Predicting the yield of micro-wind turbines in the roof-top urban environment

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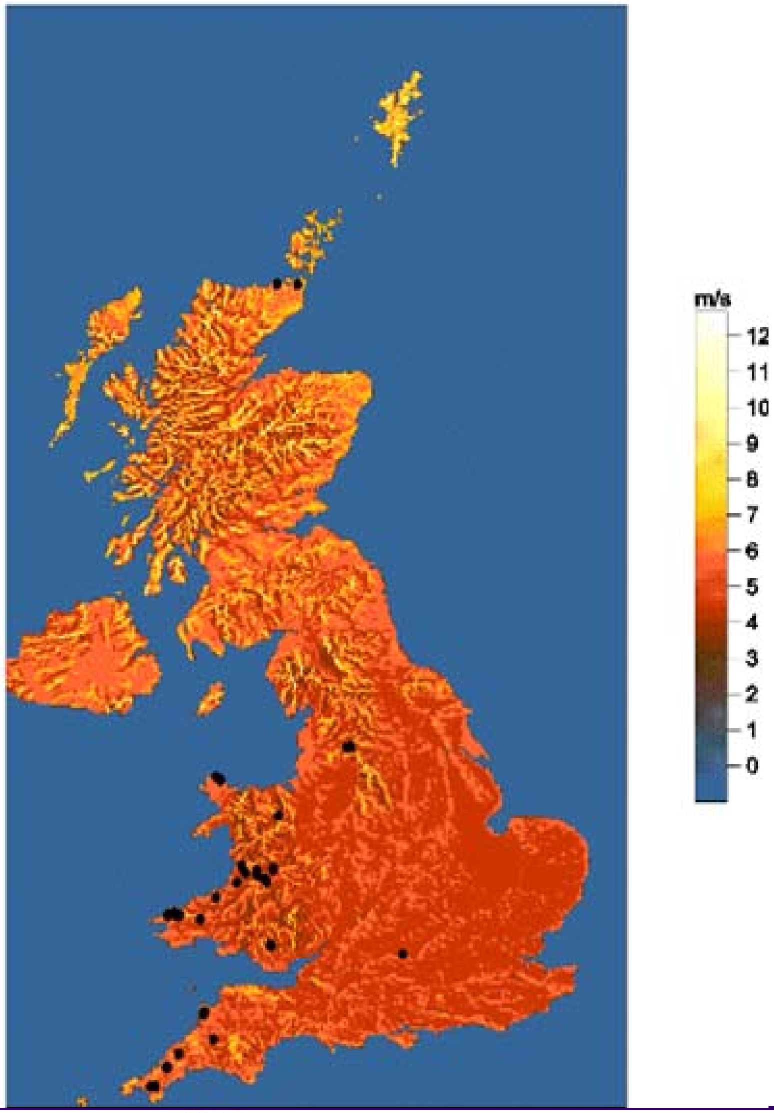
Overview

- Background to micro-wind
- Methodology
- UK wind atlas
- Urban wind profile
- CFD modelling of wind around buildings
- Energy yield example
- Conclusions and recommendations

Background to micro-wind

- Growing interest in micro-generation
- Low carbon/carbon neutral buildings
- Micro-wind power one possible solution
- But large uncertainties in expected output in urban areas

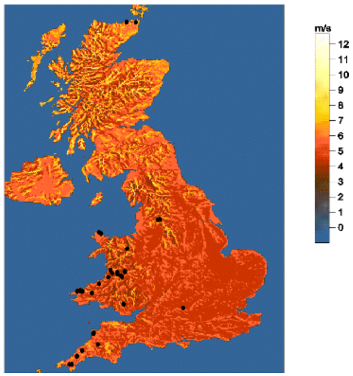
UK Wind Atlas



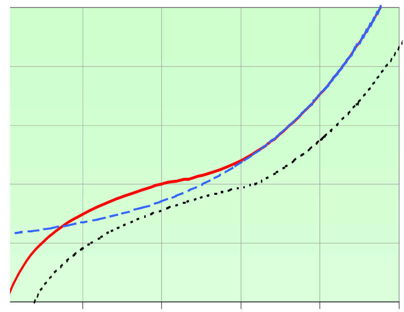
- Uses data from UK met stations
- Mass consistent model to interpolate wind field
- 1km x 1km grid
- 10m, 25m and 45m
- Uniform low roughness
- No account for obstacles
- Not ideal for urban wind resource assessment

