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Experiences with small scale wind turbines

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Draft

- Small scale wind turbines – high expectations
- Wind speed measurements - wind rose
- Distribution - Weibull
- Correlation – comparison – rescaling
- Wind mapping of a building – Measurement & Simulation
- Estimation of the production
- Pperformance measurements
- Characteristics measurements
- Battery and electonics
- Evaluation

Deployment at an airport

Before mounting

Sollight 1000

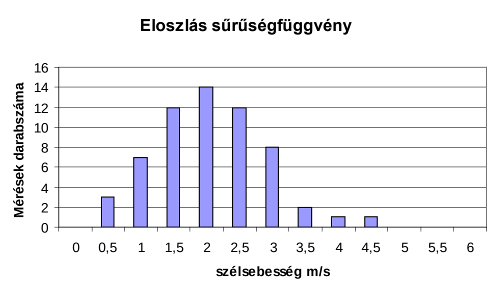
PER 500

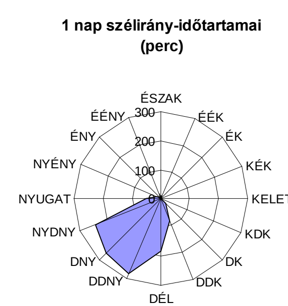
WinPower 600

SAWT 600

Airport

400 W HAWT


Eloszlás sűrűségfüggvény
Mérések darabszáma
0
2
4
6
8
10
12
14
16
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
szélsebesség m/s


1 nap szélirány-időtartamai
(perc)
ÉSZAK
ÉÉK
ÉK
KÉK
KELET
KDK
DK
DDK
DÉL
DDNY
DNY
NYDNY
NYUGAT
NYÉNY
ÉNY
ÉÉNY
0
100
200
300

1 kW VAWT

UNITEK anemometer

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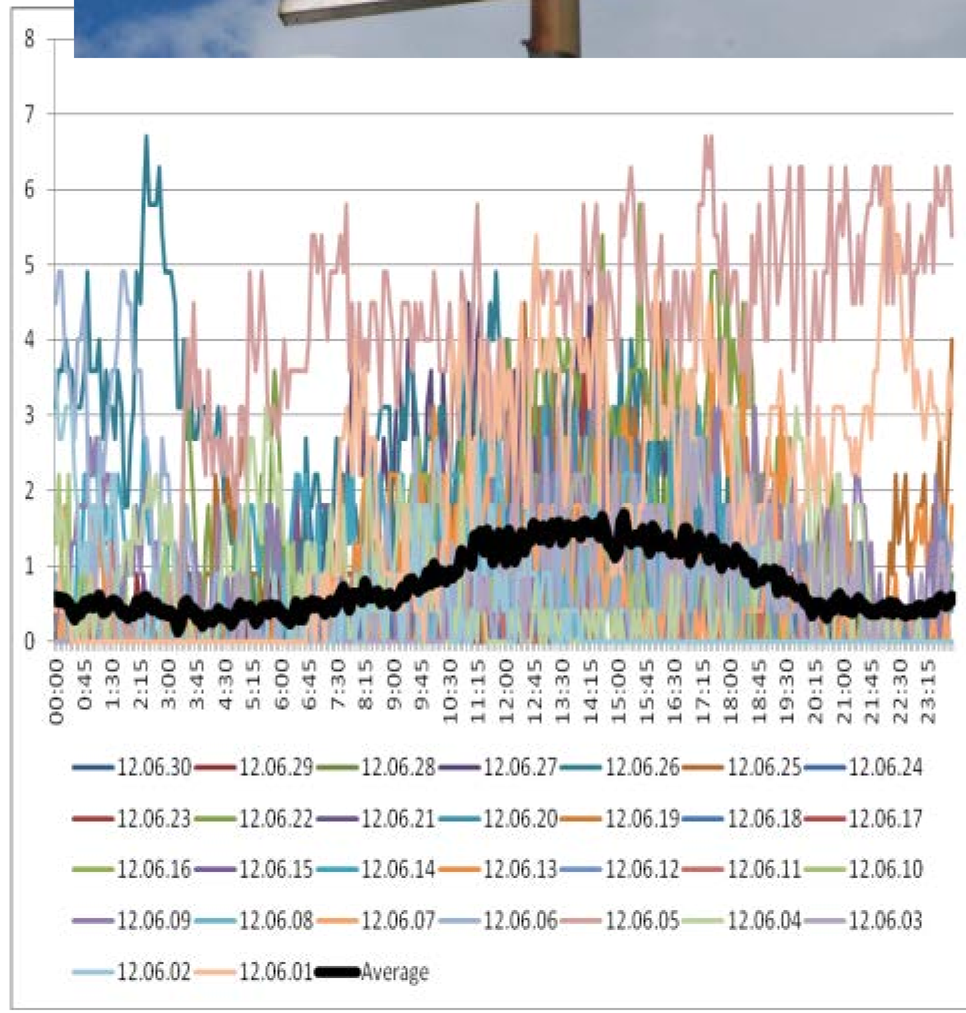
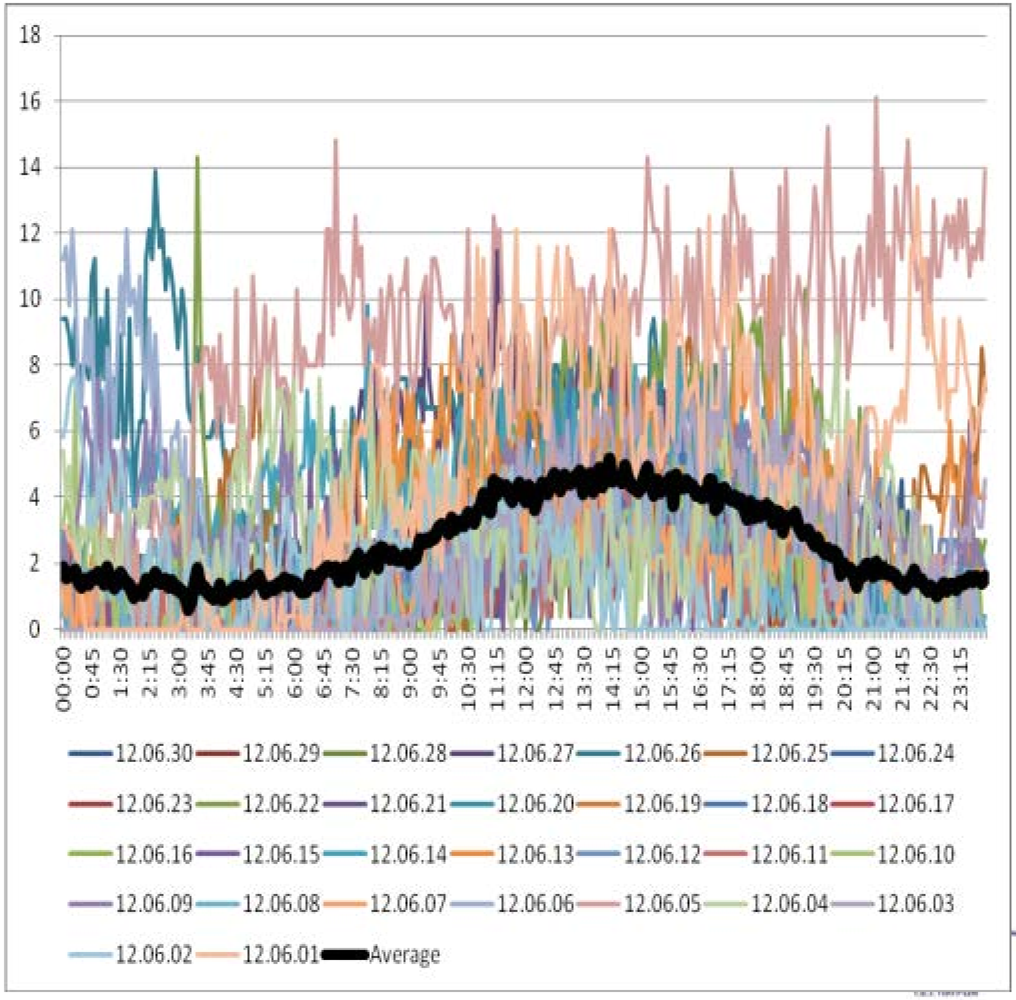
Daily wind run

- Daily average of wind speed in June 2012 by 5 min **average** measurements

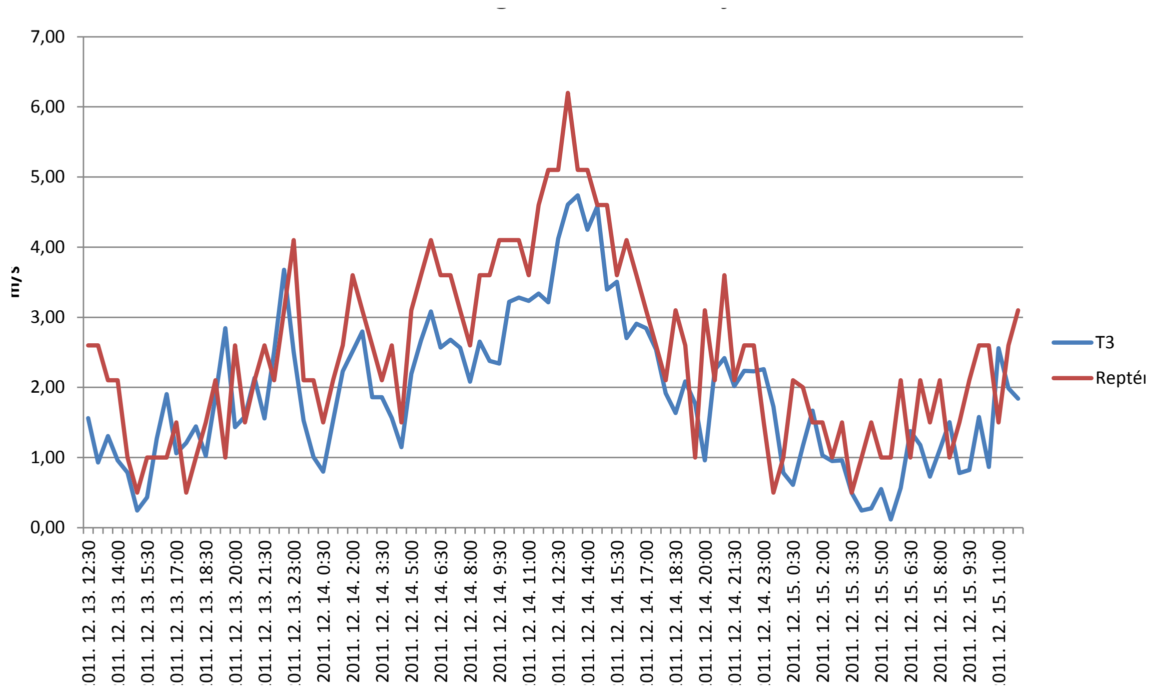


Daily wind run

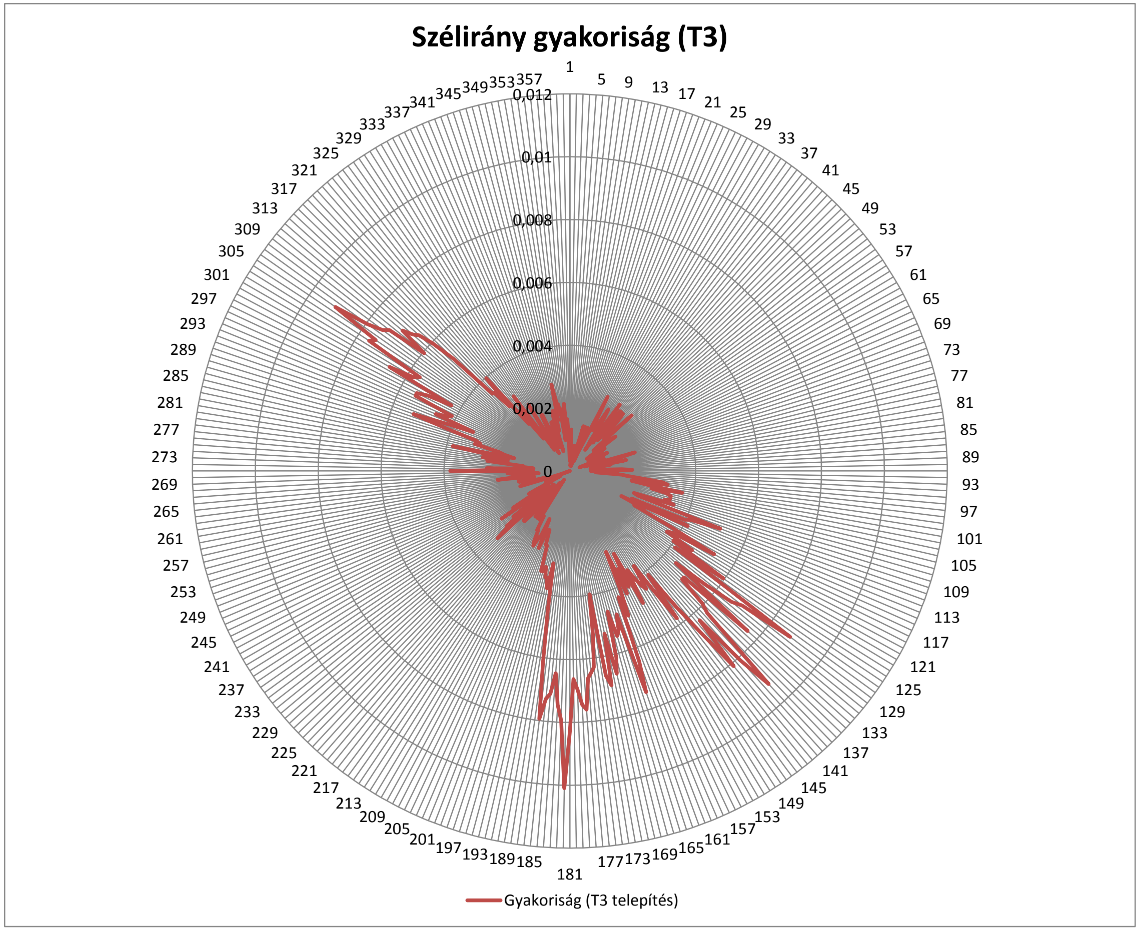
- Daily average of wind speed in June 2012 by 5 min **peak** measurements



