom the air is flowing back into the area it came from. If the air transported in a minute would flow back in the next minute and the reverse like water on a beach we would call it vibration. It would have a vibration time T of 60sec with a frequency f of 1/60 = 0.017 vibrations per second or 0.017Hz (hertz).

Vibrations in the air from 16 vibrations per second (vibration time 0.063 sec) to 20 000 are accepted by our eardrums as sound. Vibrations slower then 16Hz are called infrasonic, faster then 20 000 ultrasonic. You can not hear infrasonic vibrations in the air until 16Hz, but you sometimes can feel them in your lungs Minnaert (1975). The frequences used in music are nearly competely covered by the 88 keys of piano. It counts more then 7 octaves (Fig. 309) starting with 27.5Hz (the most left key A_1) and ending with 4186Hz (the most right key c_5, part of the 8^{th} octave, not fully covered).

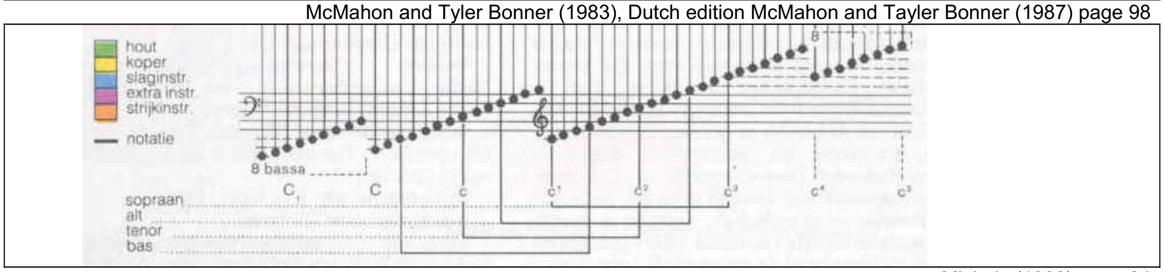
code	A_1	A	a	a_1	a_2	a_3	a_4	a_5	
frequency f	27.5	55	110	220	440	880	1760	3520	Hz
wave length λ	12.364	6.182	3.091	1.545	0.773	0.386	0.193	0.097	metres
$f \times \lambda$	340	340	340	340	340	340	340	340	m/sec

Fig. 309 *Starting notes of octaves on the piano*

Any next octave doubles the frequency. An octave is subdivided in 12 notes (named a, ais or bes, b, c, cis or des, d, dis or es, e, f, fis or ges, g, gis). Because $2^{1/12}$ = 1.0594630944, the frequency of any next key is a factor 1.0594630944 higher then the previous one. So you can calculate the frequency of any note (n=0…87) by $f(n)=27.5 \times 1.0594630944^n$ (Fig. 310).



McMahon and Tyler Bonner (1983), Dutch edition McMahon and Tayler Bonner (1987) page 98



Michels (1993) page 24

Fig. 310 *The span of music*

The travel speed of sound c in air is in normal conditions 340m/sec (in steel 5064m/sec). And speed is the number of vibrations per second f times their length λ: c=f x λ (Fig. 309). So, the wave length λ of audible sound in air (λ = c / f) varies between 340/20 000 = 21.25m and 340/16 = 0.017m.

Take a drawing tube of L = 0.65m closed at one side (width does not matter), drum on it and you hear primarily a sound of 130Hz, which is musical note c with wave length 4 x 0.65 = 2.60m. But it is mixed with a specific range of overtones (Fig. 311).

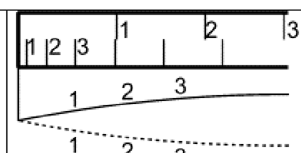
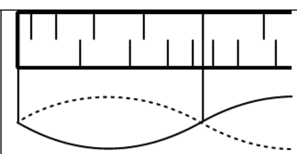
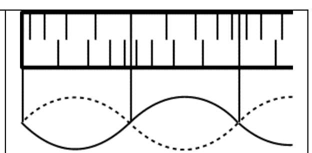
			
	λ_0=4L/1=2.60m	λ_1=4L/3=0.867	λ_2=4L/5=0.52
	f_0=340/λ_0=131Hz	f_1=340/λ_1=392Hz	f_2=340/λ_2=654Hz
	'c'	'g$_1$'	'cis$_2$'

