A detailed comparison between urban and rural circulation at two nearby sites

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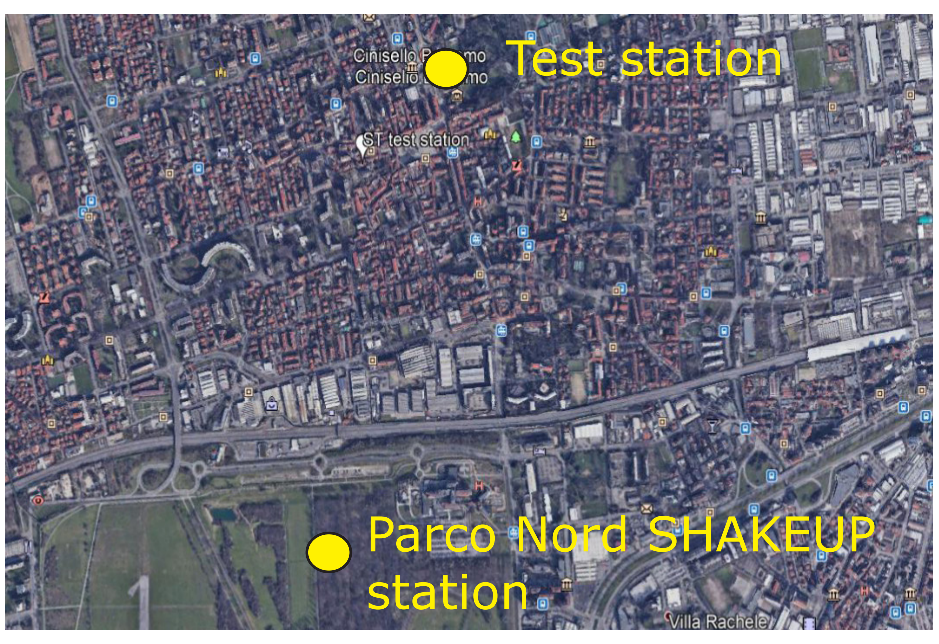


In June 2016 a MeteoFlux® Core V2 station was installed on the author's company office roof, within the densely packed urban area, for testing purposes. The actual tests completed on Octobed 2016.

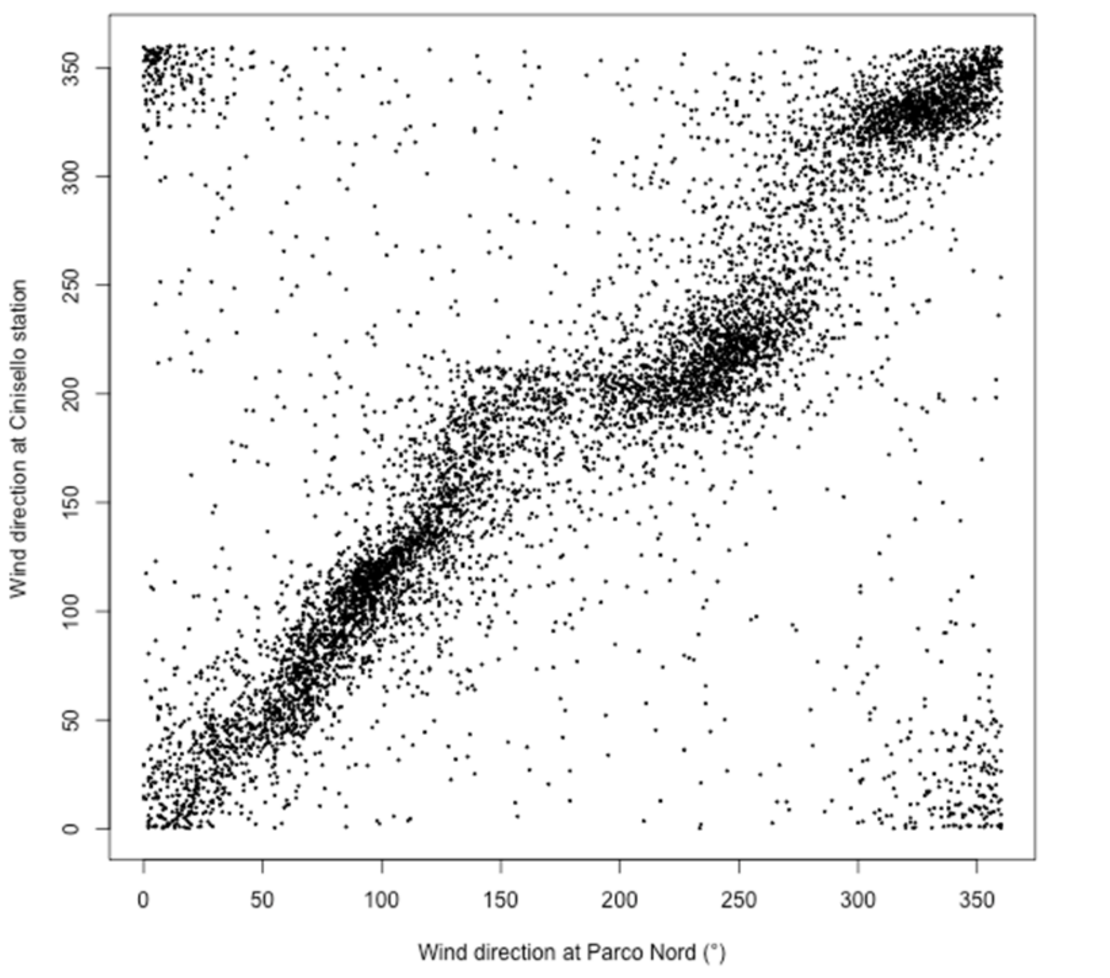
Unattended, and substantially forgotten, the station continued to run until October 2017, collecting raw and processing 3D ultrasonic anemometer data, with almost no gaps.