Davies’ speed meter – daily run



Wind rose



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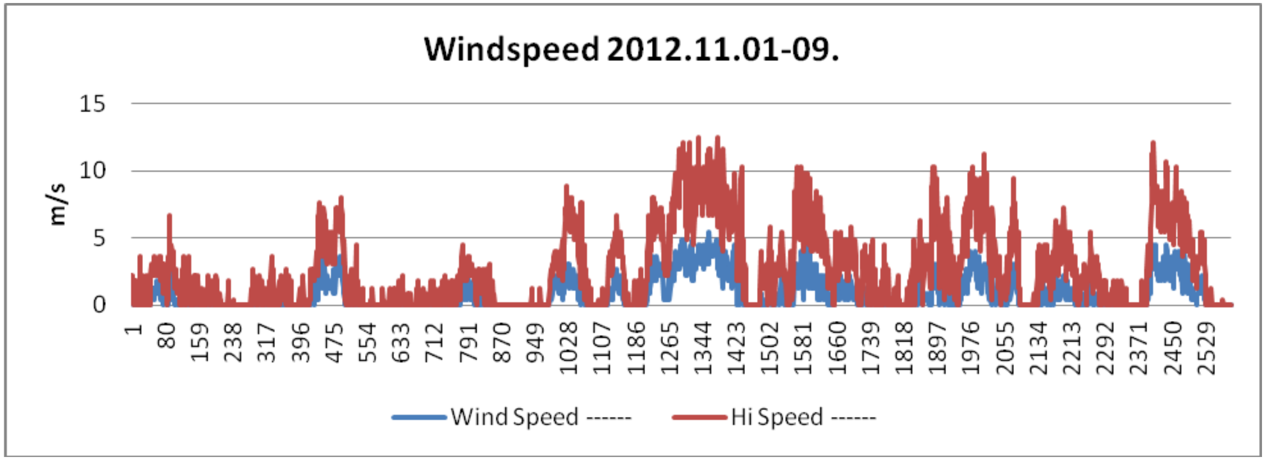
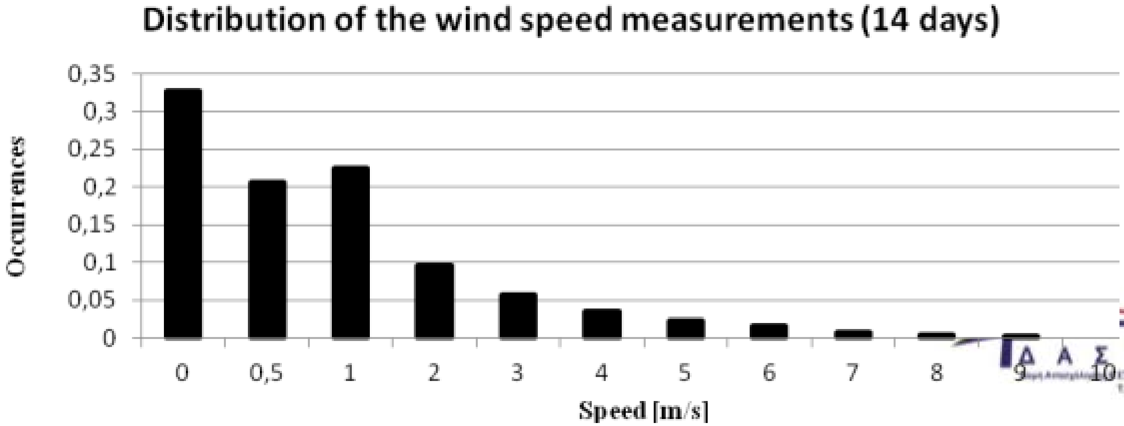
Wind speed measurements and distribution



$$P = 0{,}5\ \rho\ A\ v^3\ \eta$$



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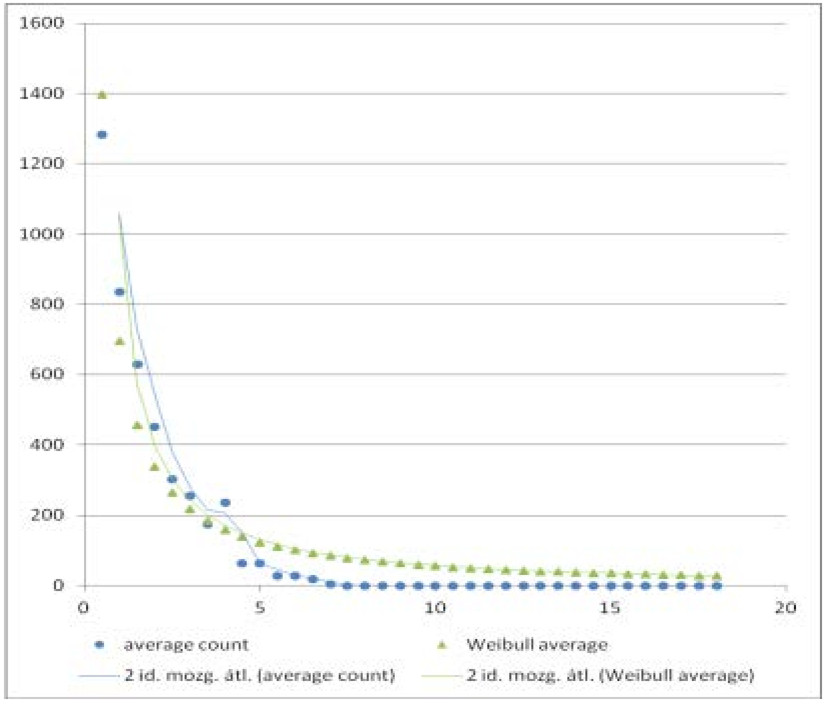
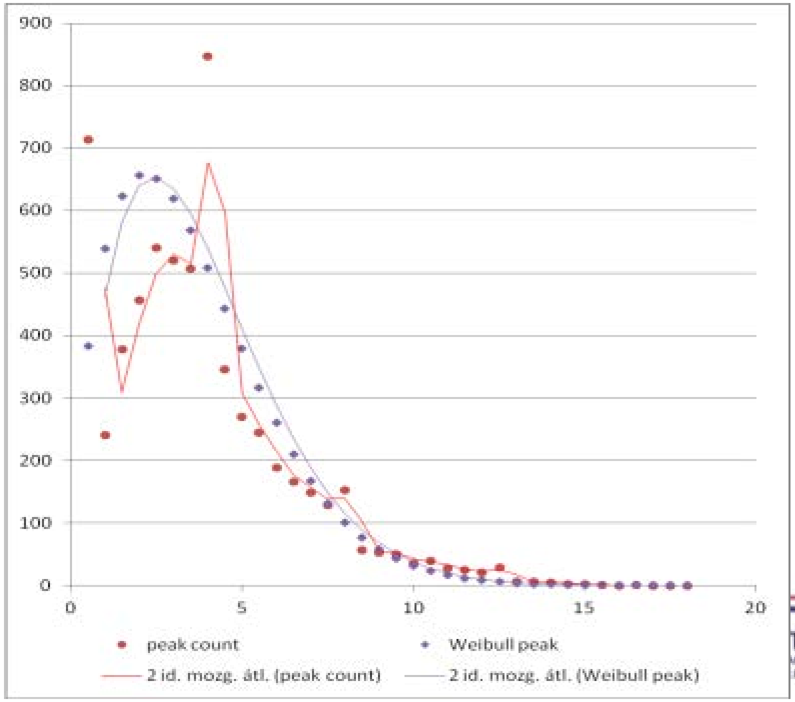
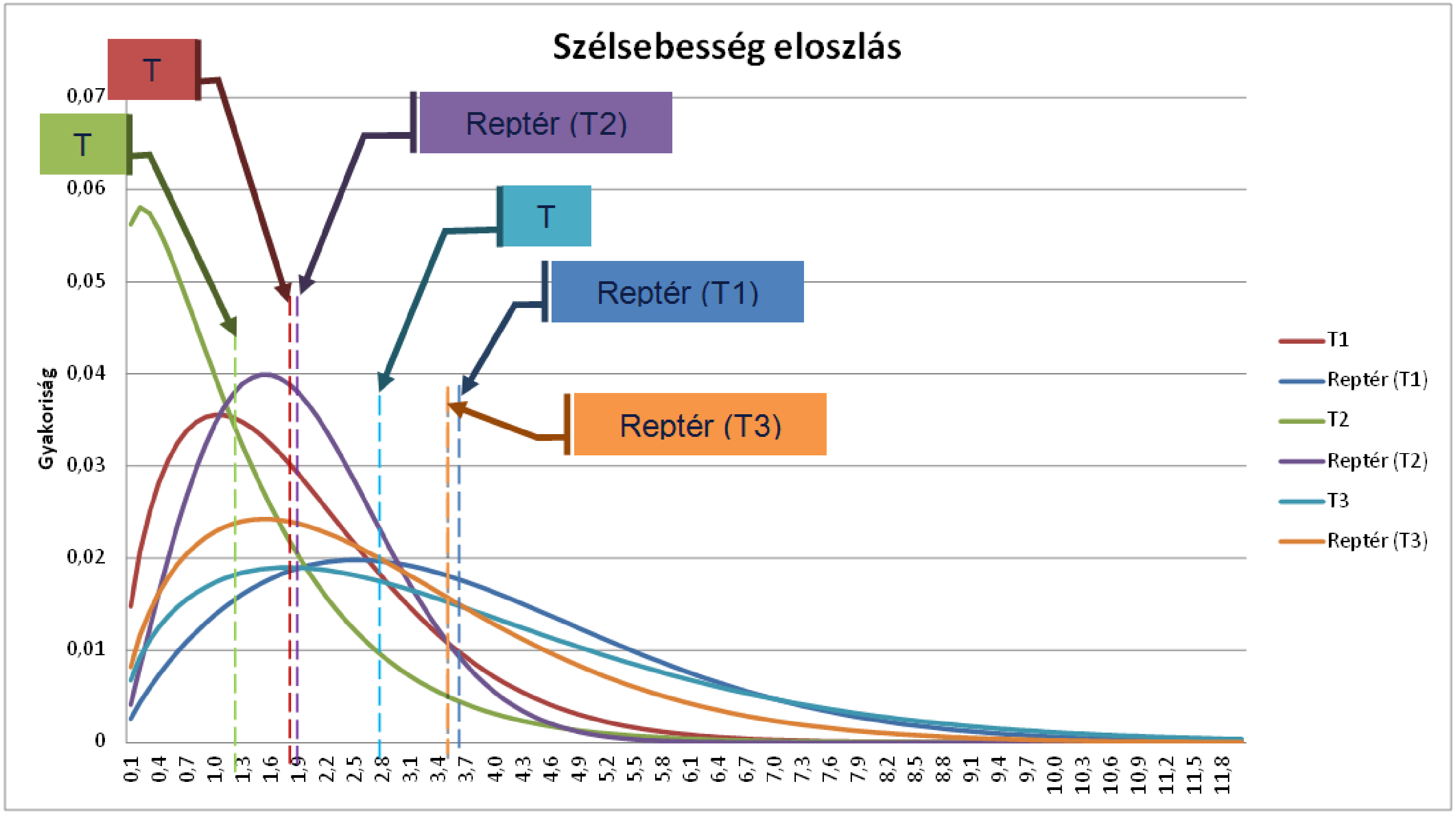
Weibull distribution