Fig. 311 *Tones produced by a tube of 0.65m closed at one side.*

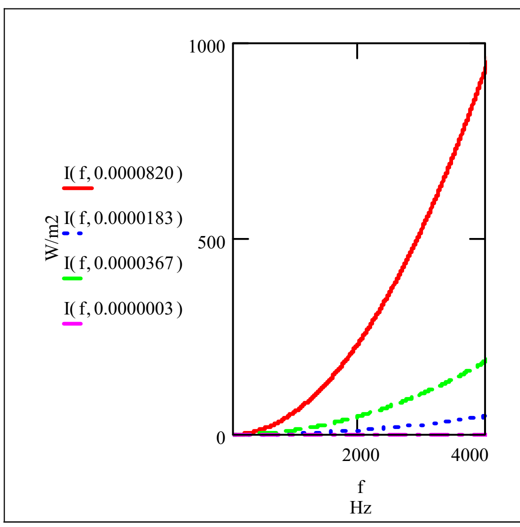
The lines drawn in the tube represent the position of particles in extreme phases as if there were only some of them. The distance between the extreme phases (1-1, 2-2, 3-3 …) are different, represented in the sinuses below. The closed left side of the tube forces a 'node' (line elongated into the sinus) where particles stand still as centres of condensing and thinning, the open side an 'antinode', where they move most, enjoying the freedom of the end of the tube. So, possible wavelengths are restricted to λ = 4/1, 4/3, 4/5 … x L and frequences to a proportion of 1:3:5…. In tubes open (antinodes) or closed (nodes) at both sides they are restricted to λ = 2/1, 2/2, 2/3 … x L, supposed you do not force local antinodes by openings (like a flute does). The frequences appear in a proportion of 1:2:3…, just like strings fixed at two sides do. A voice with less then 9 overtones sounds dim, a voice with more then 14 overtones sounds shrill.

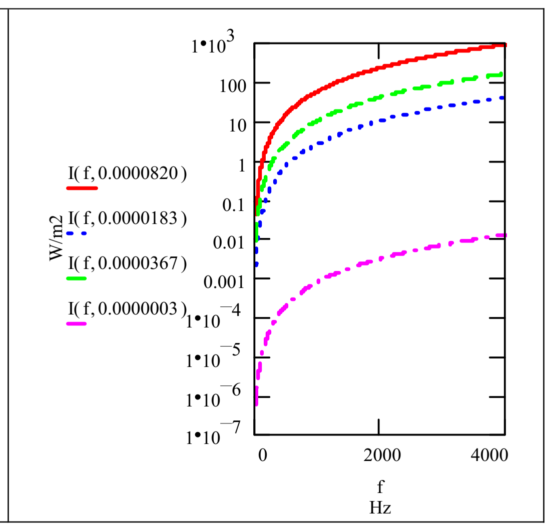
The primary frequency of a string f_s depends on length L, tension σ and density ρ (1 290g/m3) according to $f_s = L/2 \sqrt{\sigma/\rho}$. A string with given density and tension tuned by the right force will give a lowest tone with wavelength 2 x L. Touching the string softly (flageolet, causing a node there without losing the lowest tone) half way you will hear a tone with wavelength L (one octave higher) as well. Touching at one third you will hear a tone with wave length 2/3 x L as well, a combination called fifth (kwint, 2:3). Dividing further you get fourths (kwart, 3:4), tierces (terts, 4:5) and so on.

2.7.2 Power or intensity

Air particles between nodes move very fast around their quiet position like a sinus shown in Fig. 311 causing change in air density. Concentration causes increase of temperature and heat loss. However the particles move fast enough to prevent substantial energy loss by heat exchange (keeping the process reversible, adiabatic). The maximum divergence of particles is called amplitude A. The power of a sound wave (called intensity ‘I’ and expressed in W/m^2) depends on that amplitude, but also on frequency f, air density (normally $1.290 kg/m^3$), and travel speed (normally 340m/sec) according to $I = \rho \times (2 \times \pi \times f \times A)^2 \times c/2$. So, in normal ρ and c conditions power depends on amplitude A and frequency f according to $I = 8658 \times (f \times A)^2$.

