Rooftop Wind / Urban Wind

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National Renewable Energy Laboratory

August 15 2010

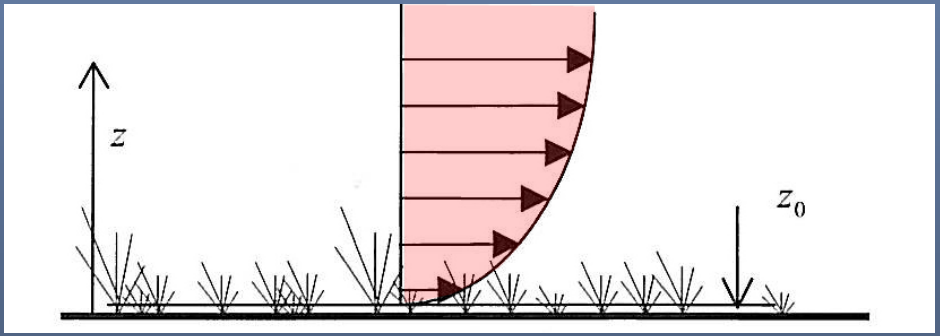
Wind 101

BUILDING-INTEGRATED WIND POWER

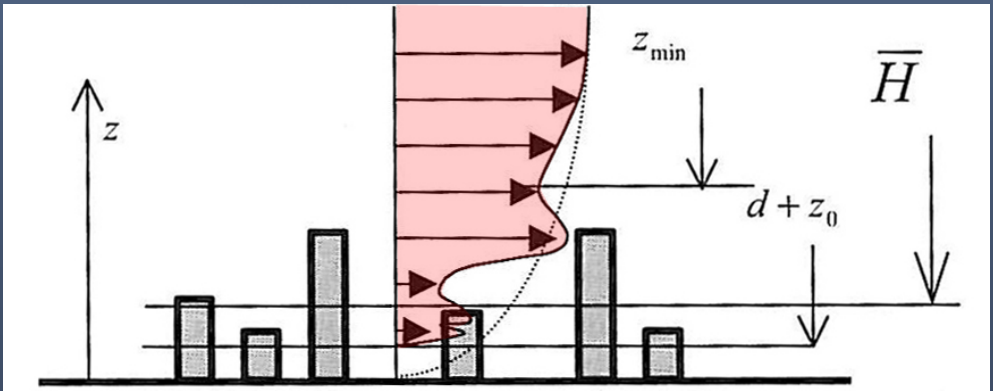
Twelve West – Portland, Oregon

Wind Energy in the Built Environment

Effects of Buildings



Wind Flow – typical velocity profile over open grassland

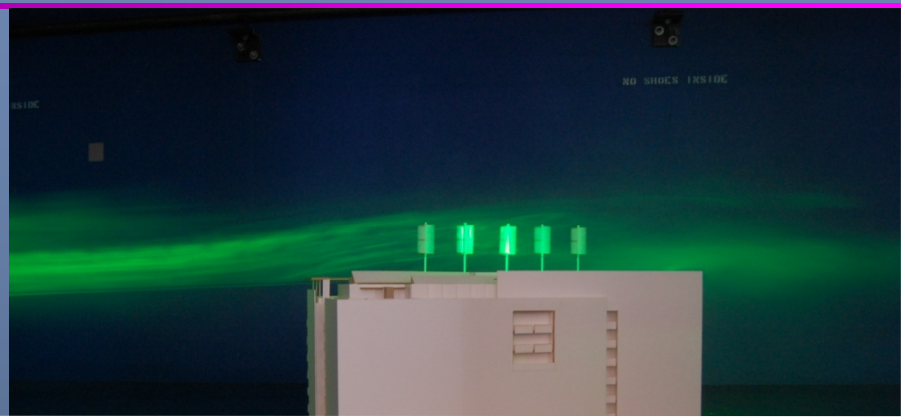


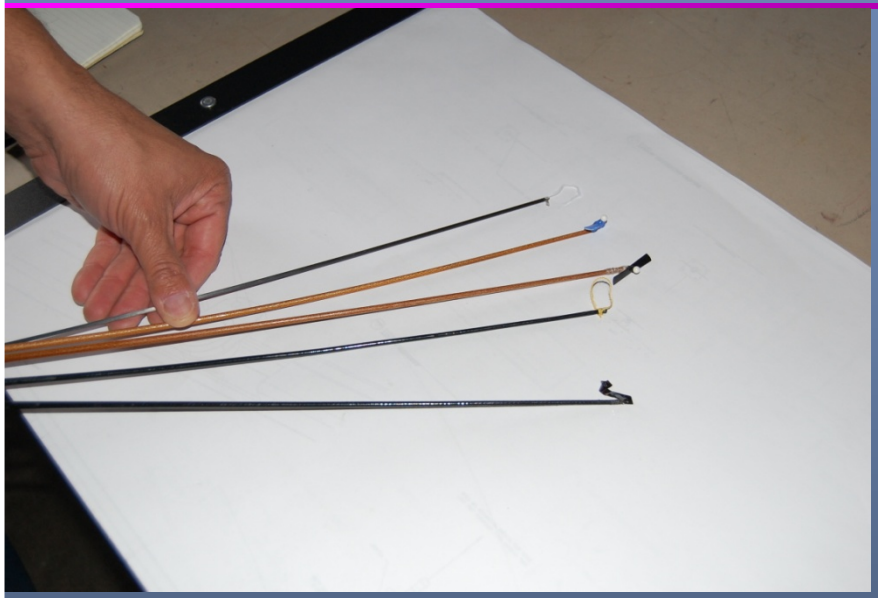
Wind Flow – complex velocity profile over urban environment