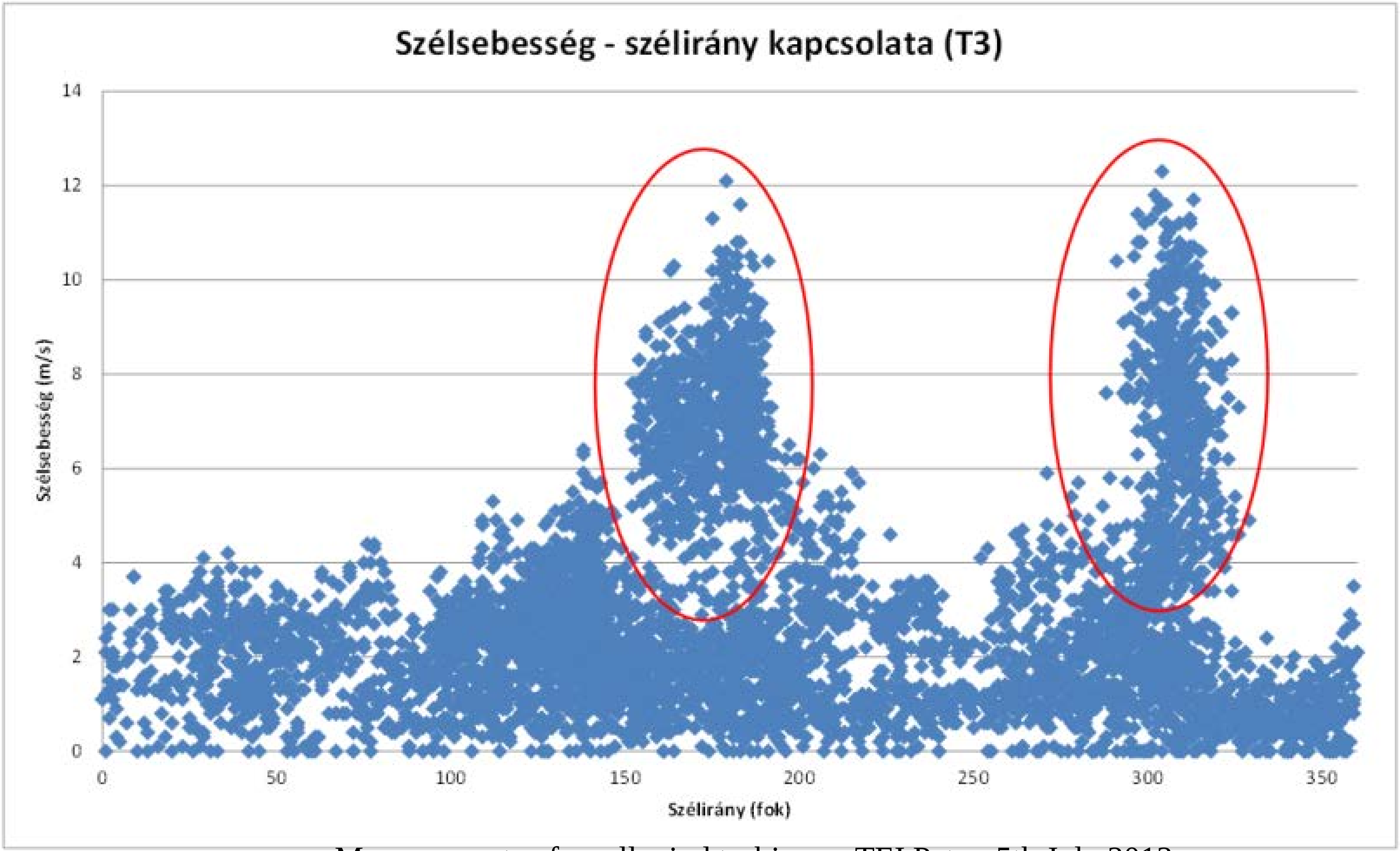
$$f(x;\alpha,\beta)=\begin{cases}\frac{\alpha}{\beta^{\alpha}}x^{\alpha-1}e^{-(x/\beta)^{\alpha}} & x\geq 0\\ 0 & x<0\end{cases}$$






Szélsebesség eloszlás
T
T
Reptér (T2)
T
Reptér (T1)
Reptér (T3)
Gyakoriság
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0,1 0,4 0,7 1,0 1,3 1,6 1,9 2,2 2,5 2,8 3,1 3,4 3,7 4,0 4,3 4,6 4,9 5,2 5,5 5,8 6,1 6,4 6,7 7,0 7,3 7,6 7,9 8,2 8,5 8,8 9,1 9,4 9,7 10,0 10,3 10,6 10,9 11,2 11,5 11,8
T1
Reptér (T1)
T2
Reptér (T2)
T3
Reptér (T3)

Direction and speed



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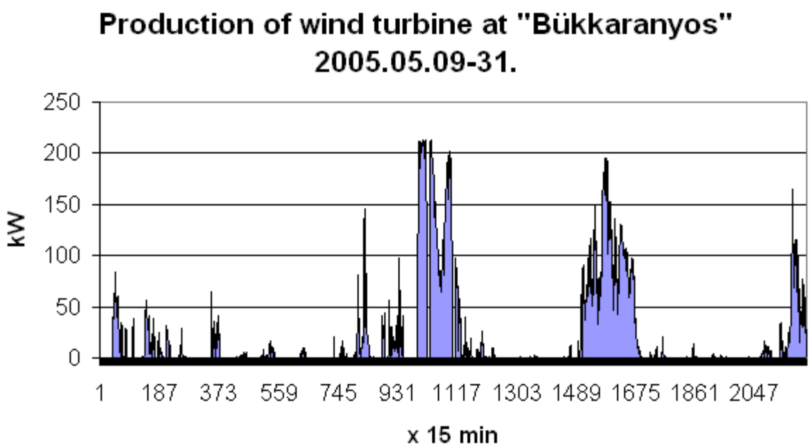
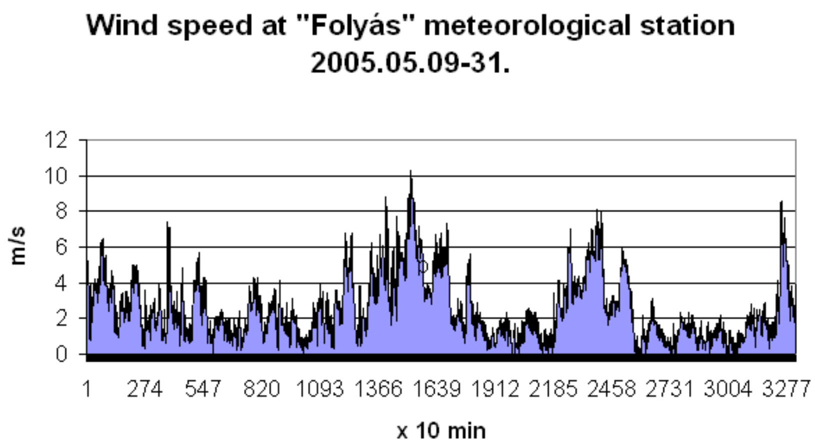
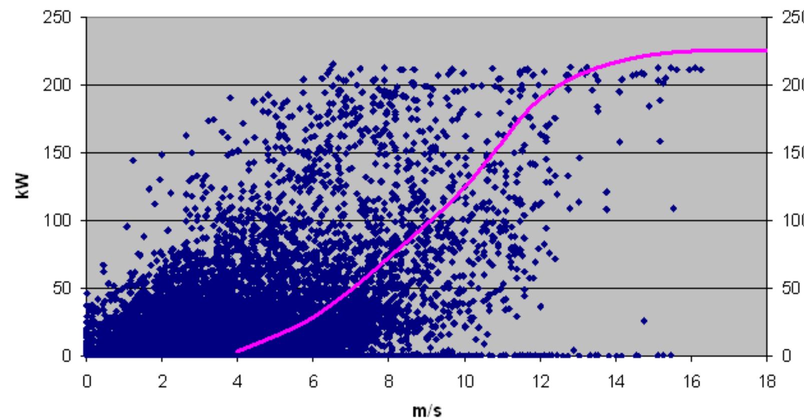
Characteristics based on pure measurements





?



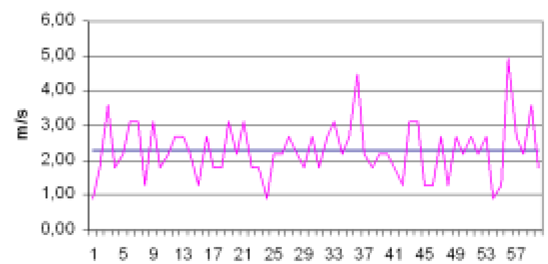
Correlation?

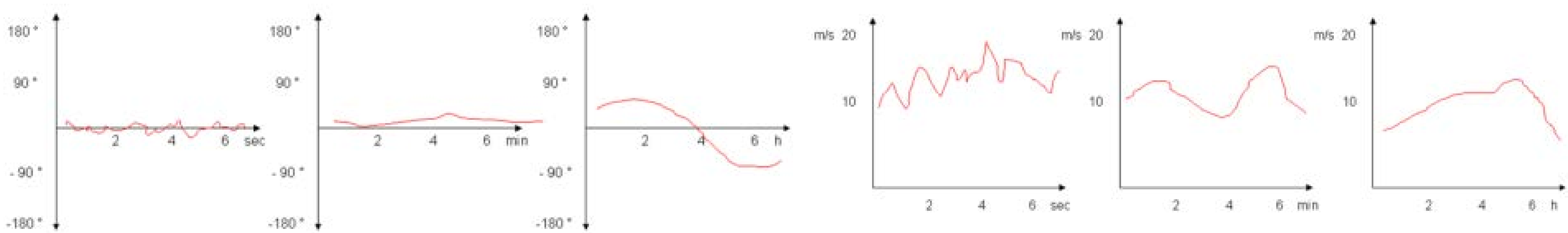
The causes of the lack of correlation are

- The *distance* between the wind turbine and wind measurement
- The local wind turbulences that create difference in the wind blow at the two measurement points.

Other causes: turbulence

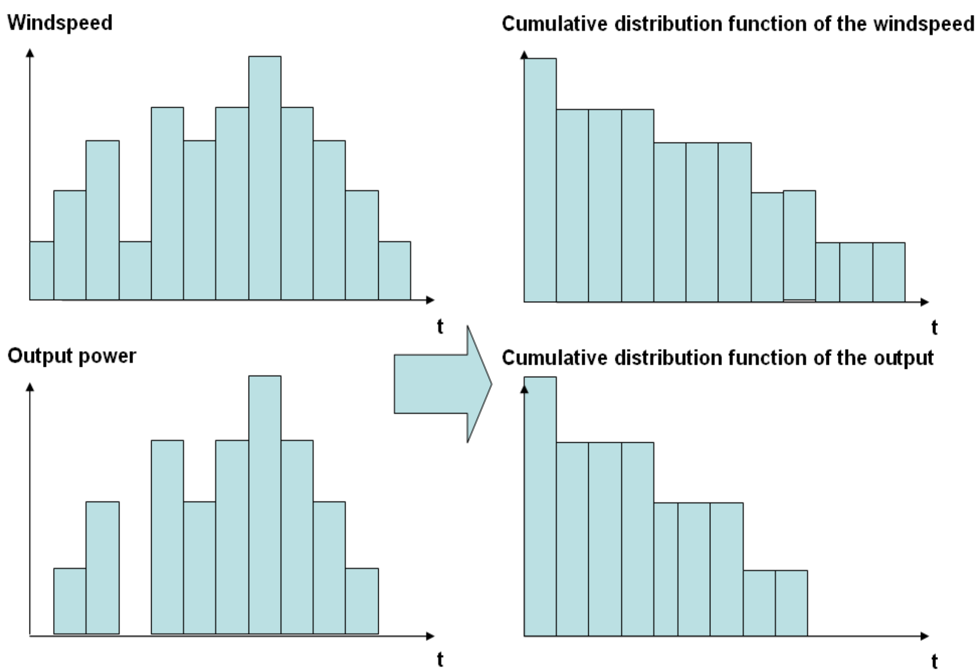
- The local wind turbulences that create difference in the wind blow at the two measurement points.
- fast (1-6 sec), the medium (1-6 min) and the slow (1-6 hour) changes.
- The fast and medium wind speed and direction changes are not handled (followed) by the turbine, it causes *deviances*.
- Turbine dynamics and measurement *errors*, etc.
  - Wind speed changes
  - Wind direction changes
  - Wind speed changes measurement on minute scale

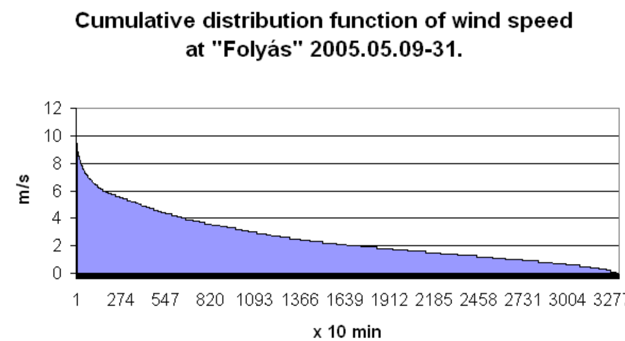


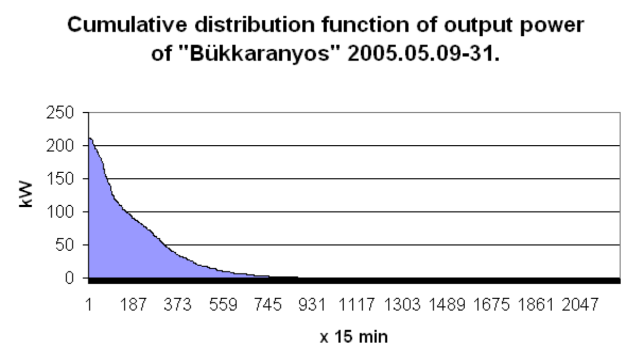


Distributional reorganization: a functional transformation

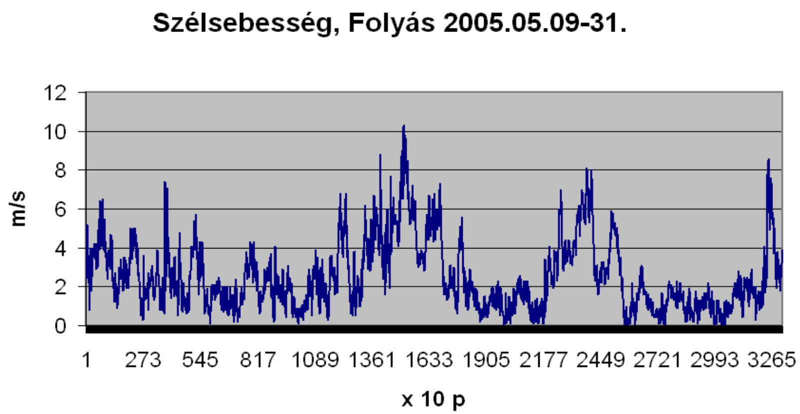
An ideal wind speed and power output measurement at the same tower should give the factory characteristics of the wind turbine, the two measurements correlate on the factory curve. If we prepare the cumulative distribution function of both measurements, the previous correlation is still valid and we get the same curve.