Quite serendipitously, another station operates continuously in close proximity to Cinisello test station. This station, part of the SHAKEUP network by ARPA Lombardia, based on the same technology (3D ultrasonic anemometer and MeteoFlux® Core V2), is located at Parco Nord in an area having rural characteristics.

The distance between the two stations. about 1500 m, and the huge context difference, suggested no relationship might have been found between measurements at the two sites...

What was actually found resulted in a surprise. Just a scatter plot of wind horizontal direction revealed some correlation to exist.

The correspondenceis not really compatible with a conventional linear model. An important visual departure from linearity occurs between 150° and 250° (Parco Nord). This is due to one important obstruction nearby the Cinisello test station (below).



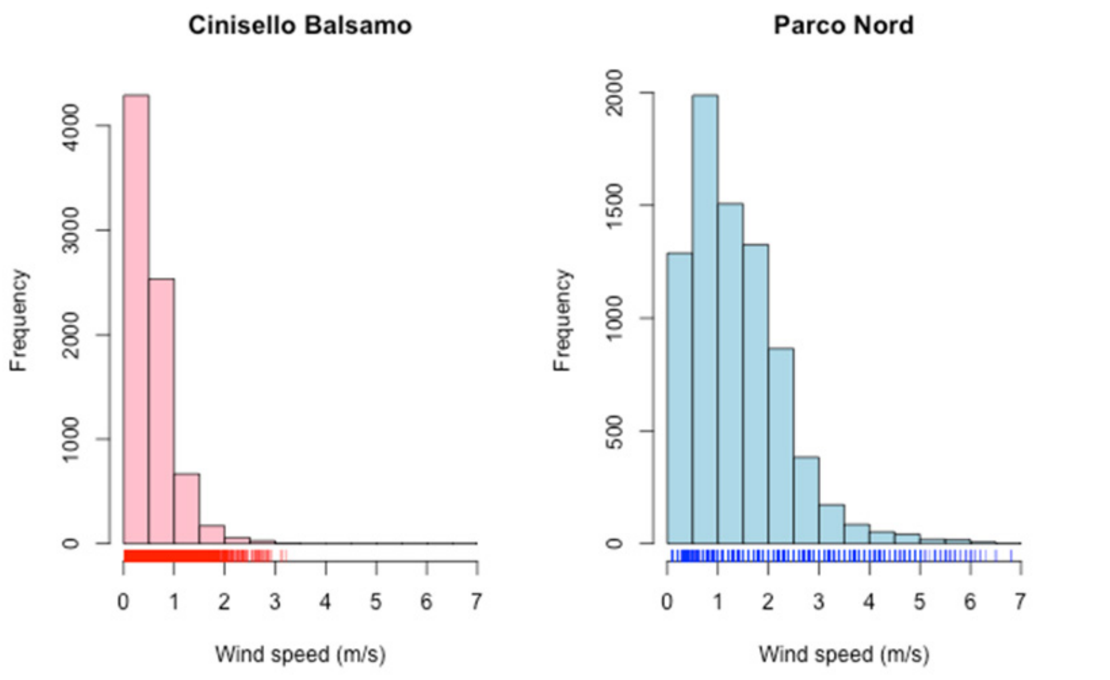
Wind speed, as expected, shows an important reduction from the "rural" Parco Nord to the "urban" Cinisello test station.