A speaking voice produces 10^{-5} W. A globe with a radius of 28cm has a surface of $1m^2$. So, at 28cm distance that voice has a power of 10^{-5} W/m^2. It is composed by adding $8658*(f \times A)^2$ for every frequency and its accompanying amplitude in the voice. But suppose it produces tone c only, without overtones (in reality produced by electronic device only), then frequency is 131Hz, and amplitude A should be 0.0000003m. A piano produces maximally $0.2W/m^2$ and if it would be produced by tone c only the amplitude should be 0.0000367m. For an exended symphony orchestra and a loudspeaker the figures would be 5W/m2 (A=0.0000183m) and $100W/m^2$ (A=0.00082m).
Fig. 313 shows the dependency of intensity I on these particular amplitudes and on musical frequencies from 27.5 to 4000Hz).





- Fig. 312 *Intensity (frequency, amplitude)*
- Fig. 313 *Represented logaritmically*

The logarithmical representation (Fig. 313) shows the range from soft to loud better. Dividing the intensity by a standard of 10^{-12} W/m2 (comparing it with that standard) we get positive logarithms from 0 to 14 only, starting with what is just audible. Multipying it by 10 we get a useful range of decibells (dB) from 0 to 150 (Fig. 314).

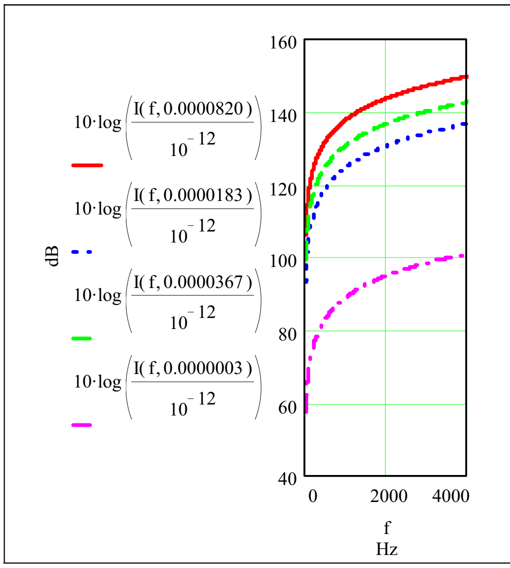


Fig. 314 *Changing intensity into decibells*

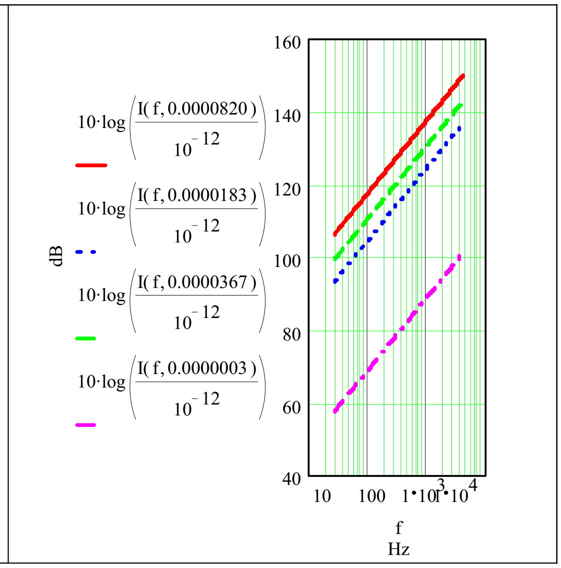
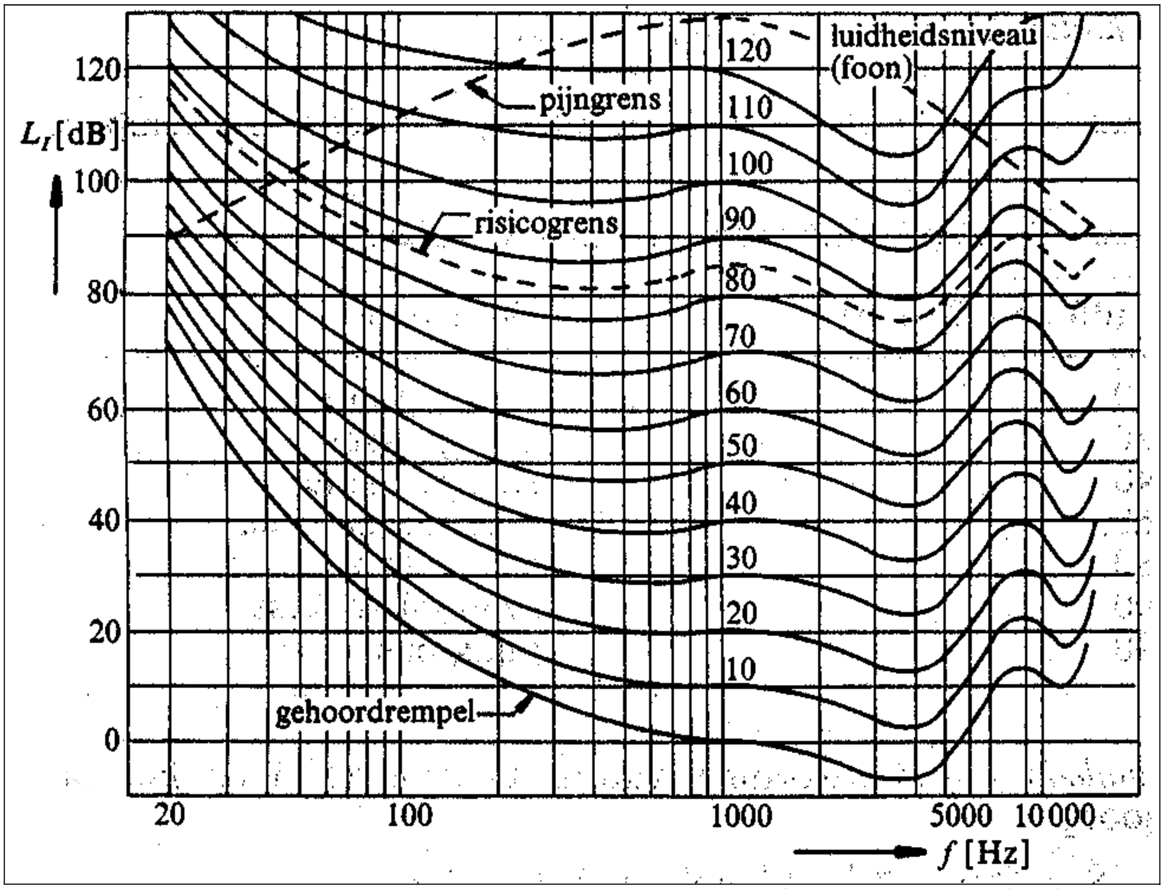


Fig. 315 *Represented logaritmically*

Changing the frequency axis in a logaritmical scale (Fig. 315) we get beautiful straight lines of growing deciBells by increasing frequencies for every amplitude. Fig. 316 is the same graph with the boundary of what we think to hear.



Creemers, Atteveld et al. (1983) page 186

Fig. 316 *Pain boundary (above) and impression of sound.*

At 1000Hz our impression of sound could be approximated by deciBells. However, on both sides of this centre we hear less from the actual pressure of lower and higher tones on our eardrums. That can be dangerous. Lines of equal sound impression more or less parallel to the boundary below connect the same levels of sound impression (loudness) expressed in 'foons' in the same range of deciBells at 10^3Hz. An often used rough correction is the audible deciBell dB(A) (Fig. 317).