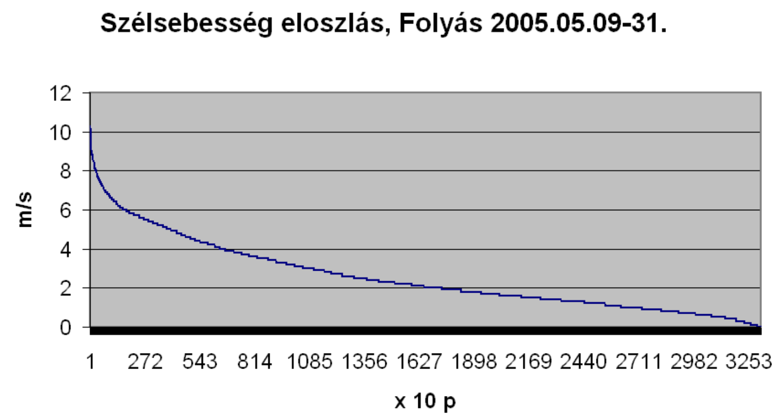


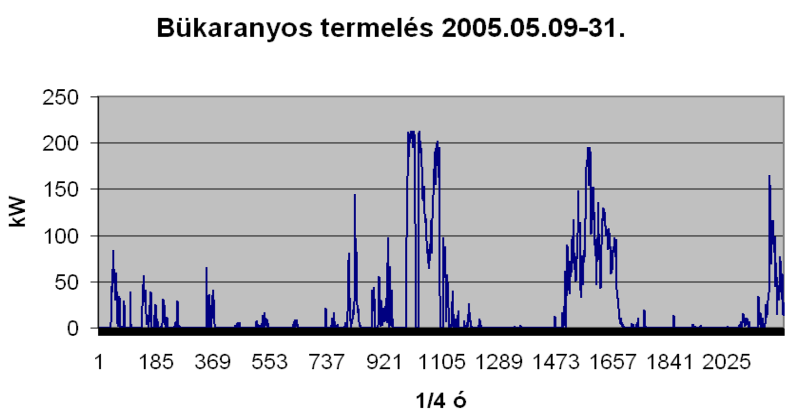


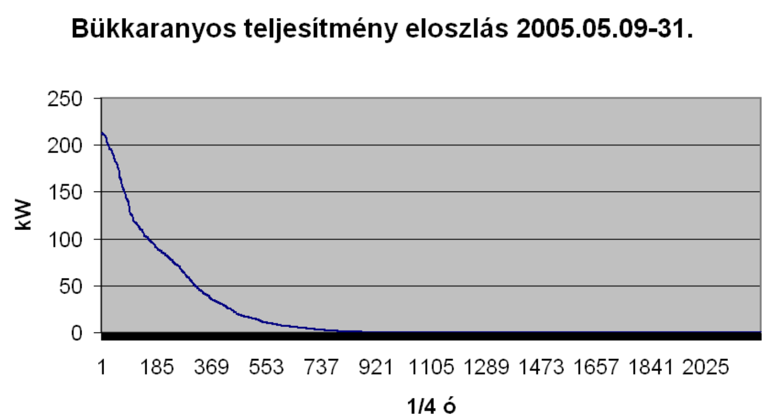


Back to the measurements
(distance of Bükkaranyos – Folyás = 33km)



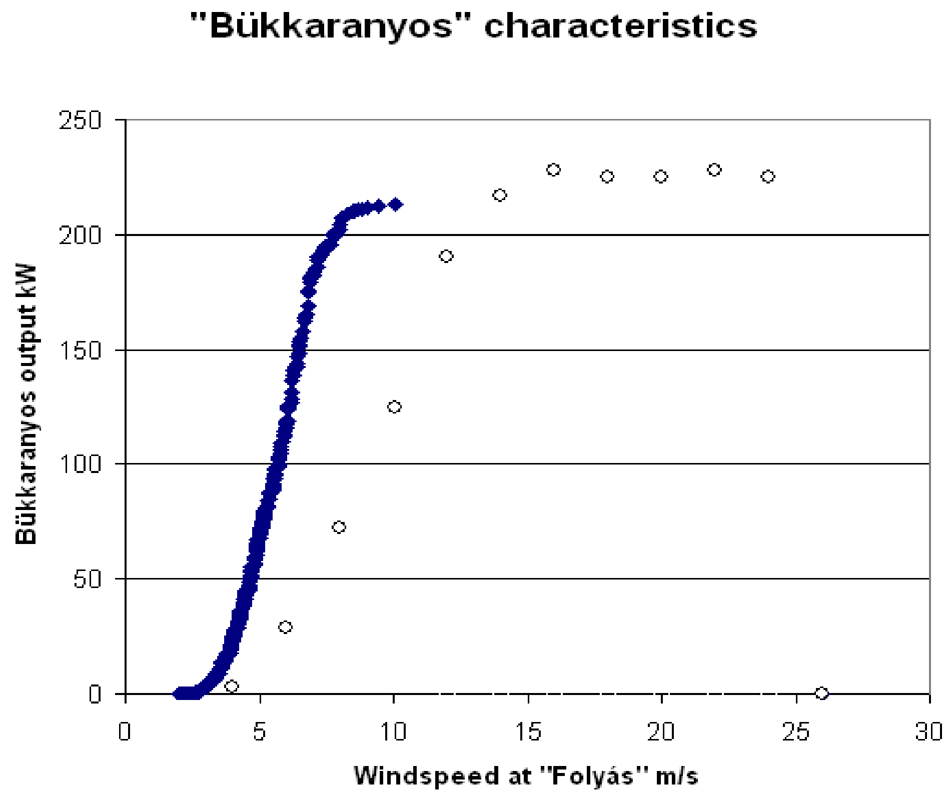






Characteristics matching

Based on the above mentioned, the locally differently running curve is substituted by a globally similarly cumulated distribution function. We investigate not the specific synchronized moments but the same period, so we integrate the power into generated energy. This is an energy based characteristics retrieval. Figure shows characteristics similar to the factory characteristics (marked by dots).



Meaurement distances

Name of wind measurement place	*Distance of the wind turbine "Bükkaranyos"*
Folyás	33 km
Agárd	187 km
Túrkeve	98 km
Mosonmagyaróvár	263 km
Győr	238 km

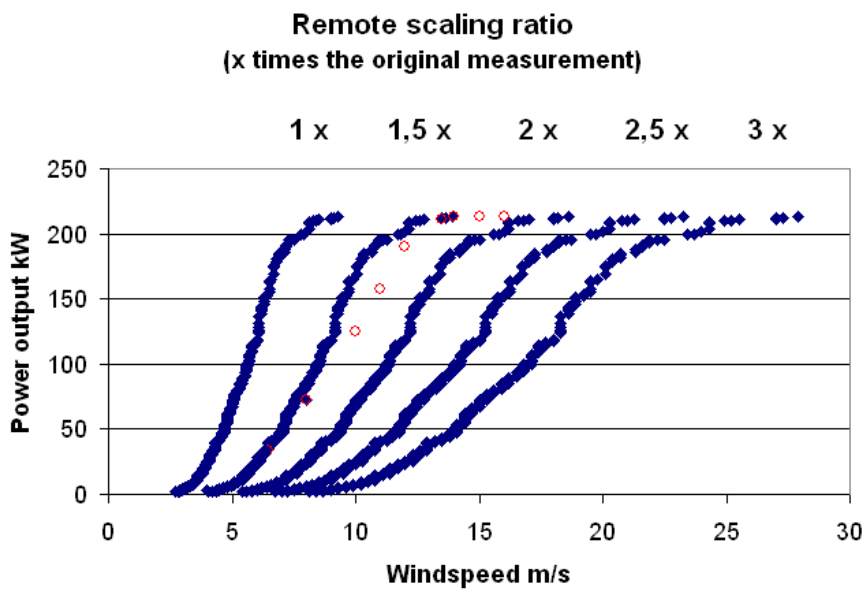
Upscaling

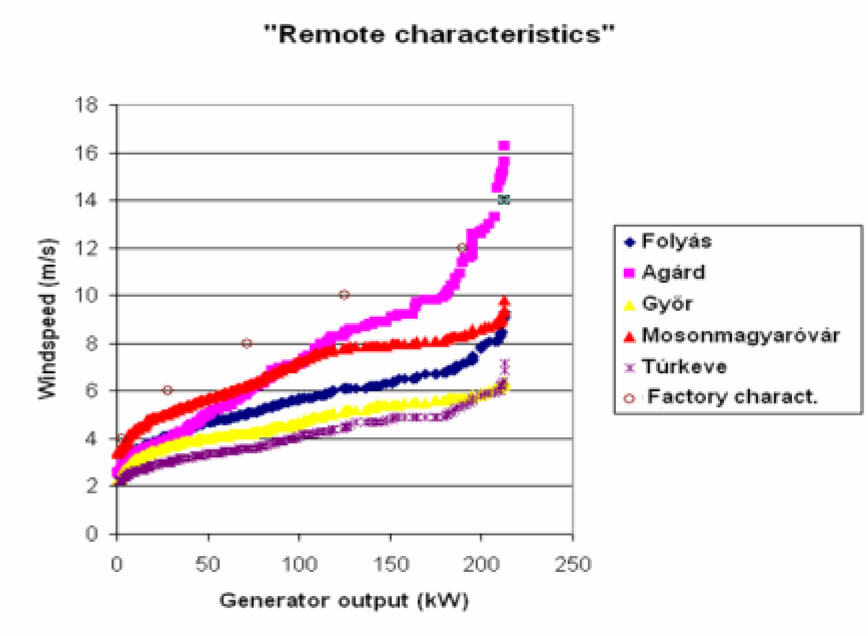
- The previously shown remote upscaling factor is defined by the energy production of a time period. Applying the Hellmann equation (1) for the same tower (height 33 m, measurements height 10 m), the exponent is 0,445, that is a good experimental result.

$$u_z = u_m \left(\frac{z}{z_m} \right)^a \ [\mathrm{m\,s^{-1}}]$$

$$1{,}7 = (33/10)^{0{,}445}$$

Remote scaling





Korreláció mérések

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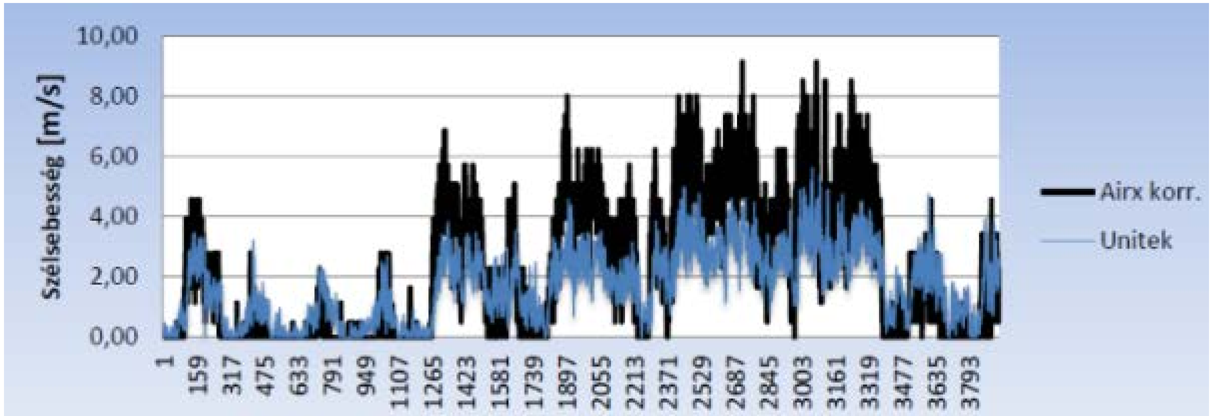
Wind mapping - correlation



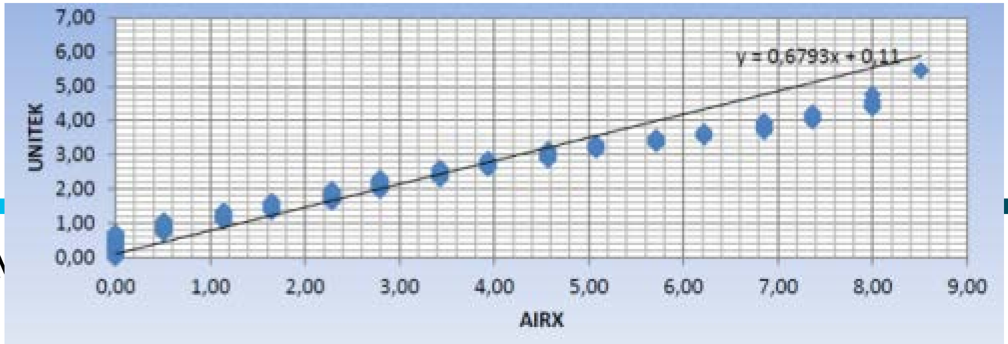
Two meterings

First we calibrated the two meters.