Wind Energy in the Built Environment

Aerovironment, Inc. Monrovia, California

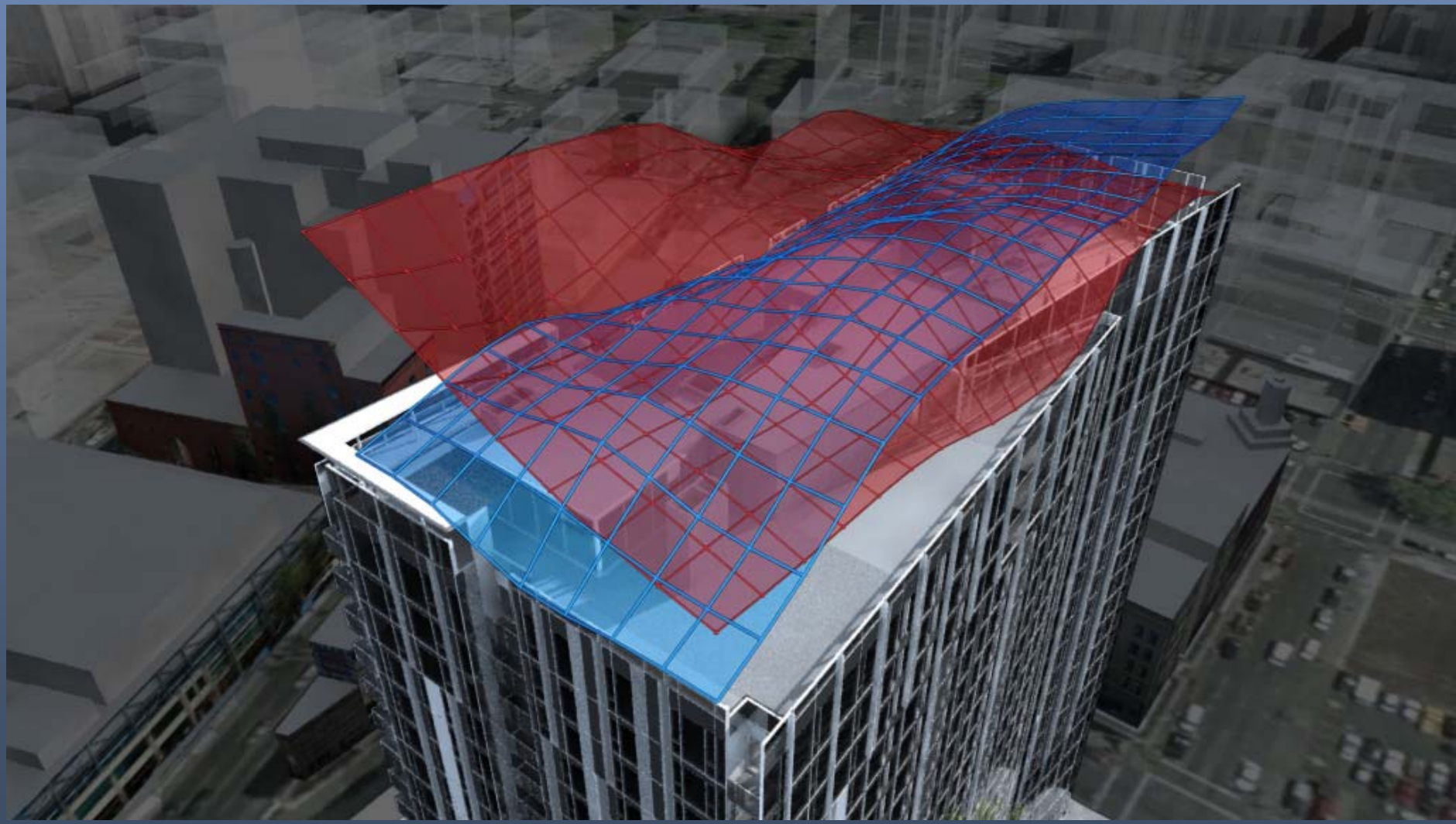
Wind Tunnel Testing



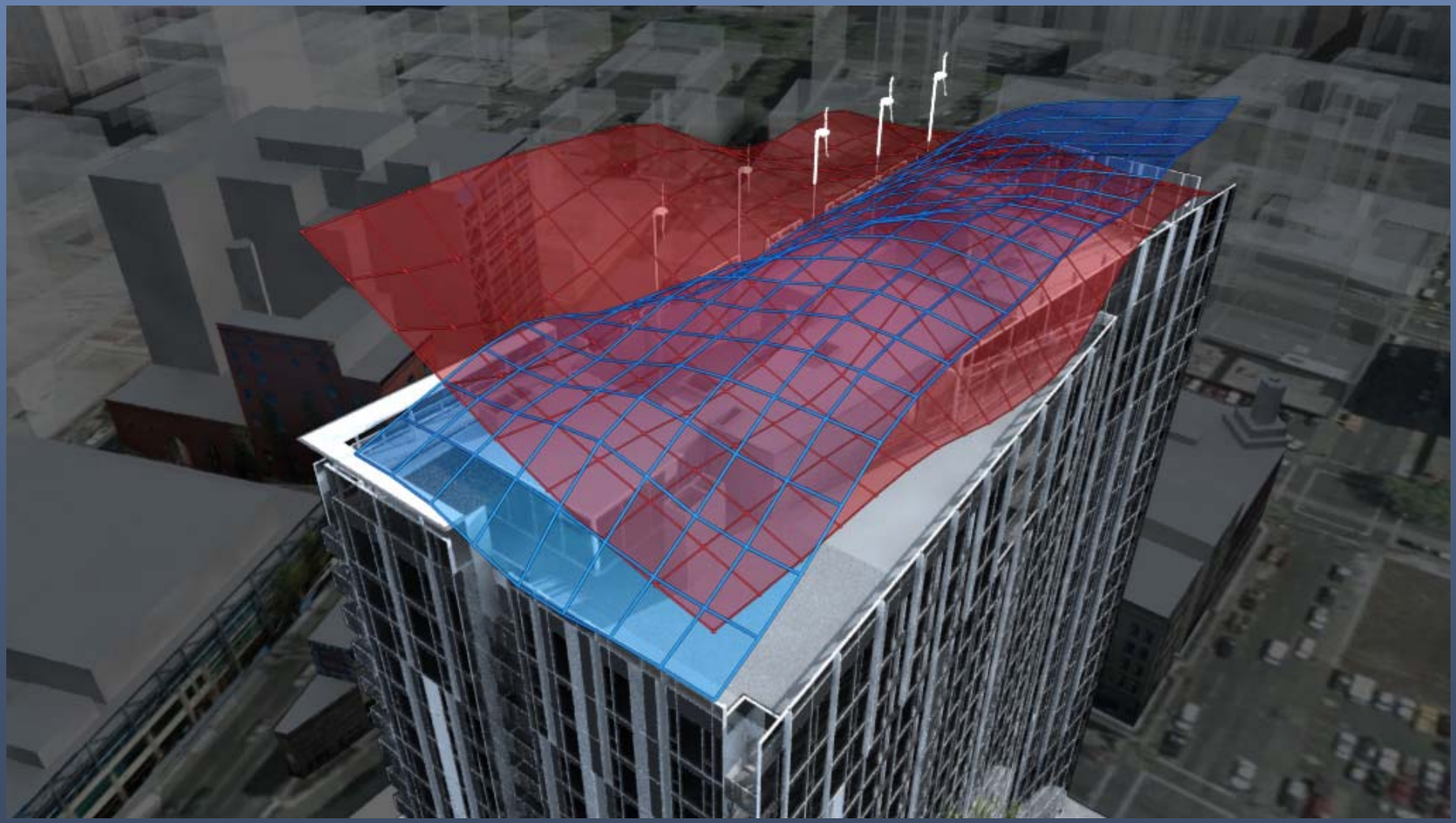


Wind Energy in the Built Environment

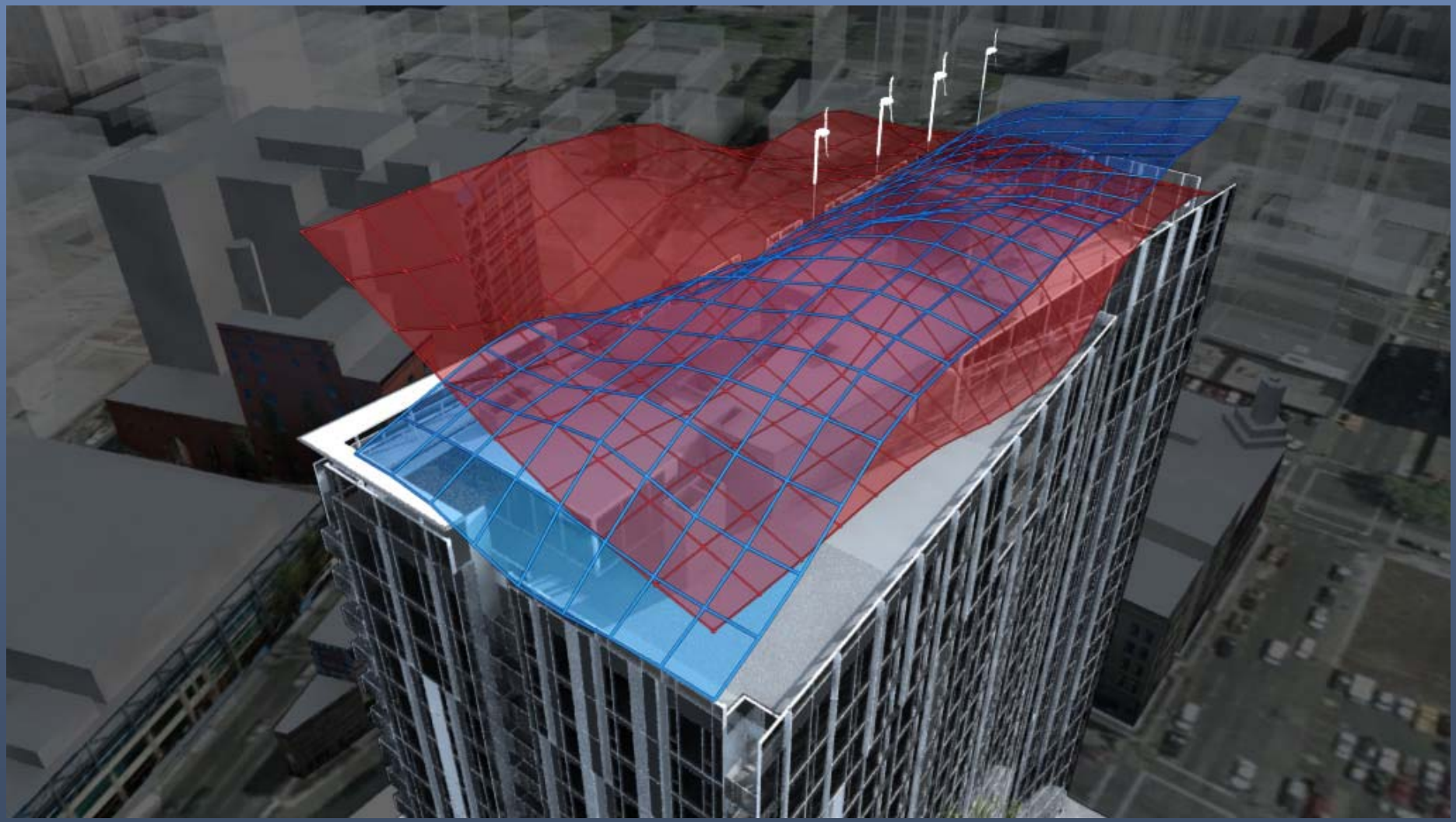
Wind Energy in the Built Environment



Wind Energy in the Built Environment



Wind Energy in the Built Environment



SMALL SCALE WIND TURBINES
updated
24-Nov-07

Vertical Axis

Manuf	Windside	Windside	Helixwind	Helixwind	Helixwind	Turby	Ropatec	Cleanfield Energy	Windterra	XC02	Pacwind	Pacwind	Pacwind
Model	WS-4	WS-2B	Savonius 2.0-low wind	Savonius 2.0-medium wind	Savonius 5.0		Mini-vertical	3.5 kW vaert	Eco1200	Quiet Revolution QR5	Delta I	Delta II	Aeolian
URL	http://www.windside.com/	http://www.windside.com/	http://www.helixwind.com/	http://www.helixwind.com/	http://www.helixwind.com/	http://www.turby.nl/	http://www.ropatec.com/en/products	http://www.cleanfieldenergy.com/	http://www.windterra.com/	http://www.quietrevolution.co.uk/	http://www.pacwind.net/	http://www.pacwind.net/	http://www.pacwind.net/
Type	Savonius	Savonius	Savonius	Savonius	Savonius	Darrieus	Darrieus	Darrieus	Darrieus	Darrieus (helical)	Darrieus	Darrieus	