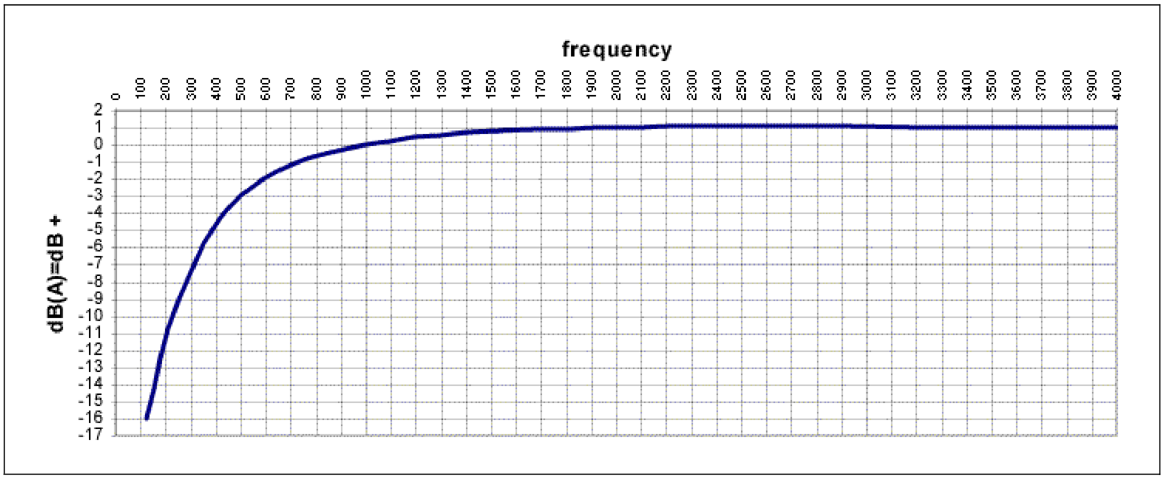


Fig. 317 Corrections on deciBells to get audible dB(A).

2.7.3 Sound and noise

The combined tones of an instrument make a sound. When we complete the sinuses into λ = 4 x 0.65m and add the overtones of Fig. 311 with supposed smaller amplitudes neglecting the higher overtones we get a representation of the sound of the tube (Fig. 318).

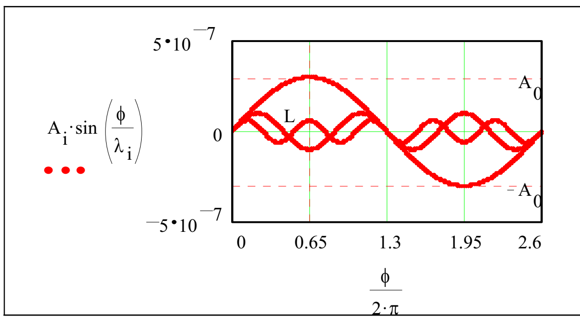


Fig. 318 *Combined complete sinuses of Fig. 311*

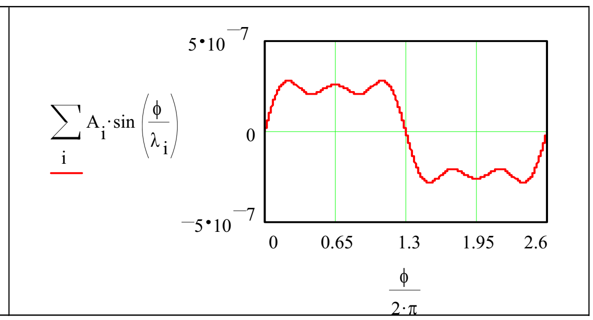
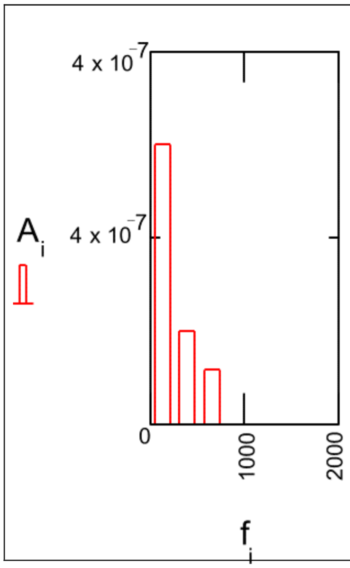
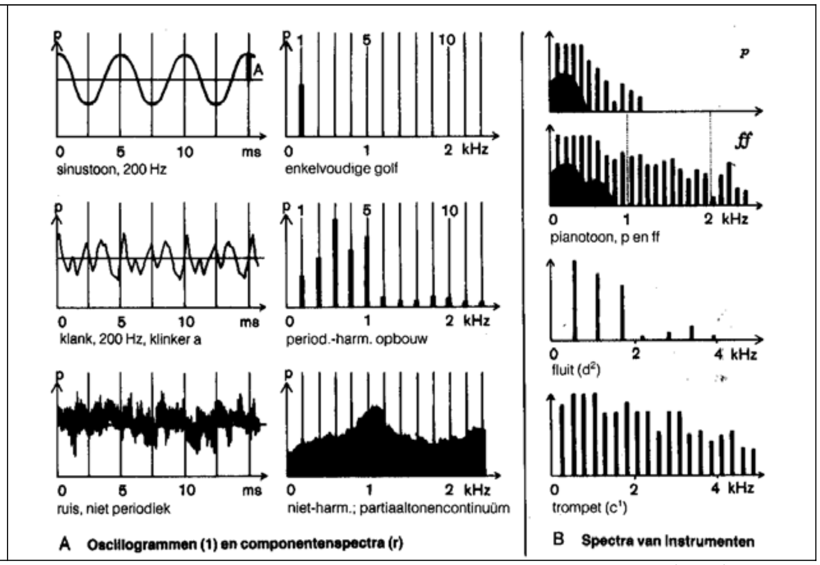