Ratio related to the reference point: 4653 / 5095 =0,91

that is “the wind in point 3. is only 0,76 of the reference speed calculated on base of the average speed.

$$\text{windspeed}_{\text{point 4}} = 0{,}6793 * \text{windspeed}_{\text{refpoint}} + 0{,}11 \text{ [m/s]}$$



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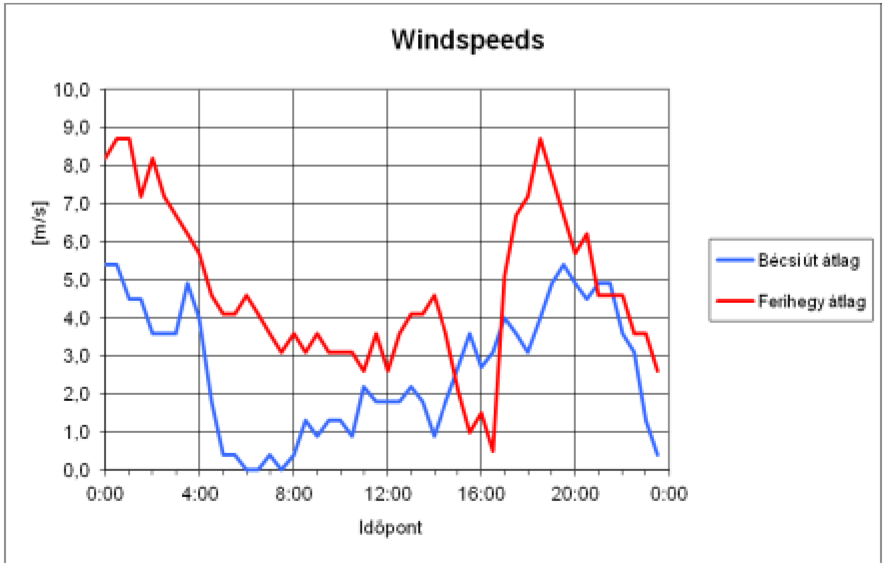
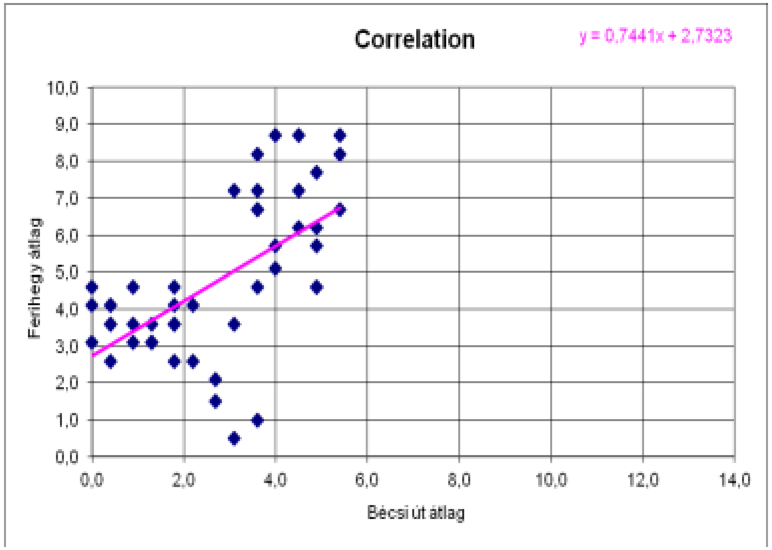
Wind run at both sites

Time function of A and B and the **real-time** correlation

$$v_B = 0{,}7441\, v_A + 2{,}7323$$

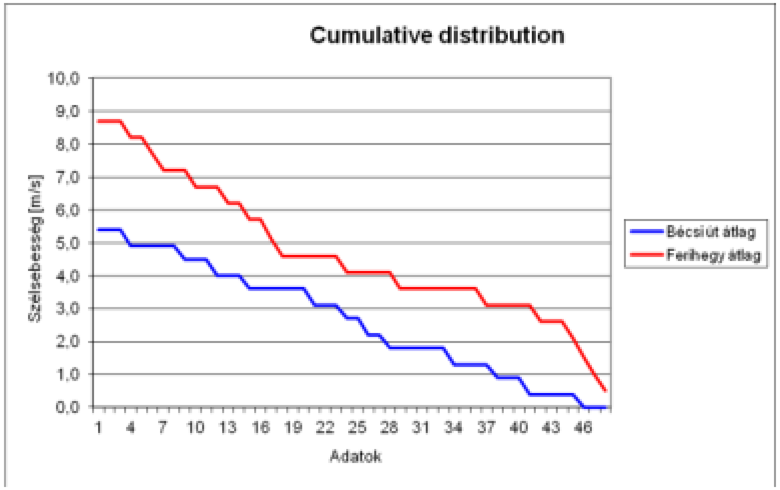


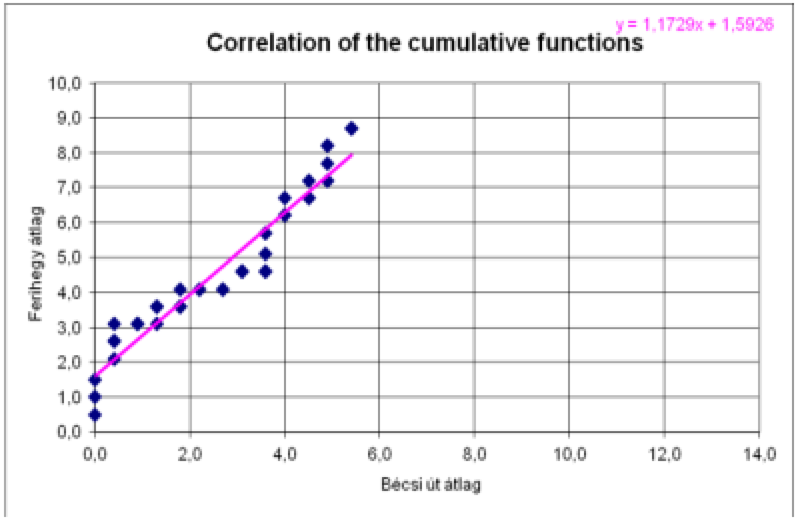


Correlation

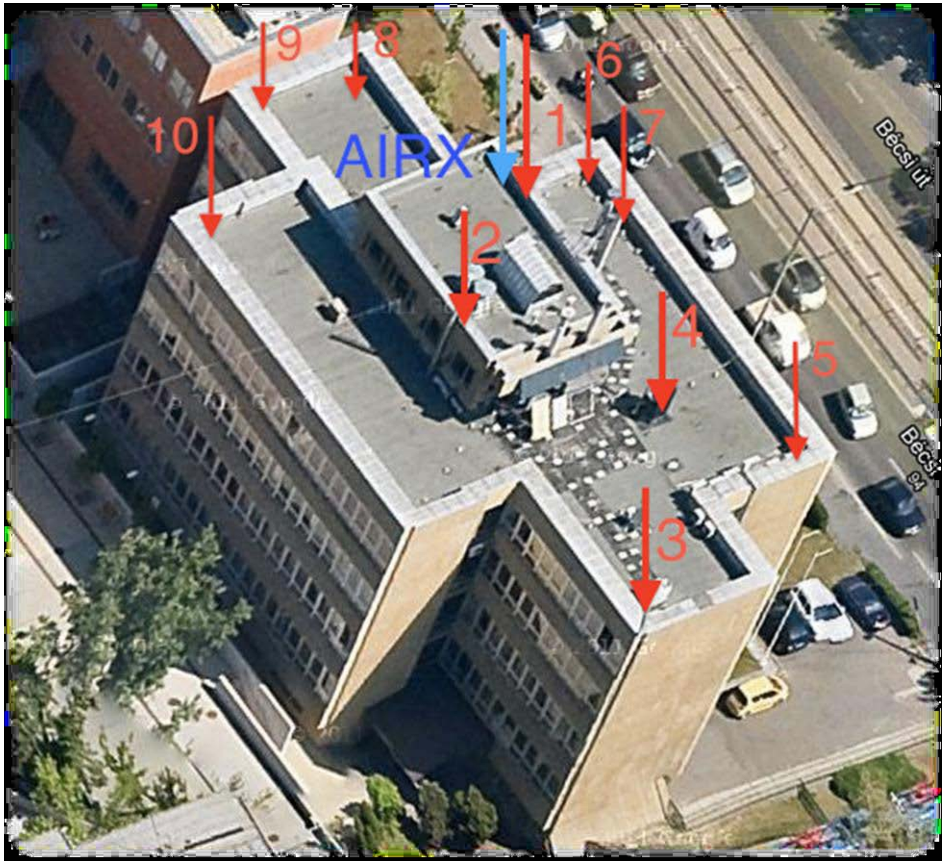
Cumulative distribution function of A and B and the **non real-time** correlation