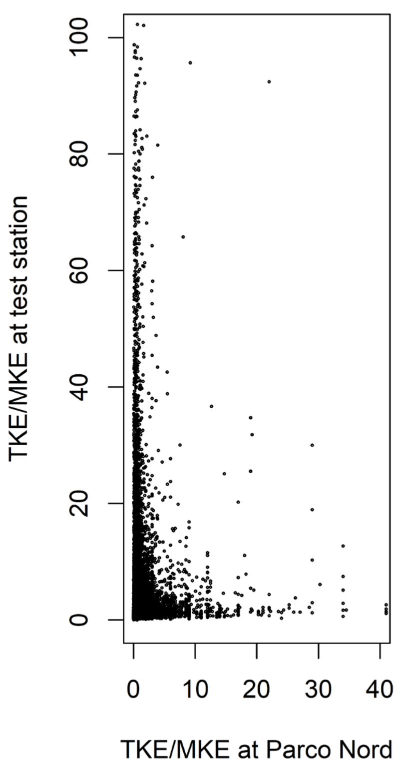
Why did this occur?

One possible reason may be the very special urban texture of that part of Cinisello Balsamo where the station resides, where "ancient" average-two-story buildings with rural destination have been replaced in part by many-story blocks scattered everywhere at random, yet not occupying the whole surface. As we can see in the photo above.

So, tall buildings are relatively isolated: they may perturb airflow locally, but their overall effect seems not enough to change importantly the wind direction in most cases.

With wind speed the story is quite different, especially if measurements are taken at 2m above a roof - likely well within the urban canopy. But, is this change confirmed by changes in the repartition between turbulent and mean flow energy?

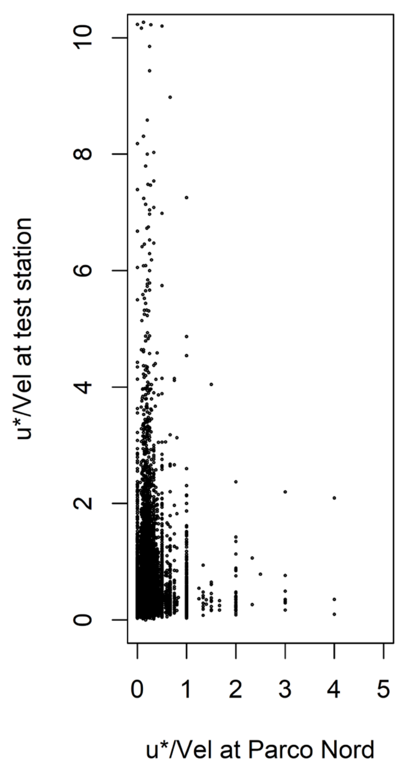


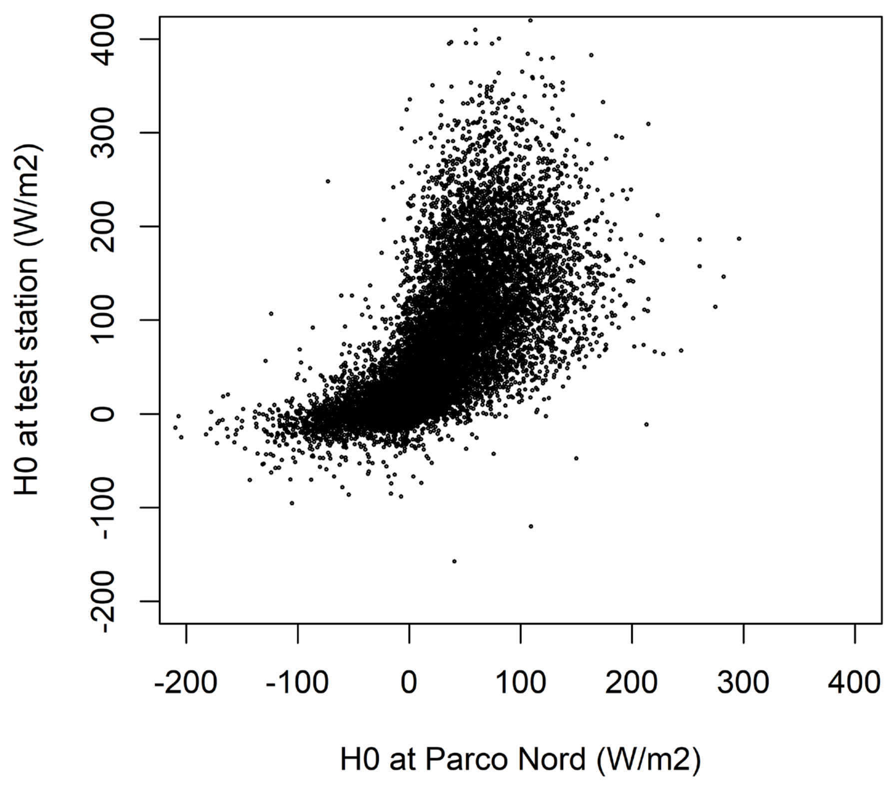


An interesting indication may come from the study of the ratio of the turbulent kinetic energy $TKE = \frac{1}{2}\left(\overline{u'v'} + \overline{u'w'} + \overline{v'w'}\right)$ to mean kinetic energy $MKE = \frac{1}{2}\left(\overline{u}^2 + \overline{v}^2 + \overline{w}^2\right)$ where u, v, w represent respectively the wind components along West-East, South-North and down-up directions, $u = \overline{u} + u', v = \overline{v} + v', w = \overline{w} + w'$ their Reynolds decompositions in mean and fluctuation parts, and $\overline{u'v'}, \overline{u'w'}, \overline{v'w'}$ their covariances.