Loughborough University

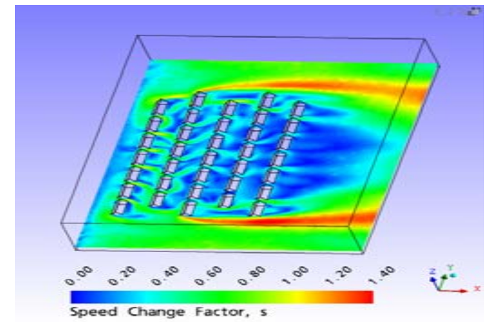
Proposed methodology to downscale UK wind atlas



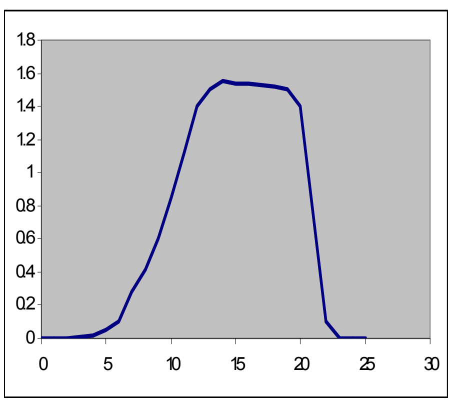
Wind atlas



Urban wind profile

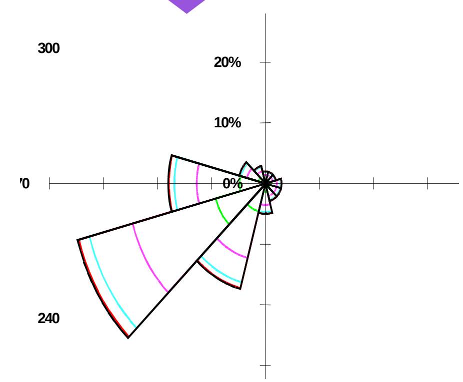