$$v_B = 1{,}1729\, v_A + 1{,}5926$$



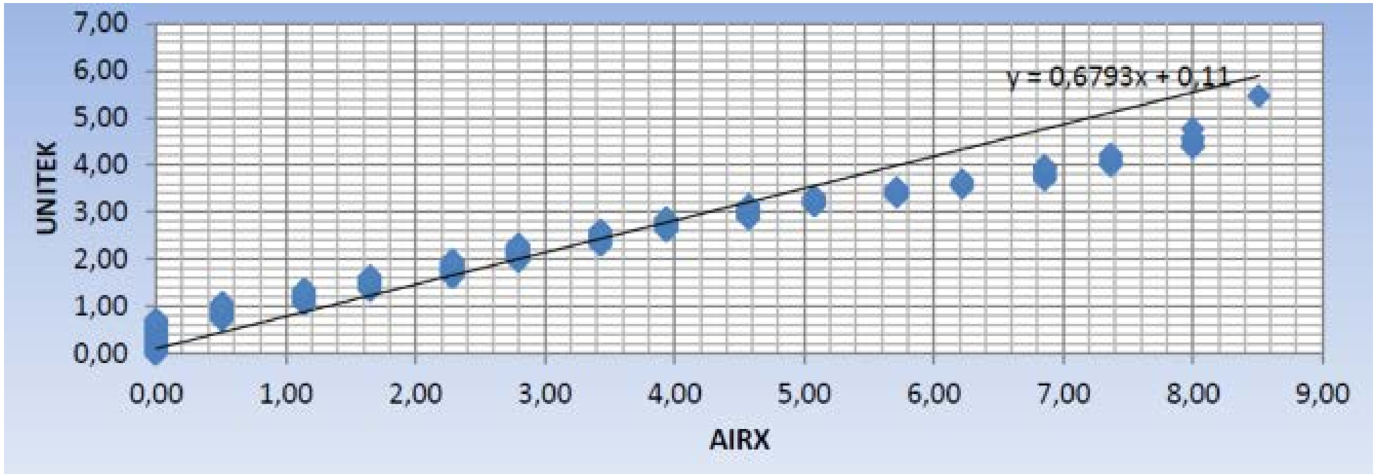


Wind climate mapping

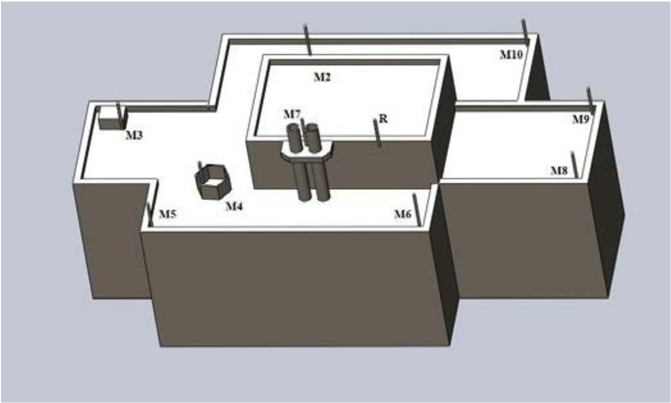


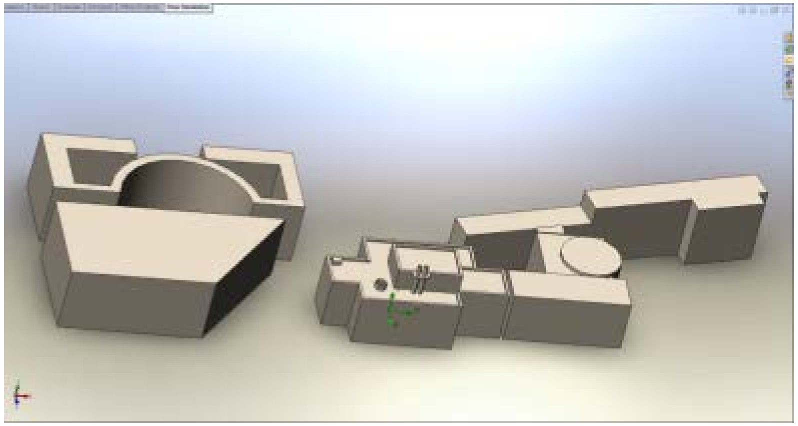
Meas. no.	location	correlation	ratio of averages
1.	Reference point	y = 0,930x - 0,11	1,35
2.	Box-on-roof	y = 0,934x - 0,16	1,11
3.	Water tank	y = 0,796x + 0,53	0,76
4.	PV octogon holder	y = 0,679x +0,11	0,91
5.	SE corner	y = 1,180x - 0,39	1,39
6.	NE corner	y = 1,242x - 0,36	1,56
7.	Chimney	y = 1,749x - 0,89	2,44
8.	N corner	y = 0,832x + 0,048	0,97
9.	NW corner	y = 0,900x - 0,27	1,41
10.	W corner	y = 927x - 0,20	1,21

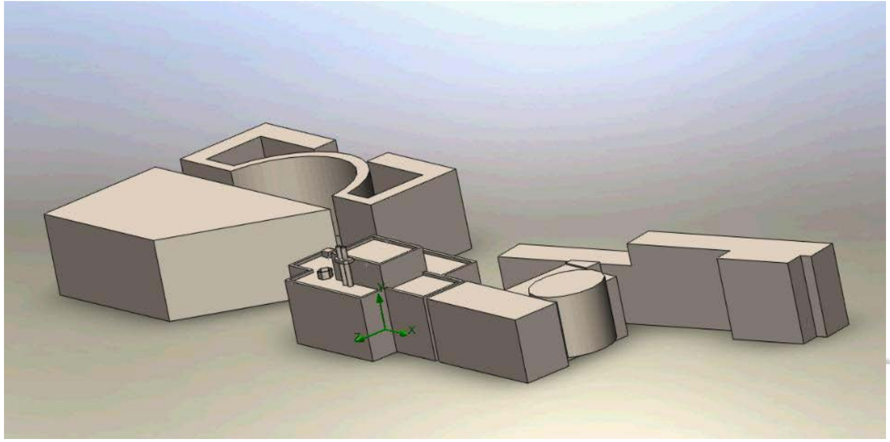
$$\text{windspeed}_{\text{point 4}} = 0{,}6793 * \text{windspeed}_{\text{refpoint}} + 0{,}11 \text{ [m/s]}$$



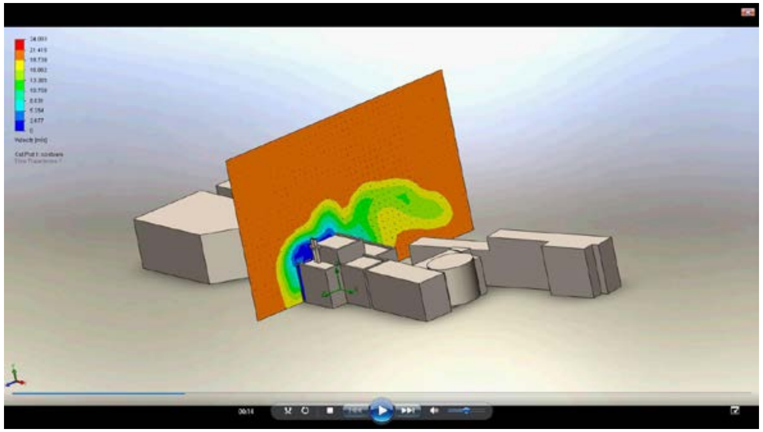
3 D model of the building

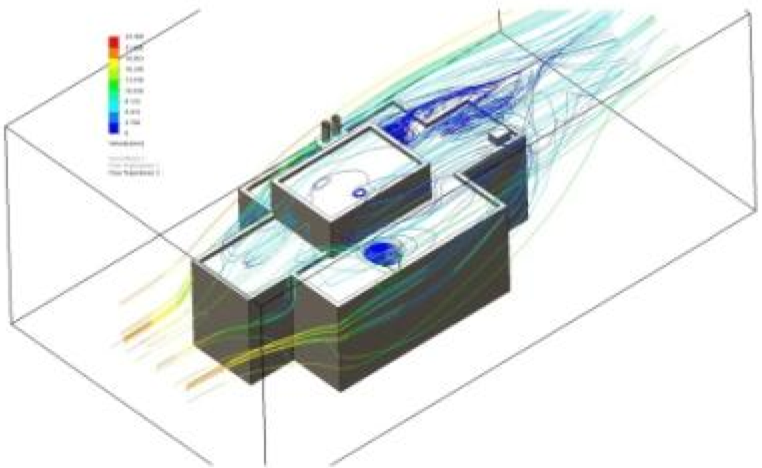


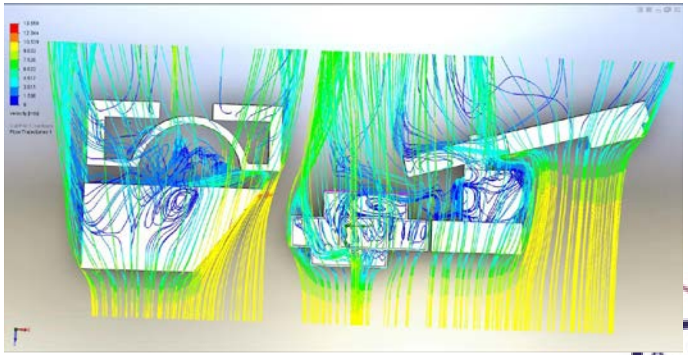




Threads of flow







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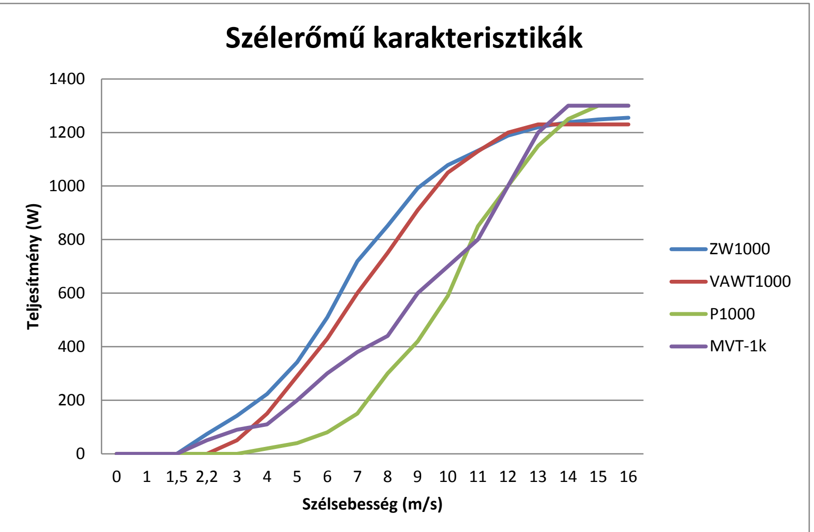
Simulation results

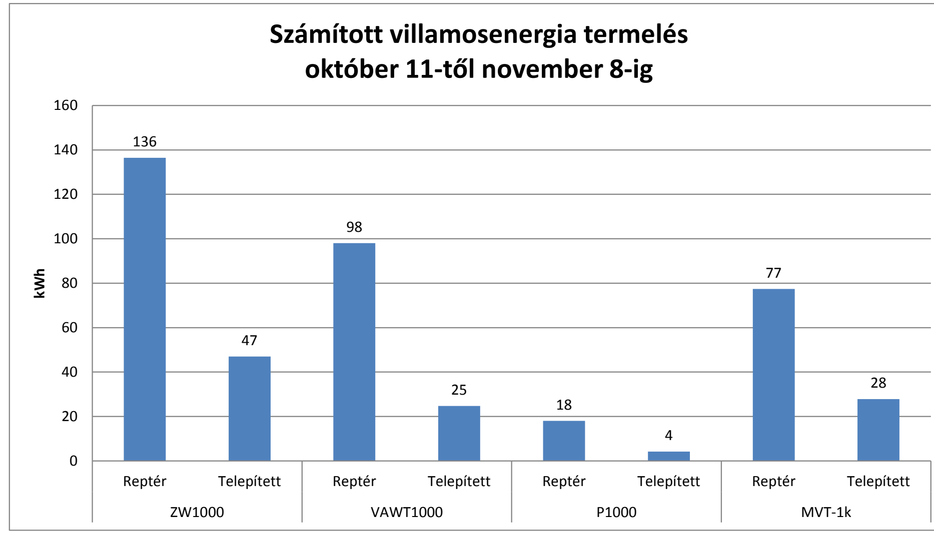
		M2	M3	M4	M5	M6
		Villámhárító	Víztartály	Napelem oktogon	Légkondicionáló sarok	Észak- Kelet sarok
Mérési arányszám		1,11/0,93	0,76	0,91	1,39/1,17	1,59/1,24
Szemből (É-K)		------------	------------	------------	------------	------------
	5 m/s	2:4,5=0,44	2,5:4,5=0,55	3,5:4,5=0,77	3,8:4,5=0,84	3,2:4,5=0,71
	10 m/s	3:4,5=0,66	4,5:7,5=0,6	7:7,5=0,93	8:7,5=1,066	7,5:7,5=1
	15 m/s	4,5:9,1=0,49	8:11=0,72	10:13=0,76	12:13=0,92	11:13=0,846
	20 m/s	6:15=0,4	15:18=0,83	13:18=0,72	16:18=0,88	15:18=0,83
Balról (D-K)		------------	------------	------------	------------	------------
	5 m/s	3,5:3=1,16	3,4:3=1,13	2,2:3=0,73	3:3=1	3:3=1
	10 m/s	6:5=1,2	4,5:5=0,9	3,2:5=0,64	6:5=1,2	4:5=0,8
	15 m/s	9:7=1,28	4:7=0,57	4,6:7=0,65	11,5:7=1,64	5,5:7=0,78
	20 m/s	9:8=1,1	12:8=1,5	7:8=0,875	6,5:8=0,81	6:8=0,75
Jobbról (É-Ny)		------------	------------	------------	------------	------------
	5 m/s	1,5:2,8=0,53	1,4:2,8=0,5	0,3:2,8=0,11	0,5:2,8=0,18	3:2,8=1,07
	10 m/s	2,6:5,2=0,5	2,7:5,2=0,52	1,3:5,2=0,25	1,3:5,2=0,25	2,7:5,2=0,52
	15 m/s	4:6=0,67	4,1:6=0,68	2:6=0,33	1,9:6=0,32	5,8:6=0,97
	20 m/s	5,3:10=0,53	5,4:10=0,54	1:10=0,1	1,8:10=0,18	9,1:10=0,91
Szimuláció átlaga		0,74	0,75	0,57	0,7	0,84

Measurement – worst sites			Simulation – best sites		
1	M3	Water tank	1	M9	NW corner
2	M4	PV octagonal holder	2	M4	PV octagonal holder
3	M8	N corner	3	M8	N corner

Measurement – best sites			Simulation – best sites		
1	M7	Chimney	1	M7	Chimney
2	M6	NE corner	2	M6	NE corner
3	M5	SE corner	3	M3	Water tank