Rating (KW)	**0.24**	**1.44**	**2.0**	**2.0**	**5.0**	2.5	0.75	3.5	1	6	?	10	
Rated Speed (m/s)	15					14	14	12.5	11	?	?	12.5	
Rotor Dims (m)	1.02 d x 4 h	1.02 d x 2.0 h	1.2 d x 1.8 h	1.2 d x 1.8 h	1.2 d x 4.57 h	1.99 d x 2.65 h	1.5 d x 1.5 h	2.75 d x 3 h	2.66 d x 2.25 h	3.1 d x 5 h	2.0 d x 1.2 h	4.0 d x 3.0 h	6.0 d
Swept Area (m^2)	4	2	2.23	2.23	4.46	5.3	2.25	8.25	5.99	15.5	2.4	12	
Cut-in (m/s)	1.5	2	2.68	2.68	2.8	4	3	3	3	4	?	3.6	
Cut-out (m/s)	-	20	15.65	15.65	-	14	-	40	-	16		-	
UL listing			*in-progress*	*in-progress*	*in-progress*			*in progress*		*No*		?	
Models installed								10 for 1 year, 20 in progress					
Grid Connection					110 VAC, 240 VAC, 50-60 Hz			110 VAC, 240 VAC, 50-60 Hz					
Braking			Manual for maintenance	Manual for maintenance	Manual for maintenance			Dual - gen. short, gen. brake		above 14 m/s - shutdown at 16 m/s			
Weight (kg)					362.8			130					
Warranty					5 years						5 year	5 year	5 year
Yaw													
List Price			$8,500	$8,500	$16,500			$16,000 Aug '07		$25,500 (new 2007)		$16,000-20,000	
Power Curve (KW)													
wind speed (m/s) 0	0	0	0.000	0.000	0.000	0	0	0	0	No Data Has Been Released By The Manufacuter			