CFD flow simulation



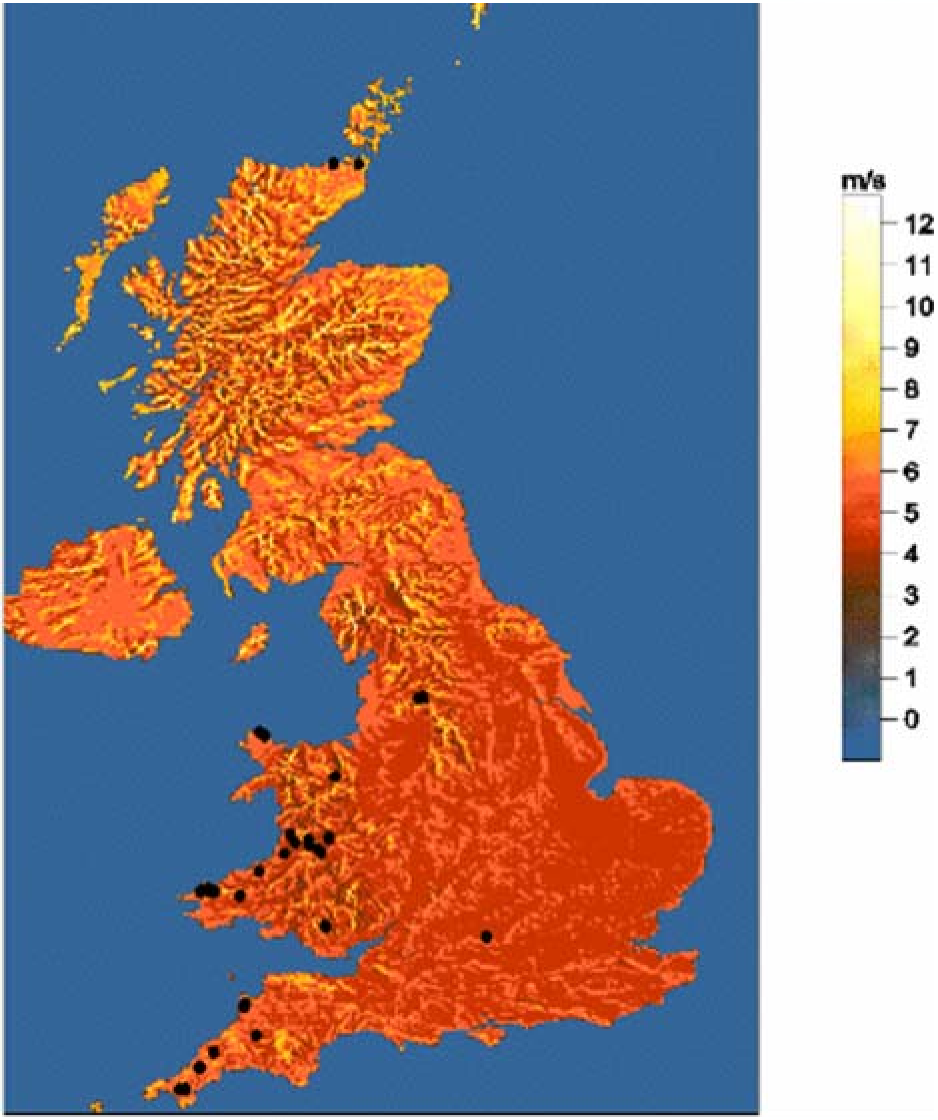
Power curve

Energy Yield



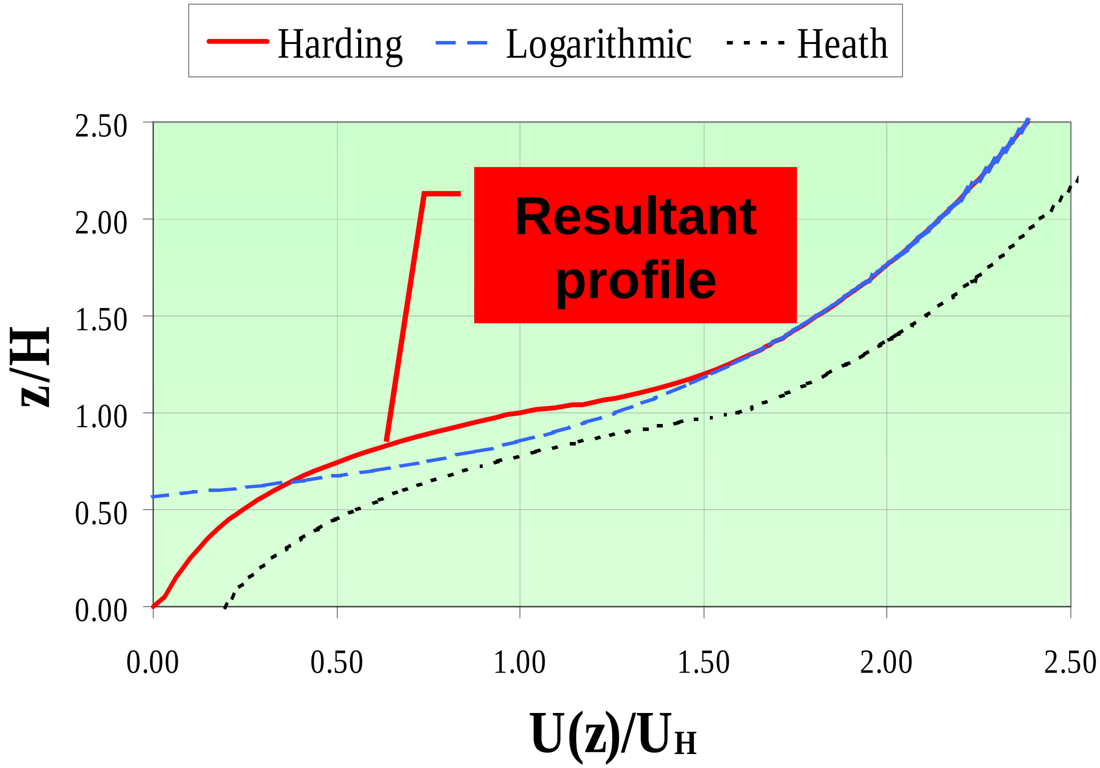
Wind rose

UK wind atlas



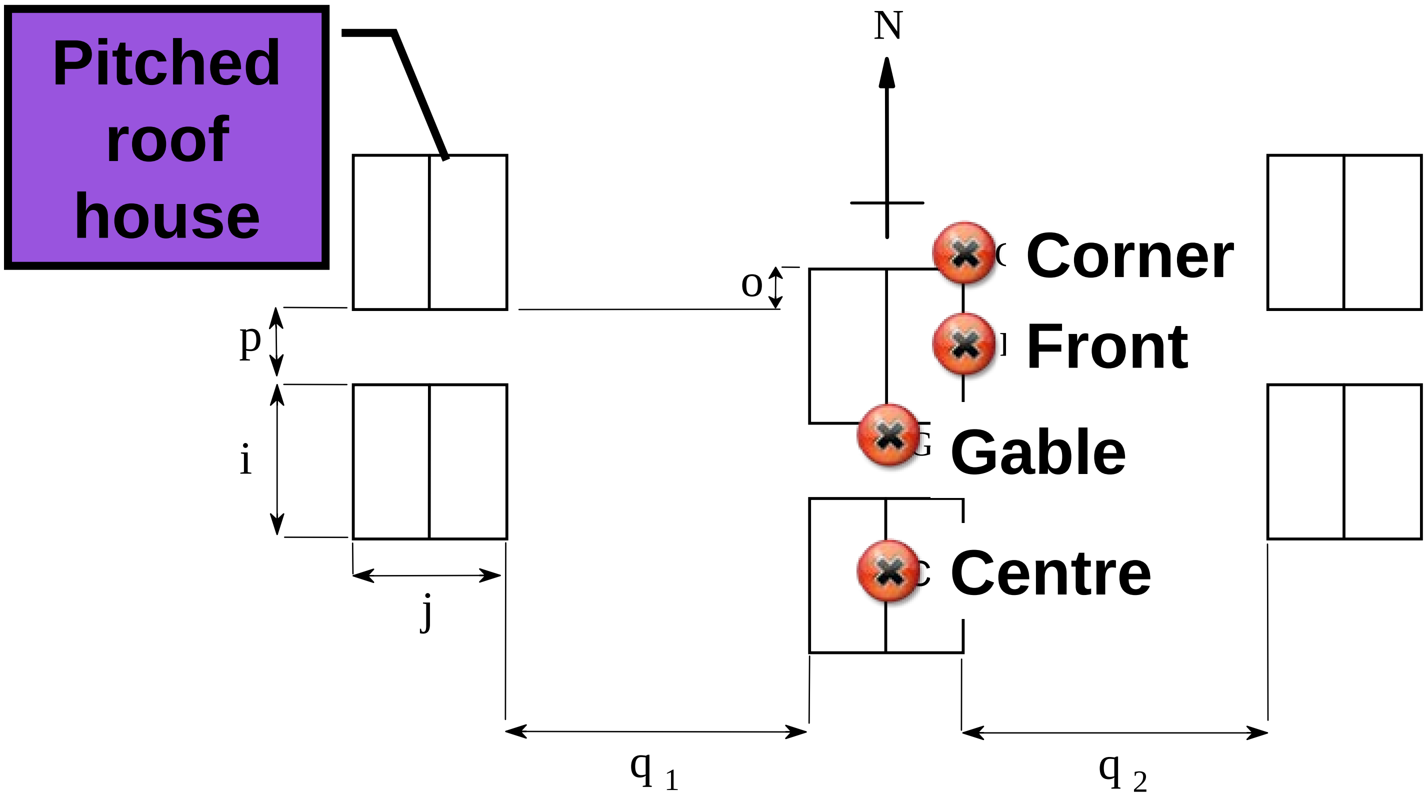
- Data from UK met. stations
- Mass consistent model: NOABL
- 1km × 1km grid
- Output: 10m, 25m, 45m
- Uniform low roughness
- No buildings
- Not really suitable for urban wind resource assessment in 'raw' form