Energy production





$$E = \int_{t_1}^{t_2} v(t) * P(v)\, dt$$

where

E = the energy produced by during period $t_1 - t_2$

$v(t)$ = wind speed function of time

$P(v)$ = turbine characteristics function of wind speed

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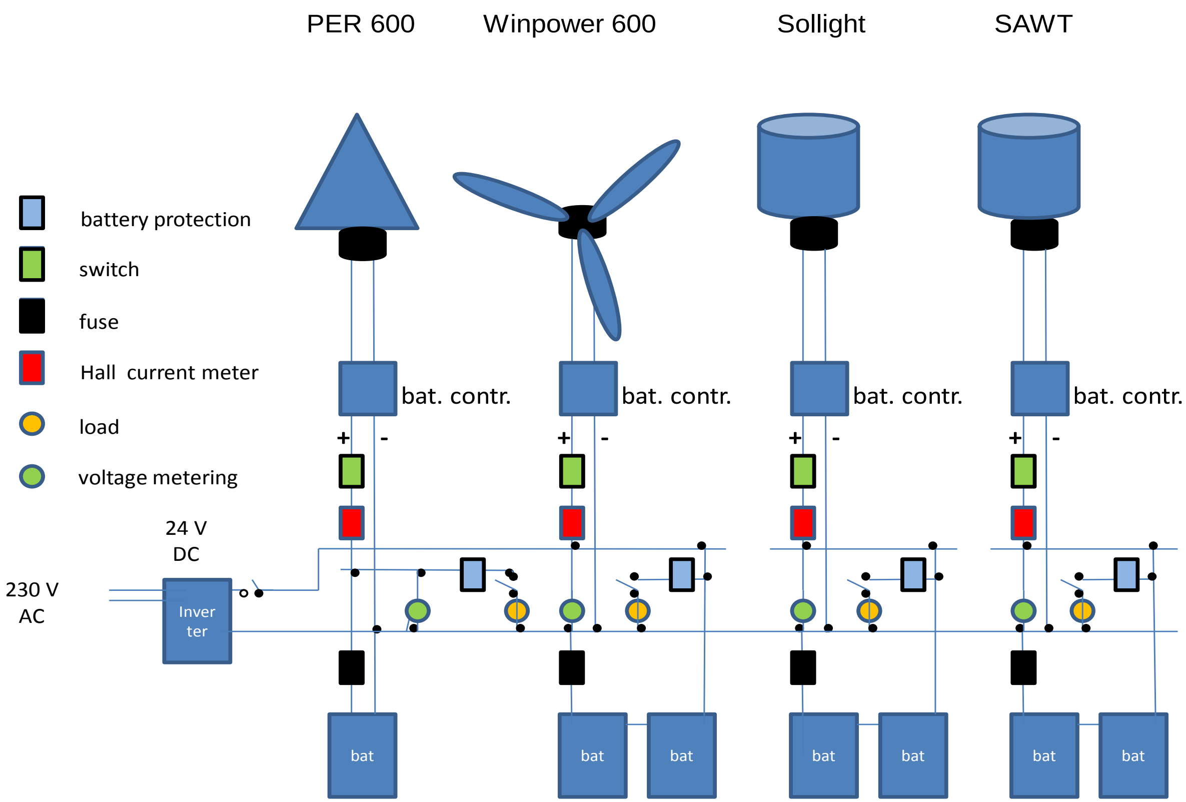
Metering scheme



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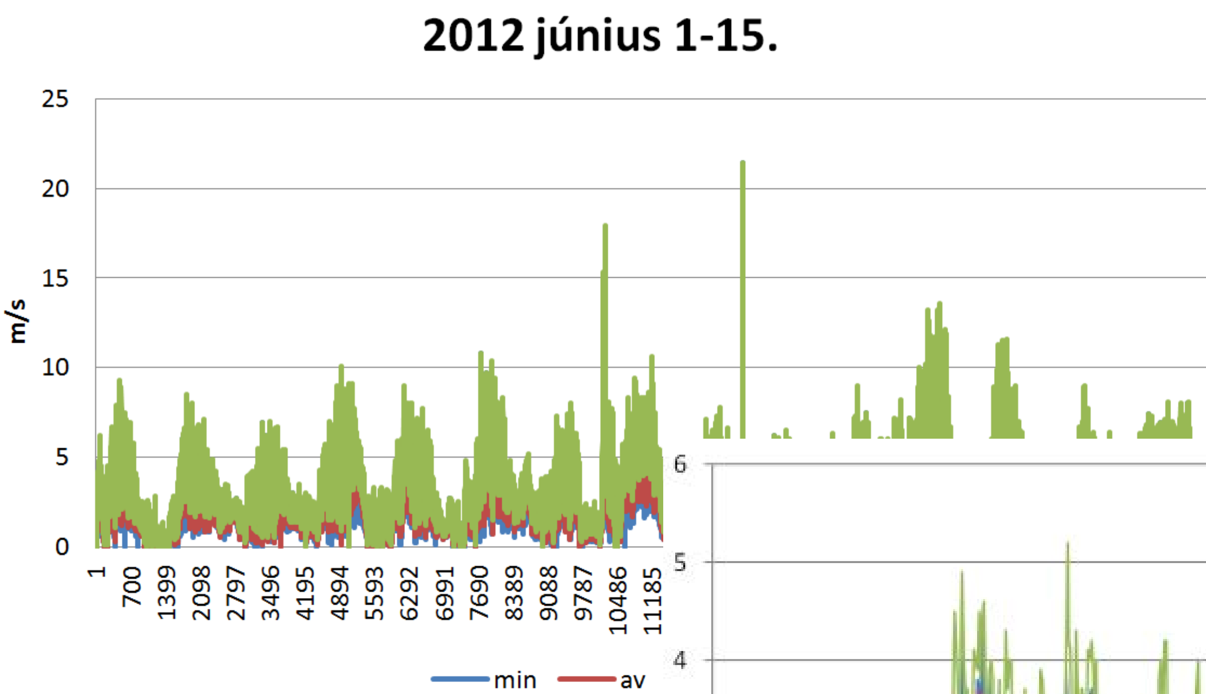
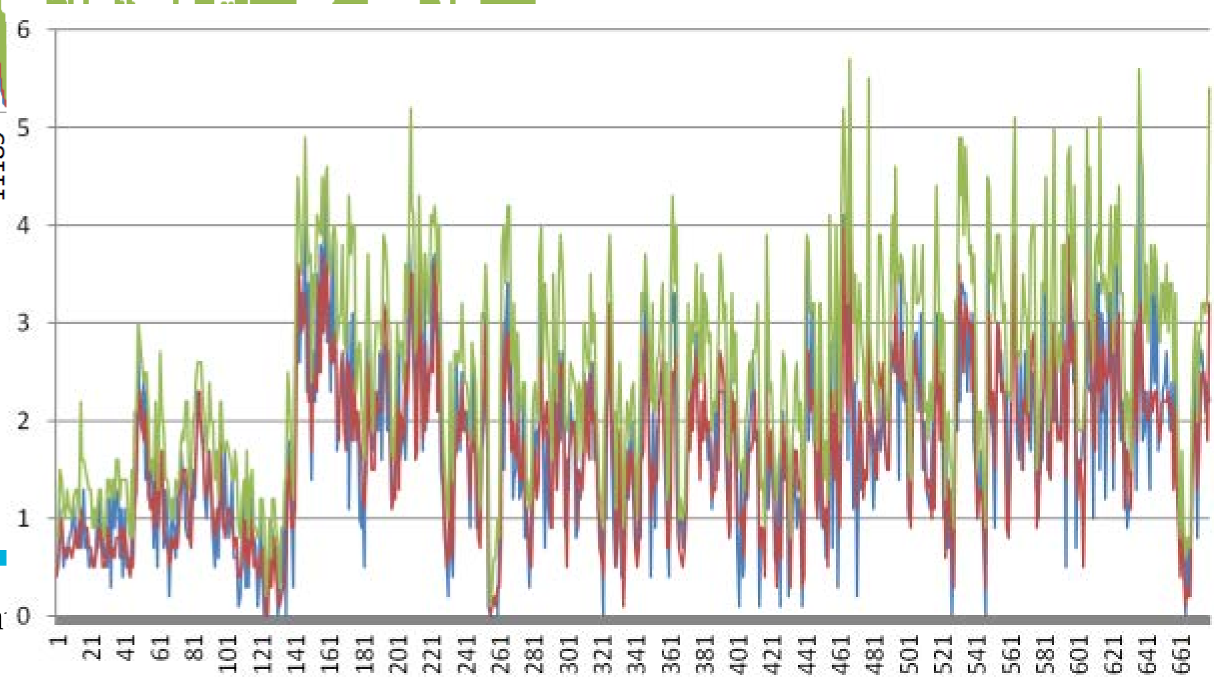
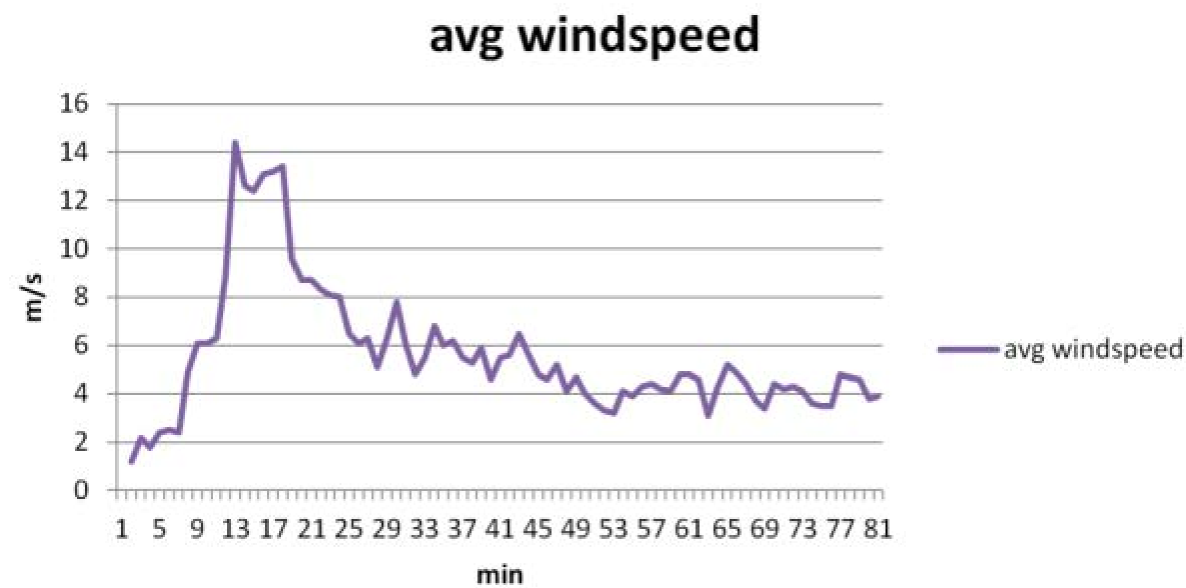
Wind run