1	0	0	0.000	0.000	0.000	0	0	0	0			0	
2	0	0	0.079	0.025	0.000	0	0	0	0			0.024	
3	0.02	0.01	0.242	0.172	0.250	0	0.015	0.05	0.025			0.437	
4	0.04	0.02	0.282	0.313	0.564	0.059	0.02	0.1	0.05			0.721	
5	0.07	0.035	0.398	0.448	0.827	0.11	0.04	0.25	0.12			0.913	
6	0.1	0.05	0.546	0.579	1.081	0.199	0.055	0.45	0.195			1.178	
7	0.15	0.075	0.745	0.705	1.325	0.317	0.095	0.65	0.36			1.451	
8	0.21	0.105	0.972	0.827	1.561	0.473	0.14	0.95	0.425			1.808	
9	0.3	0.15	1.215	0.946	1.790	0.675	0.2	1.4	0.65			2.306	
10	0.4	0.2	1.461	1.061	2.013	0.922	0.27	1.9	0.96			2.993	
11	0	0	1.698	1.174	2.228	1.234	0.355	2.5	1.03			4.101	
12	0	0	1.913	1.284	2.439	1.594	0.475	3.25	1.18			5.262	
13	0	0	2.095	1.392	2.646	2.024	0.595	3.5	1.18			6.629	
14	0	0	2.231	1.489	2.850	2.45	0.74	3.5	1.18			8.293	
15			2.308	1.605	3.051							9.487	
16			2.314	1.710	3.250							9.904	
17			2.237	1.815	3.449							10.047	
18			2.064	1.920	3.647							10.047	
19			1.793	2.026	3.846							10.047	
20			1.382	2.133	4.046							10.047	
21			0.848	2.242	4.248							10.047	
22												10.047	
23												10.047	
24												10.047	
25												10.047	