Urban wind profile



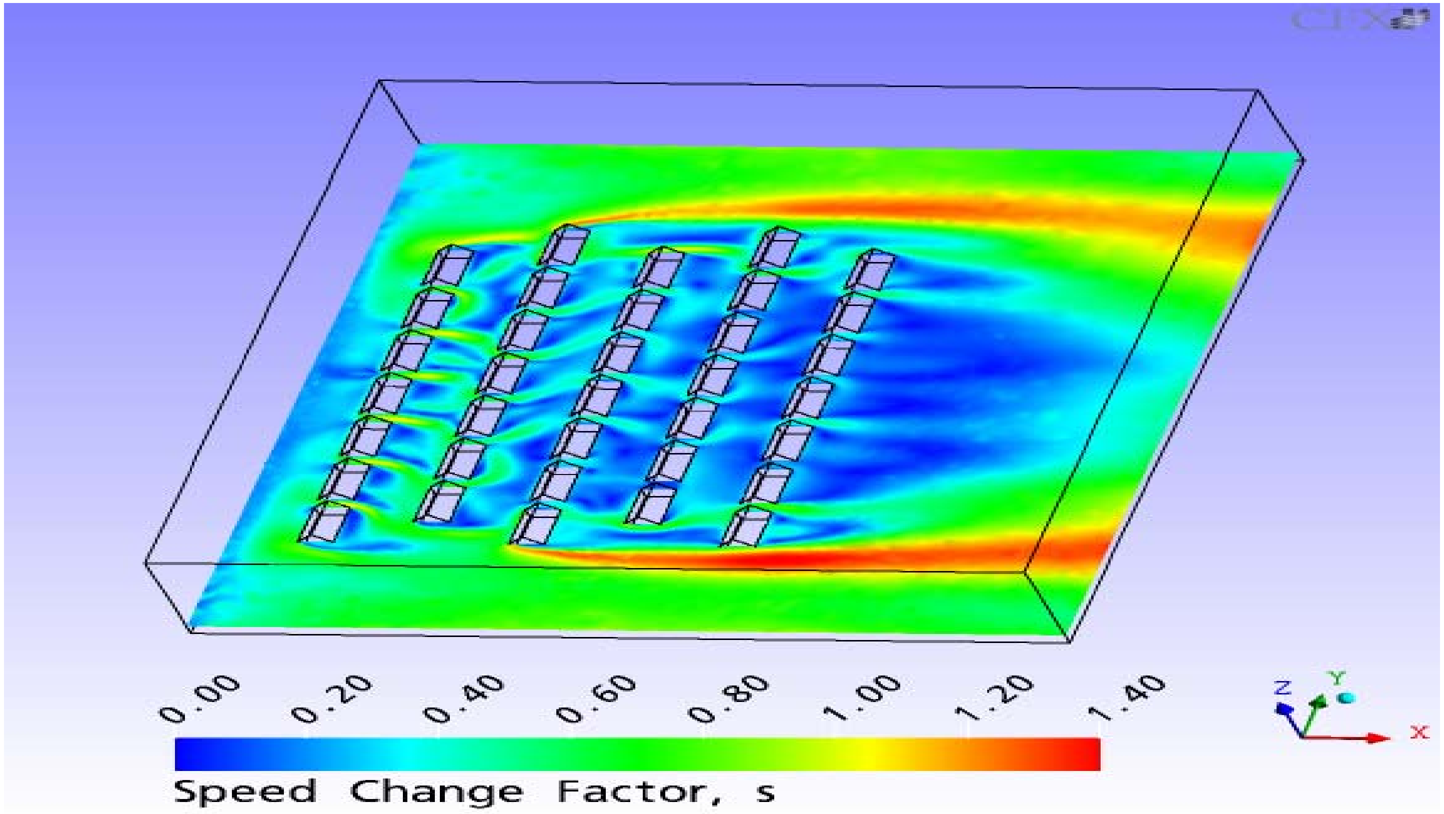
- Scale profile using wind atlas at site of interest
- Resultant profile function of:
  - Surface roughness
  - Building density
  - Av. building height