As we can see from the plot on left, the TKE/MKE ratio spans a much larger interval at Cinisello test station site than at Patco Nord. This is consistent with the intuitive feeling that at an urban site the generation of turbulence is larger than at a rural site nearby, in part due to the larger and more diffused roughness elements in the former (hence a larger "mechanical" turbulence), and in part due to the mostly impermeable surface at urban sites, with the consequent drop in turbulent latent heat flux: this is compensated by an increase of turbulent sensible heat flux and a larger generation of "thermal" turbulence.

The two plots below show the comparisons of friction velocity to wind speed ratio (left) and of turbulent sensible heat flux (right) at the two sites. The friction velocity scatter closely reminds the TKE/MKE's: very large span at Cinisello test station, and very narrow at Parco Nord.





Ratio values so high can be considered exceptional: in flat rural areas values tend to be in the order of 0.1 (friction velocity about 10% than wind speed). At Cinisello, the friction velocity is is much larger than 1 in many cases: the amount of mechanical turbulence is massive, consistently with a within-canopy position.

The sensible heat flux is also interesting, and suggestive of a non-linear correlation. Indeed, for positive H0, a rough proportionality can be seen between the two sites, with a slope somewhat advantaging Cinisello: thermal turbulence is generated whenever energy is available from the Sun. On the contrary, when H0<0 at Parco Nord, the value is about 0 at Cinisello: the nocturnal evolution towards stability is not occurring at the urban site. On many "Parco-Nord-negative" hours positive sensible heat is generated at Cinisello.

So, what? In conclusion, high-resolution wind statistics at Cinisello test station tend to resemble Parco Nord's. As mentioned, this may be a site-dependent effect, caused by an urban texture whose evolution did not followed a precise plan, with a new "tall building" development model scattering around a pre-existing "low building" model. The story is completely different with turbulence, the indicator values obtained at the urban Cinisello site being, well, distinctly urban.

The Cinisello Balsamo urban texture is not that uncommon: most Milan hinterland municipalities, and important parts of Milan itself, underwent a quick, unplanned development in the '60s of last century. As a result, many existing centers did change use destination (namely from agricoltural-residential to residential-industrial), as-large-as-possible buildings being constructed wherever possible.

This means the Cinisello Balsamo situation, although site-dependent, might be representative of a something more diffused condition.

May this bear practical implications? The author guesses so: the special characteristics of urban airflow are conductive to specific pollutant dispersion and accumulation patterns; in part, they are caused by turbulence, i.e. turbulent diffusion, which may be in principle at least be estimated. What's quite difficult to predict is the mean wind direction, that is, medium and long range transport.

But is the urban mean wind "resembles" nearby rural wind to an extent sufficient to make sensible prediction, then the hope of simple correction-based within-canopy wind estimation without resorting to fluid-dynamical models is open to reality - and, further checks.

Of course, **no serendipitous finding can replace a systematic effort**. The micro-meteorological situation of urban sites is largely unexplored, especially in Northern Italy, where population size and density are unusually large as long as vulnerabilities (the SARS Cov II almost uncontrolled spread testifies). Existing networks (like ARPA Lombardia's SHAKEUP micro-meteorological station set) and private stations are still maybe not sufficient for a large-scale study, and yet exist: we have a good starting point. We cant'imagine such an endeavour to be made other than by extensive cooperation.

And Nature, as usual, will not spare us surprises.

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The angle of curiosity. That is, "how we made it".

High resolution measurements of wind and turbulence demand using special instruments. One example (used here) is the three-dimensional ultrasonic anemometer: on right, we see an uSonic-3 model, by Metek GmbH.

An ultrasonic anemometer is not enough, however: the instrument produces a stream of very high resolution wind and temperature data. The mass of readings is just too much to be of immediate use, and a real-time processor is then indispensable to distill useful data and information from it.

This is the task of (to mention the unit actually used in this work) MeteoFlux® Core V2: a real-time "eddy covariance" system.

The "eddy covariance" is a data processing technique, grounded on statistics, which is specially siuted to ultrasonic anemometer data.

Originated around the '70s of past century, to date the eddy covariance is one of the techniques closest to measuring directly turbulence: the alternative is to estimate it.

The rendering of "crude" eddy covariance statistics to useable turbulence indices is then made using "Monin-Obukhov similarity theory", aka "Surface Layer Similarity".