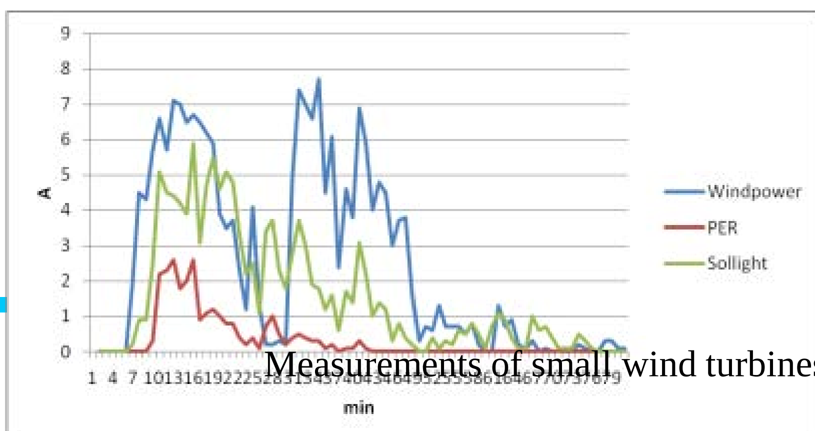




Measuremen

Wind + current





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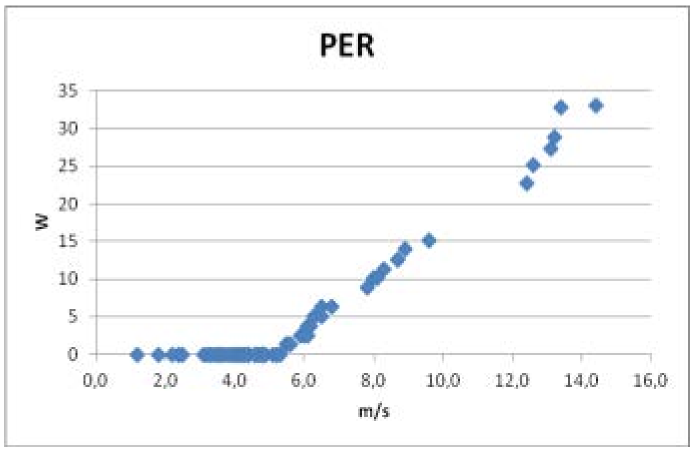
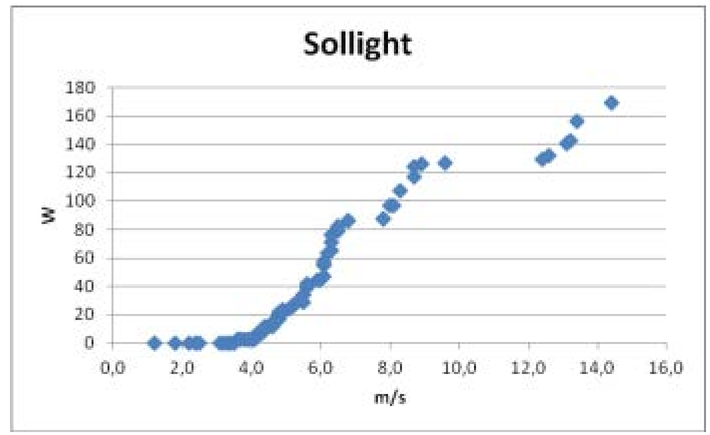
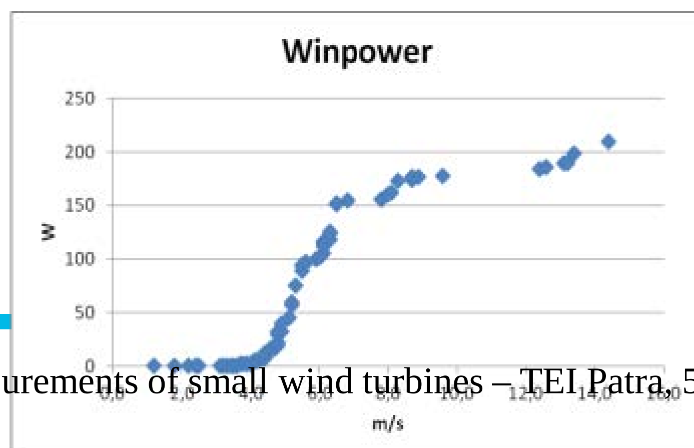
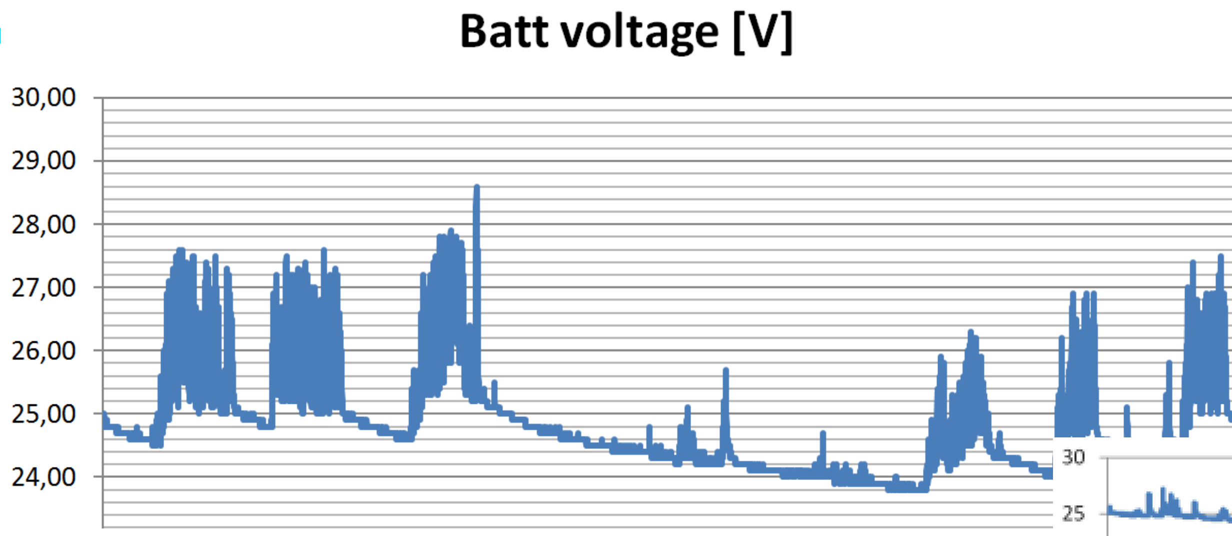
Metered characteristics **OK!!!**

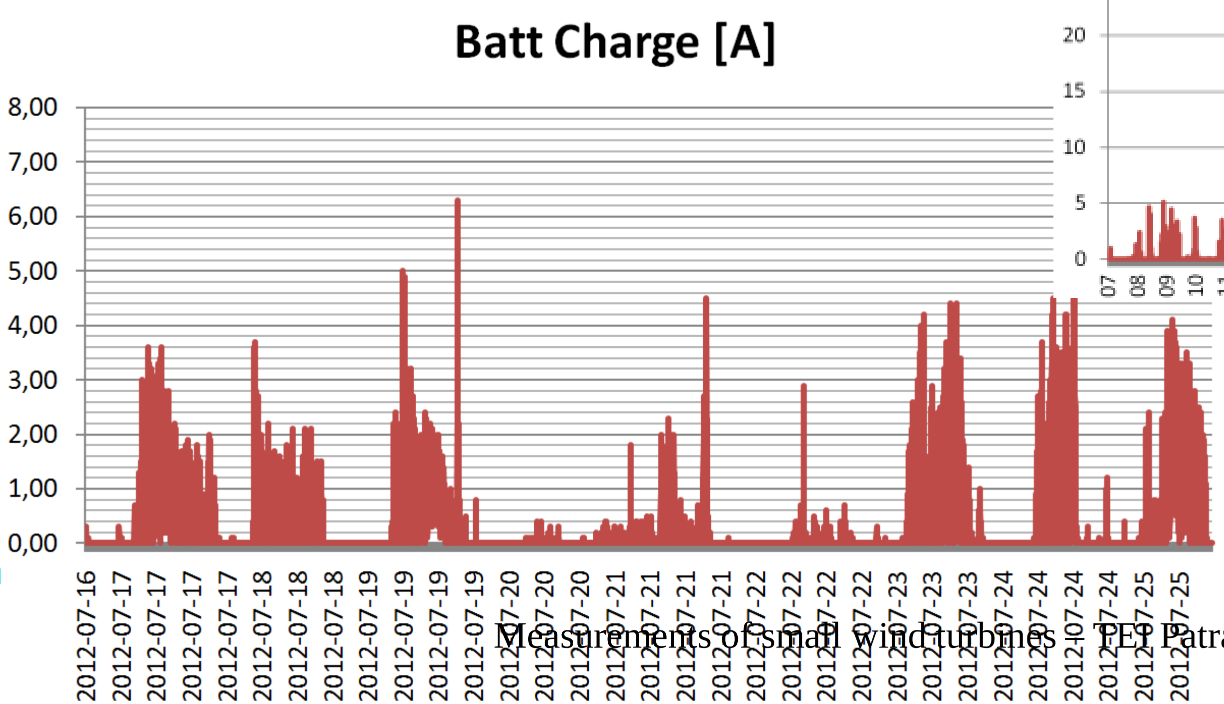


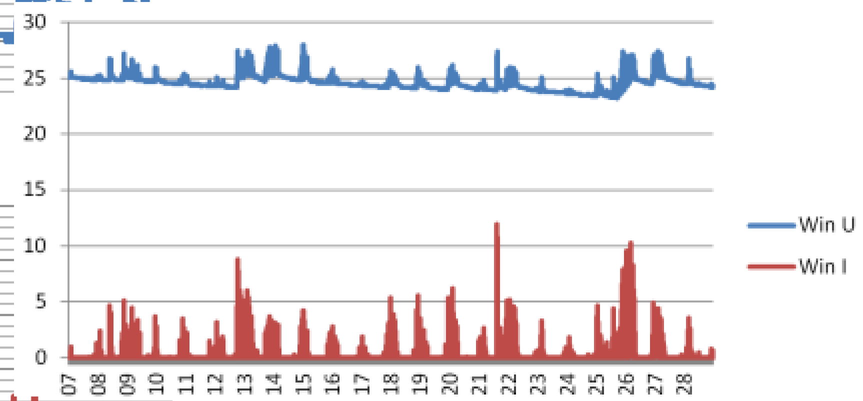




Battery


Batt voltage [V]
30,00
29,00
28,00
27,00
26,00
25,00
24,00


Batt Charge [A]
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
2012-07-16
2012-07-17
2012-07-18
2012-07-19
2012-07-20
2012-07-21
2012-07-22
2012-07-23
2012-07-24
2012-07-25


30
25
20
15
10
5
0
07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Win U
Win I

Energy balance

Half of the energy was consumed by the control electronics!

	Winpower 600	*PER600*	*SOLLIGHT*	*SAWT*
U [V]	22,8±2,002	11,99±0,2002	22,8±2,002	22,7±2,002
I[mA]	44,8±4,802	40,2±4,802	55±4,802	85±4,802

Battery ! ! !

- A weak point of the small scale island mode system is the battery. It represents not only a danger on the environment because of the poisonous waste of the batteries but also electronically has many aspects:
- the efficiency is about 70%
- the electronics will charge it only in case of well conditioned voltage (min-max)
- the fully charged battery will not store more energy
- during the storm some overcurrent can damage the battery
- the leaking current of the battery (and electronics) waste the stored energy
- in case of dead calm the battery can loose its charges
- it is hard to define the appropriate measure: small – will be discharged quickly or ovecharged – large one – won’t be fully charged, selfdischarging

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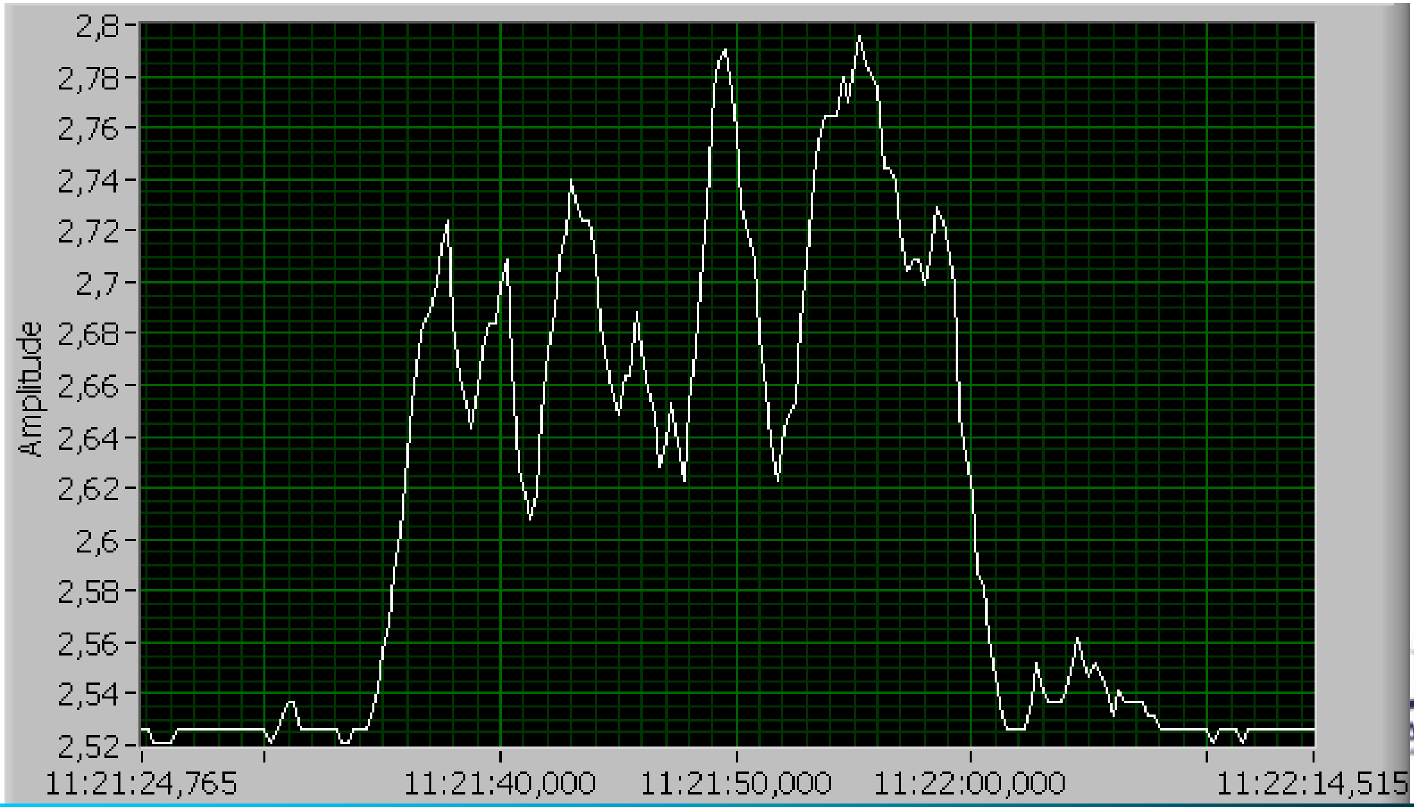
Strange dynamics

5 A peak current during continuous windrun



Bad dynamics ! ! !

The cause can be

- the turbine's sensitivity for the small turbulencies
- small inertia of the rotor
- the unknown dynamic of the electronic control of the charger (electronic breaking in case of overspeed), etc.

Conclusion

- the generated energy lags behind the expectations
- the generator characteristics fit to the manufacturers’ catalog
- the weak point of the system is the battery (dead calm, limited lifespan, over/under charge, load of the electronics)
- the electronics has a relative large self consumption
- but finally – THERE IS NO ENOUGH WIND IN THE **URBAN** AREA – The feeling of the high wind means 10 km/h that is 3 m/s. It is only the cut in speed.

Thanks for the attention!