Computational fluid dynamics (CFD) modelling



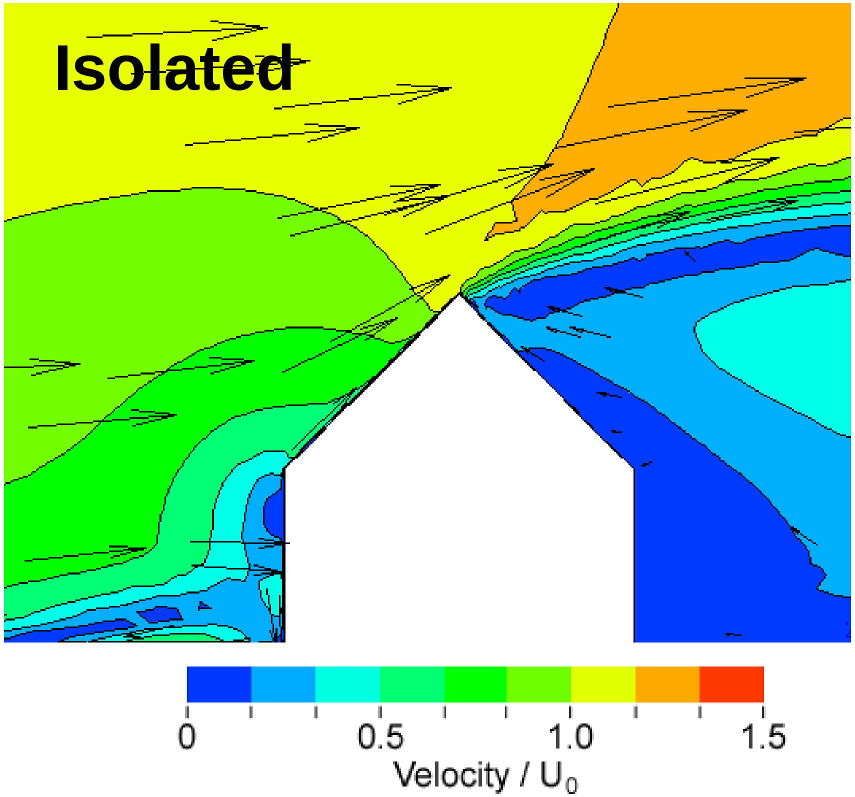
- ANSYS CFX RANS using k-ε turbulence model
- Flow simulation around an array of buildings
- Representative selection of different layouts/building types

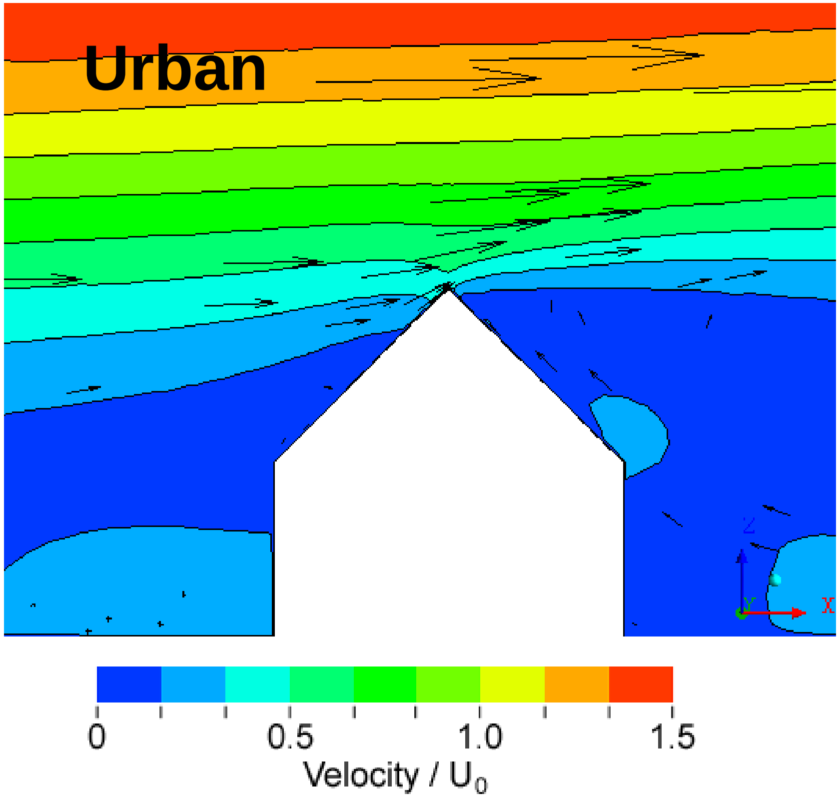
Example simulation



- Speed-up factors calculated for different directions

Isolated house vs. house in a urban area





- Pitched roof of isolated house causes wind speed-up
- This speed-up is *reduced* when embedded in a urban area (depending on building spacing)