Turbine Search

Horizontal Axis

wind a I ://www.pacwind.net/	Pacwind Delta II http://www.pacwind.net/	Pacwind Aeolian http://www.pacwind.net/	510V Aeroturbine Aerotecture International Inc. http://www.aerotecture.com/	Gual Industrie StaroEolien GSE 4 http://www.gual-industrie.com/	IR Windpower Turbo Wind Power Generator http://windpower.com/	SeaBell Group Turbo Wind Power Generator http://www.seabell-i.com/eiwing.html	SW Windpower Skystream 3.7 http://www.windenergy.com/index_wind.htm	WESS Tulipo http://www.windenergysolutions.nl	Aerovironment, Inc. AVX1000 http://www.avinc.com/	Jbomay AeroGeneradores Inclin 6000 neo http://www.bomay.com/	Iskra ATS-1 http://www.iskrawind.com/	KestraL 2500 http://www.aeroplastics.co.za
Darrieus	Darrieus	Darrieus	hybrid Savonius/Darrieus	hybrid Adjustable Wing Darrieus		Savonieus+Giromill+Darrieus						
	10	10	1	10	5		1.8	2.5	1	6	5	2.5
	12.5	12.5	38		12		9		?	12	12	
2.0 d x 1.2 h	4.0 d x 3.0 h	6.0 d x 3.0 h		4 d x 1.5 h	0.5 d x ?		3.72 d	5.0 d		4	5.4	3.8
2.4	12	18		6			10.87	19.63				
	3.6			2	1.6		3.5	3		3.5	3	2
	-			60			-	20				0
	?						?	yes	Note: non-yawing! New 5-blade model coming soon.			
							electronic stall wiredundant relay	400V/50-60 HZ 3-phase spring-powered electromagnetic				
							77	850				
ar	5 year	5 year					passivelldownwind	active				
	$16,000-20,000						$6,200 (nov 2007)	$37,500 (nov 2007 exchange rate)	$5,800 (nov 2007)			
			No Data Has Been Released By The Manufacuter									
	0						0	0				
	0.024						0	0				
	0.437						0	0.068				
	0.721						0.09	0.243				
	0.913						0.04	0.53				
	1.178						0.1	0.958				
	1.451						0.25	1.553				
	1.808						0.47	2.159				
	2.306						0.76	2.474				
	2.993						1.11	2.695				
	4.101						1.44	2.625				
	5.282						1.68	2.598				
	6.629						1.82	2.552				
	8.293						1.9	2.382				
	9.487						1.9	2.192				
	9.904						1.85	1.96				
	10.047						1.76					
	10.047											
	10.047											
	10.047											
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	10.047											
	10.047											