Fig. 319 *Fig. 318 added*

However, especially string instruments have to improve the contact with the air by surfaces vibrating with the string to get a louder sound. These constructions resonate with the own velocities, amplitudes and frequencies of their material and form adding new wave lengths producing the typical sound of the instrument. The amplitudes per frequency are called the spectrum of the instrument (Fig. 320 and Fig. 321).





Michels (1993) page 16

Fig. 320 *Supposed amplitudes of the tube from Fig. 311*

Fig. 321 *Spectra of other instruments*

There are harmonious spectra with natural proportions of frequencies and chaotic spectra called noise. When you are able to recognise the composing sinuses by Fourier analysis or measurement you can calculate the power of a spectrum summing all intensities per amplitude by integration to predict power. But there are deciBell meters to do it afterwards.

2.7.4 Traffic noise

There are many sources of noise in town. Traffic and aviation are the most important ones. Traffic is a linear and fluctuating source. You can predict the average intensity in dB(A) from 7 o'clock during 12 hours day or night according to Volksgezondheid Volksgezondheid en Milieuhygiene (1981), SRM1, see *Fig. 322*. Backgrounds are discussed in Nijs (1995) . Download Jong, T.M. de (2003) *TrafficNoise.xls* from www.bk.tudelft.nl/urbanism/team publications 2003, say 'yes' to the macro's, fill in the yellow parts and try.

	speed	quantity	emission	
	km/h	*mv/h*	*dB(A)*	
light motor vehicles	50	300	69,48	
middle heavy motor vehicles	50	50	72,90	
heavy motor vehicles	50	50	77,70	
motorcycles	50	100	75,21	
Total		500	**80,81**	+
% truck traffic	10 %			
road surface	fine	rough	clinker (selected)	
Road surface correction			**3,63**	+
distance to crossing	100 *m*			
Crossing correction			**0,80**	+
%reflection other side of road	75 %			
Reflection correction			**1,13**	+
distance to source	10 m			
Distance reduction			**10,00**	-
Air muffling reduction			**0,20**	-
height of observer	1,5 m			
height of source	0 m			
%soft ground to road axis	0 %			
Ground reduction			**0,00**	-
Meteo reduction			**0,57**	-
Total			**75,59**	*dB(A)*

Jong (2003)

Fig. 322 *Calculating traffic noise*

This calculation is valid only if:

- there are no noise protection screens or buildings;
- there are no slopes;
- the road is more or less straight;
- some other conditions,

otherwise you should use SRM2.

Fig. 323 shows some indications for traffic load you can use in designing stage.

Indication:

radius served urban area			traffic lanes	width	mv/h
30m				3m	30
100m		street	1	10m	100
300m	neighbourhood	street	2	20m	500
1km	district	road	3	30m	1000
3km	town	highway	4	40m	2500
10km	subregional	highway	≥ 4	50m	5000
30km	regional	highway	≥ 4	60m	10000
100km	subnational	highway	≥ 4	70m	25000

Fig. 323 Indications of traffic load

National Law (see www.overheid.nl click Wet- en regelgeving, look for ‘geluidhinder’) demands in new plans for urban area less then 50 dB(A) within 200m from streets with 1 or 2 traffic lanes or within 350m from roads and highways with more then 2 traffic lanes causing that amount of noise. But Burgomaster and Aldermen can request the Provincial Council on the basis of a noise survey to increase the norm to 55 dB(A). In special cases named in the Law it can be increased until 70 dB(A). Comparable norms are given for other souces like industy.
To calculate noise from aeroplanes Kosten units (Ke) are used. They take into account maximum level of noise per movement, number of movements per year and time of the day.

2.7.5 References to Sound and noise

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