Matrix of speed-up values

Wind	Moniker	Heath	Ref	Fltr	Flat	Semi	Trc	Inline	Crvd	FrNbr	SGdn	IncE	IncS
Optimum Mounting Positions: z' = 1.0													
N	**Max S @**	Cnr SE/SW	Frt W	Cnr SE	Cnr SE	Cnr SE	Cnr SE	Cnr SE	Cnr SW	Cnr NE	Cnr SW	Cnr SE	Cnr NE
	Max S	1	0.97	1.09	1.17	0.97	0.95	0.97	1.05	1.19	0.99	1.87	0.92
W	**Max S @**	Frt W	Frt W	Gbl N	Cnr SW	Gbl S	Gbl N	Gbl S	Gbl S	Gbl S	Frt W	Frt W	Gbl N
	Max S	0.5	0.62	0.60	0.58	0.78	0.67	0.77	0.99	0.83	0.49	1.07	0.96
NW	**Max S @**	Cnr SW	Cnr SW	Cnr SE	Cnr SW	Cnr SW	Cnr SW	Cnr SW	Cnr SW	Cnr NW	Cnr SE	Cnr NE	Cnr NW
	Max S	0.8	0.91	1.13	[illegible]	[illegible]	…7	0.73	1.18	1.03	0.79	1.79	1.17
Even	**Location**	Cnr ALL	Cnr NE/SW	Frt E/W	Cnr [illegible]	[illegible]	[illegible]	Cnr NE/SW	Cnr SW	Cnr NE/SW	Cnr SW	Frt W	Cnr NE
	Av S	0.6	0.75	0.88	[illegible]	0.74	0.81	0.74	0.78	0.86	0.70	1.22	0.90
	Av UH'	-	0.35	0.34	0.33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.36
	Av U' *(sic)*	-	0.26	[illegible]	0.27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.32
Optimum and Central Mounting Positions: 3m Mast Length													
N	**Max S @**	[illegible]	[illegible]	Gbl S	Cnr SE	Gbl S	[illegible]	[illegible]	Cnr SW	Cnr NE	Gbl S	Gbl S	Cnr NE
	Max S	[illegible]	[illegible]	1.52	1.62	1.30	[illegible]	1.35	1.47	1.66	1.51	2.10	1.32
	Ctr S	[illegible]	[illegible]	1.51	1.54	1.2…	[illegible]	1.34	1.34	1.65	1.50	2.09	1.30
W	**Max S @**	[illegible]	[illegible]	Frt W	Frt W	Fr…	Cnr SE	[illegible]	…E	Gbl S	Frt W	Frt W	Cnr NE
	Max S	0.9	1.16	1.22	1.25	1.32	1.41	[illegible]	…27	1.30	1.12	1.78	1.44
	Ctr S	-	1.13	1.22	1.2…	1.31	0.77	[illegible]	…62	1.05	1.08	1.68	1.27
NW	**Max S @**	Cnr SW	Cnr SW	Cntr	Cntr	Cnr SW	Gbl S	Cnr SW	Cnr SW	Cntr	Cnr NW	Cnr NE	Frt E
	Max S	1.1	1.50	1.69	1.75	1.44	1.36	1.24	1.58	1.55	1.38	2.11	1.58
	Ctr S	-	1.37	1.69	1.75	1.06	0.90	1.15	1.49	1.55	1.38	1.70	1.58
Even	**Location**	Frt E/W	Cntr	Cntr	Cntr	Frt E/W	Gbl N/S	Cnr	Gbl S	Cntr	Cntr	Frt W	Gbl N
	Av S	1.0	1.34	1.53	1.56	1.20	1.21	1.18	1.30	1.45	1.34	1.71	1.44
	Av UH'	-	0.35	0.34	0.33	0.39	0.45	0.44	0.34	0.38	0.34	0.36	0.36
	Av U' *(sic)*	-	0.47	0.51	0.50	0.47	0.53	0.52	0.44	0.55	0.45	0.61	0.51

Flat roof

3m mast

Max. speed up: Centre mount

NW wind

1.75

N.B. Flatter roof buildings tend to give rise to higher speed-up values than pitched roof

Some Results from Speed-Up Matrix

- When wind parallel to ridgeline, house shape most important factor
- When wind perpendicular to the ridgeline, building stagger dominates
- Influence of shape depends on wind direction; influence of stagger and spacing, and to a lesser extent, curvature of a street, do not
- Max wind speed at turbine:
  - $\sim 0.5U_{mean}$ at 1.3 × building height a.g.l.
  - $\sim 0.3U_{mean}$ at building height a.g.l.
- When wind along ridgeline, maximum speed-up occurs at downstream end