Warwick Urban Wind Trial

www.warwickwindtrials.org.uk

- 26 roof-mounted winds turbine on a variety of buildings and locations
- Objective:
  - *"To see how grid-connected microwind turbines perform on a variety of building types and to see if any patterns emerged that could provide a helpful guide to potential purchasers"*
- Measurements during ~15-month trial:
  - Wind speed (at hub height) and wind turbine energy
  - 2-15 months of data from individual turbines
  - First **quantitative** study of it's kind!
- Final report published January 2009

Warwick Wind Trial

Scope of investigation

- Wind resource
- Wind turbine energy production
- Wind turbine power curves – comparison to manufacturers data
- Wind turbine capacity factors
- Wind turbine parasitic power
- Scaling factors to correct the national wind map for urban sites

Warwick Wind Trial

Scope of investigation

- Wind resource
- Wind turbine energy production

} **Focus of this presentation**

- Wind turbine power curves – comparison to manufacturers data
- Wind turbine capacity factors
- Wind turbine parasitic power
- Scaling factors to correct the national wind map for urban sites

Wind Turbines Used in the Trial

Turbine	Full model name	Specification
Ampair	Ampair 600 230	600 W
Air Dolphin	Zephyr AirDolphin Z1000	1 kW
StealthGen	Eclectic StealthGen D400	400W
Windsave	Windsave WS1000 and WS1200	1 kW and 1.25kW Windsave modified their WS1000 machines during summer 2007. These are being replaced in 2008 by the WS1200.

- All turbines were grid-connected
- All were from UK manufacturers
- Rotor diameters 3.6-6.0 ft (1.1-1.8 m)
- Numerous mechanical or electrical failures
- Turbine noise was a significant problem at 3 sites