Example energy yield

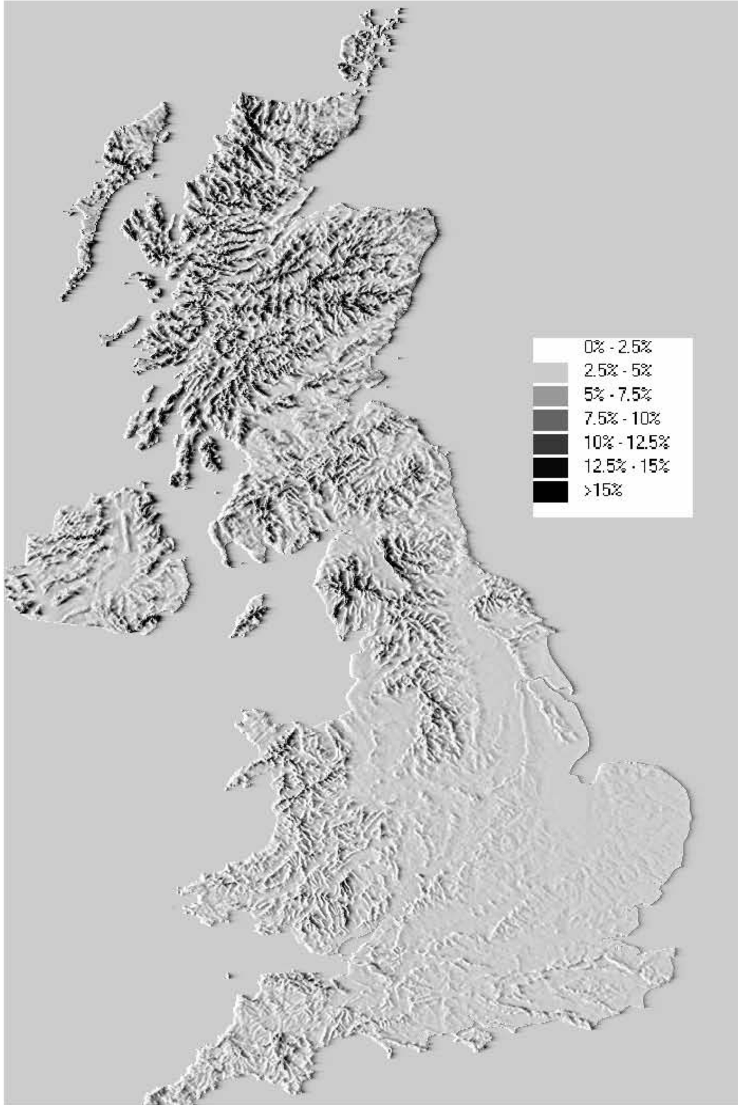
- Terraced house in West London
- Wind rose from Heathrow Airport
- 1.5kW wind turbine mounted on 3m pole

Energy yield results

Wind	Fetch (km)	U_H (m/s)	S	U (m/s)	Freq (%)	E_{100} (kWh/y) Raleigh	E_{100} (kWh/y) Weibull	E_{36} (kWh/y) Raleigh	E_{36} (kWh/y) Weibull
Trc: Optimal location for a 3m mast is Gbl (N) at z' = 1.3									
N	28	3.26	1.14	3.71	10%	174.86	122.57	63.65	44.62
NE	38	1.55	1.00	[illegible]	[illegible]	[illegible]	0.02	2.86	0.01
E	46	1.38	1.36	[illegible]	[illegible]	[illegible]	2.45	5.22	0.89
SE	28	1.56	1.36	[illegible]	[illegible]	[illegible]	9.61	7.14	3.50
S	15	3.30	1.17	[illegible]	[illegible]	[illegible]	221.10	114.67	80.48
SW	4	1.68	1.36	[illegible]	[illegible]	[illegible]	54.14	31.59	19.71
W	4	1.51	1.31	[illegible]	[illegible]	[illegible]	[illegible]	13.80	4.44
NW	12	1.60	1.00	1.60	7%	6.52	[illegible]	2.37	0.01
Total Energy Yield per Annum						*662.92*	*422.12*	*241.30*	*153.65*
Capacity Factor						*5.05%*	*3.21%*	*1.84%*	*1.17%*

Average turbine: <2% capacity factor

UK capacity factor – semi-detached house in urban area



- For most people in a urban area, capacity factor <5%
- Those areas with higher capacity factor are where urban areas tend not to be!

Conclusions and recommendations

- Yields in urban areas likely to be low – careful site selection required
- Wind speed-up effect seen above isolated house reduced when house in an urban area
- Flatter roof buildings tend to give greater wind speed-up than pitched roof
- Siting on house critical – must be above roofline
- Onsite measurement campaigns urgently needed to validate predictions
- Need for micro-wind turbine power curves tested to standard procedures