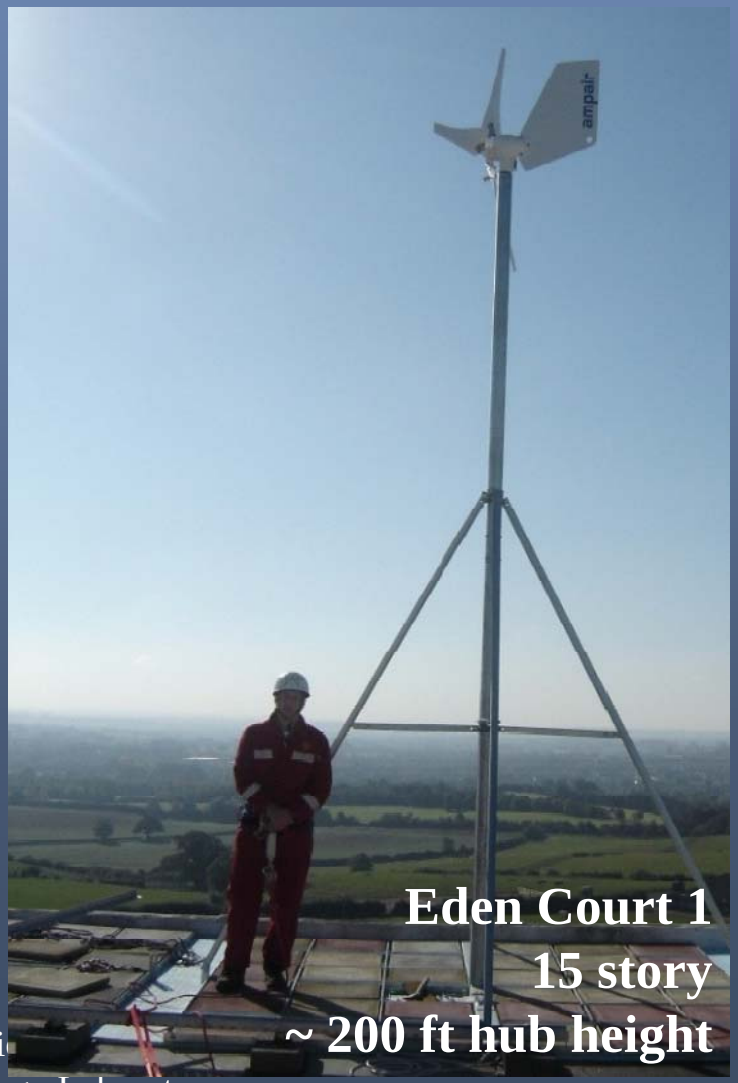
Example Trial Sites

Example Trial Sites

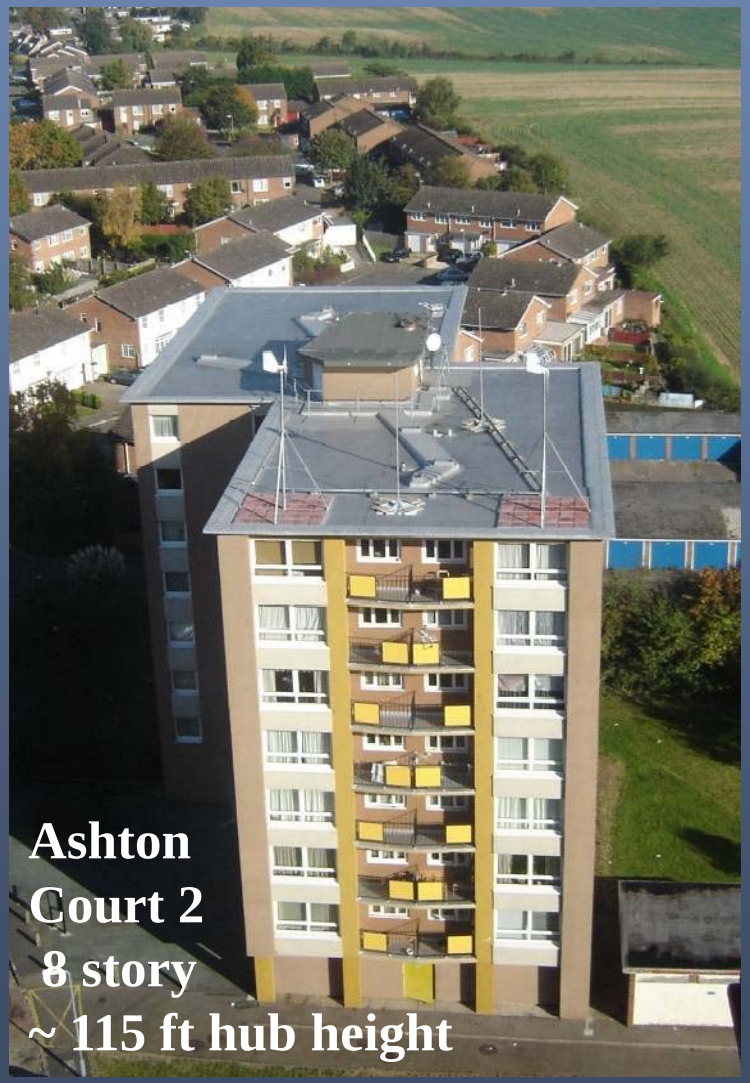
Princes Drive – warehouse

Hill Close Gardens – suburban house

Example Trial Sites:
High-Rise Apartment Buildings



Eden Court 1
15 story
~ 200 ft hub height



Ashton Court 2
8 story
~ 115 ft hub height

Site 1 – Lillington Road

- Ampair 600/230 wind turbine, hub height is 2.2 m (7.2 ft) above ridgeline
- Anemometer at hub height

Site 1 – Lillington Road

Wind Resource

- Wind speed predicted by the national wind map (NOABL)
  - 5.0 m/s at 10 m
- Wind speed measured 2.2 m above ridgeline (at turbine hub height)
  - 2.4 m/s

Wind Power Classes

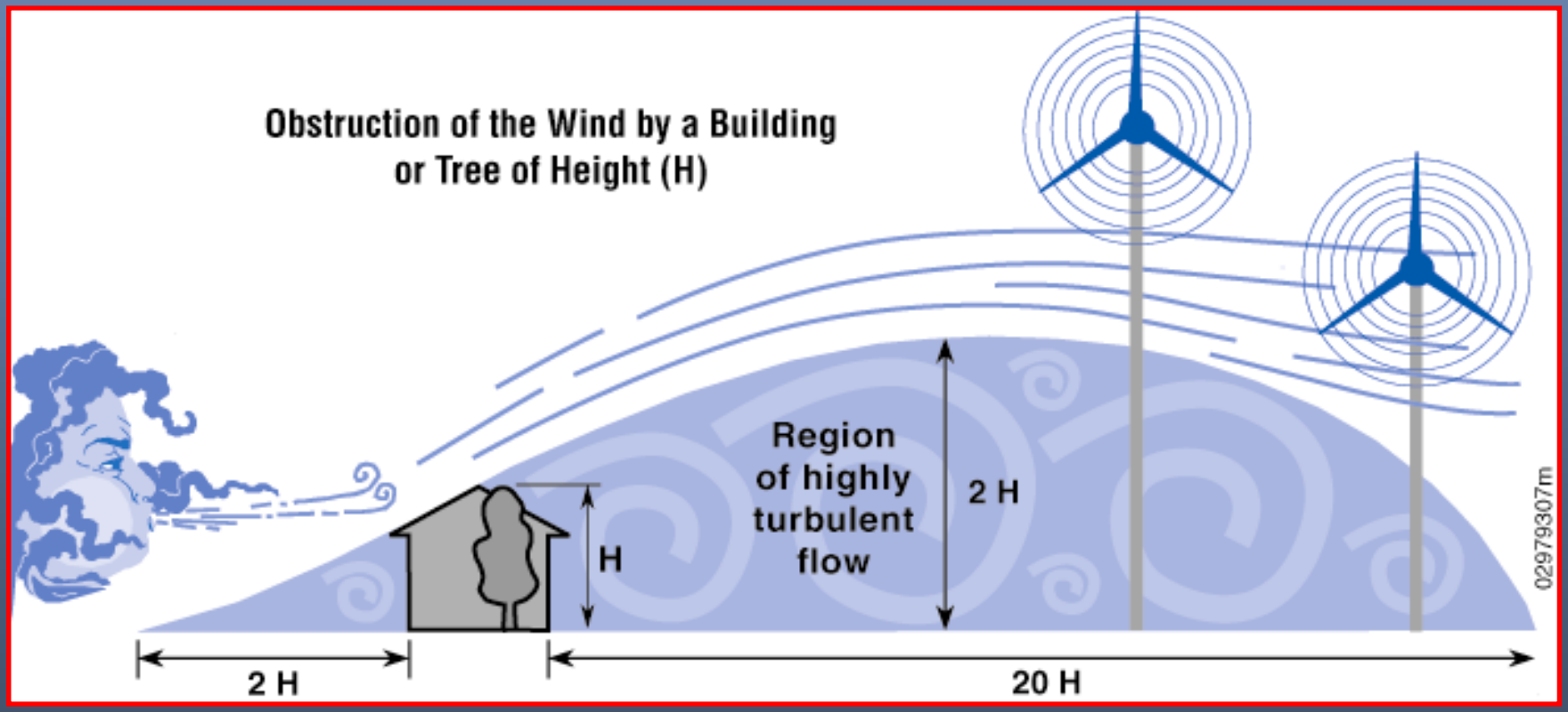
Wind Power Class	Wind Power Density W/m^2	Wind Speed at 10 m m/s	Wind Speed at 10 m mph
1	0 - 100	0 - 4.4	0 - 9.8
2	100 - 150	4.4 - 5.1	9.8 - 11.5
3	150 - 200	5.1 - 5.6	11.5 - 12.5
4	200 - 250	5.6 - 6.0	12.5 - 13.4
5	250 - 300	6.0 - 6.4	13.4 - 14.3
6	300 - 400	6.4 - 7.0	14.3 - 15.7
7	400 - 1000	7.0 - 9.4	15.7 - 21.1

Site 1 – Lillington Road

Wind Resource

- Wind speed predicted by the national wind map (NOABL)
  - 5.0 m/s → 143 W/m^2, high Class 2
- Wind speed measured at turbine hub height
  - 2.4 m/s → 16 W/m^2, bottom of Class 1
    → factor of 9 smaller than predicted!

Affect of Obstacles



Wind Resource Summary

- High rise buildings (6 sites)
- 90-279 W/m^2
- All were one wind class lower than predicted
- Unfortunately, the turbines at these better sites were usually shut off due to noises complaints from building residents
- All other buildings (19 sites)
- 6-55 W/m^2 (Class 1 resource, Class 2-3 predicted)
- Poorest sites were <u>net consumers</u> of energy due to parasitic power consumption
- Misty Farms
- Open field on a hill top near the ocean, on a tower
- 228 W/m^2 (Class 4 wind resource)

Average Energy Output, All Sites

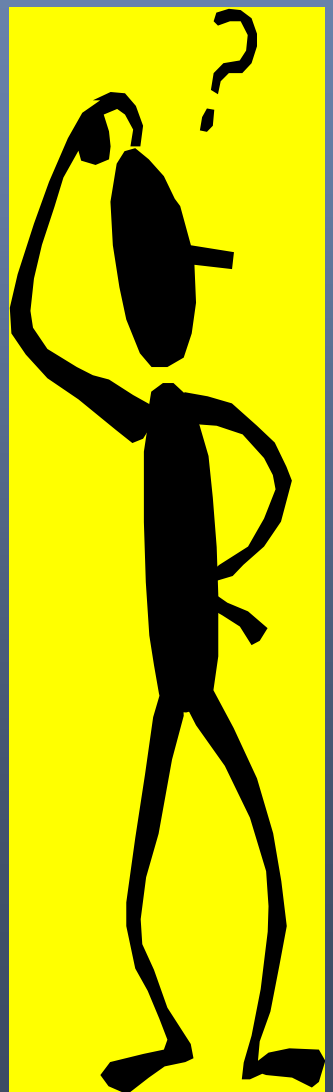
- Including periods when turbines were switched
- off or broken:
- Average energy output: 78 kWh/y (all sites)
- Excluding periods when turbines were switched
- off or broken:
- Annual energy output: 229 kWh/y (all sites)
- Annual energy output: 94 kWh/y (high rises excluded)
- Best site production: 718 kWh/y (Southorn 2)
- Consumption of the average US home:
- ~ 9,000 kWh/y

Warwick Wind Trial

Conclusions

- The wind resource on most urban roof tops is very small due to surrounding "clutter" - other buildings, trees, etc.
- High-rise buildings in exposed locations may have a viable wind resource
- Energy production in this study was trivially small
  - Low wind resource
  - Small size of the wind turbines
- The key issue with roof-mounted wind turbines is usually **wind resource**, not **technology!**
  - There is no technology "silver bullet" for a low wind resource

Questions?

For more info:
http://www.nrel.gov/wind/
http://www.awea.org/
http://rredc.nrel.gov/wind/pubs/atlas/
http://www.windpower.org/en/core.htm

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