EUROPEAN UNION

European Regional Development Fund

Regional Initiative Project

citeair II

Common Information to European Air

CAQI Air quality index

Comparing Urban Air Quality across Borders - 2012

Dissemination level	External
Component	5
Author(s)	Sef van den Elshout
Co-author(s)	Hans Bartelds, Hermann Heich, Karine Léger
Status	Final
File Name	citeair_ii_caqi_update.doc, May 23, 2012
Contact	Sef.vandenelshout@dcmr.nl, +31-10-2468368 DCMR, PO Box 843, 3100AV Schiedam, the Netherlands
Project Start Date and Duration	October 2008, 36 months

European Union
European Regional Development Fund

Co-financed by the ERDF

INTERREG IVC
INNOVATION & ENVIRONMENT
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Summary

The CAQI index is used on the www.airqualitynow.eu website since 2006. For the first time since its application it is evaluated on a large set of Airbase data. At the same time the CAQI received an update. The introduction of limit values for $PM_{2.5}$ made it necessary to accommodate that pollutant in the index. Though $PM_{2.5}$ is an important pollutant it is not included as a core pollutant. This is due to the way the EU $PM_{2.5}$ monitoring requirements are formulated and to the fact that implementation has started only recently. It should not be seen as a sign that it is less important than the mandatory pollutants nor that it hardly determines the overall index. The CAQI is calculated for hourly, daily and yearly averaged data. The calculation methods for daily and hourly data (discussed in the first 4 chapters) are quite similar. The year average index is calculated in a different way and is presented in chapter 5.

Pollutants and calculation grid for the revised CAQI hourly and daily grid (all changes in italics)

Index class	Grid	Traffic						City Background							
		core pollutants			pollutants			core pollutants				pollutants			
		NO2	PM10		PM2.5		CO	NO2	PM10		O3	PM2.5		CO	SO_2
			1-h.	24-h.	1-h.	24-h.			1-h.	24-h.		1-h.	24-h.		
Very low	0	0	0	0	*0*	*0*	0	0	0	0	0	*0*	*0*	0	0
	25	50	25	*15*	*15*	*10*	5000	50	25	*15*	60	*15*	*10*	5000	50
Low	25	50	25	*15*	*15*	*10*	5000	50	26	*15*	60	*15*	*10*	5000	50
	50	100	50	*30*	*30*	*20*	7500	100	50	*30*	120	*30*	*20*	7500	100
Medium	50	100	50	*30*	*30*	*20*	7500	100	50	*30*	120	*30*	*20*	7500	100
	75	200	90	50	*55*	*30*	10000	200	90	50	180	*55*	*30*	10000	*350*
High	75	200	90	50	*55*	*30*	10000	200	90	50	180	*55*	*30*	10000	*350*
	100	400	180	100	*110*	*60*	20000	400	180	100	240	*110*	*60*	20000	500
Very High*	> 100	> 400	>180	>100	*> 110*	*>60*	>20000	> 400	>180	>100	>240	*> 110*	*>60*	>20000	>500

NO_2, O_3, SO_2: hourly value / maximum hourly value in µg/m^3
CO 8 hours moving average / maximum 8 hours moving average in µg/m^3
PM_{10} hourly value / daily value in µg/m^3

* An index value above 100 is not calculated but reported as " > 100"

Calculation scheme for the revised year average index (all changes in italics)

Pollutant	Target value / limit value	Calculation
NO_2	Year average is 40 µg/m^3	Year average / 40
PM_{10}	Year average is 40 µg/m^3	Year average / 40
PM_{10} daily	*Number of daily averages above 50 µg/m^3 is 35 days*	*Log(number of days+1) / Log(36)*
Ozone	25 days with an 8-hour average value >= 120 µg/m^3	# days with 8-hour average >=120 / 25
$PM_{2.5}$	*Year average is 20 µg/m^3*	*Year average / 20*
SO_2	Year average is 20 µg/m^3	Year average / 20
Benzene	Year average is 5 µg/m^3	Year average / 5
CO	-	Not calculated

Acknowledgements

The EEA Airbase staff (Hermann Peifer and David Simoens) were very kind in making a pre-selection of stations and data, saving us a great deal of work in preparing our sample. Additional daily averaged data for PM_{10} and $PM_{2.5}$ was made available by Frank de Leeuw (PBL/EEA). Frank de Leeuw and Gary Fuller (Kings College) provided valuable feedback on a previous version of this document.

Box 1

CITEAIR indices in short

Air quality in European cities is presented in an easily understandable way by converting all detailed measurements for a city into a single relative figure: the Common Air Quality Index (or CAQI). To enable the comparison between cities three indices are available with a different time scale:

- **An hourly index:** which describes the air quality today, based on hourly measurements and updated every hour,
- **A daily index:** which stands for the general air quality situation of yesterday, based on daily values and updated once a day,
- **An annual index:** which represents the city's general air quality conditions throughout the year. This index is based on the pollutants year average concentrations compared to annual limit values. It is updated once a year.

The CAQI is used on www.airqualitynow.eu where the air quality of nearly 100 cities can be seen and compared.

The Hourly and daily indices

These indices have five levels using a scale from '0' (very low) to '> 100' (very high). It presents a relative measure of the amount of air pollution. The calculation is based on three pollutants of major concern: PM_{10}, NO_2, O_3. It can also take the pollutants $PM_{2.5}$, CO and SO_2 into account if these data are also available.

In order to make cities more comparable, independent of the nature of their monitoring network two situations are defined:

- City Background, representing the general air quality in an agglomeration (based on urban background monitoring sites),
- Roadside, representing the air quality in streets (based on roadside monitoring stations)

Pollution	Index Value
Very Low	0 / 25
Low	25 / 50
Medium	50 / 75
High	75 / 100
Very High	> 100

The annual air quality indices

The year average common air quality index (YAQACI) provides a relative measure of the annual average air quality in relation to the European limit values. It is also calculated both for background and traffic conditions but its principle of calculation is different from the hourly and daily indices. It is presented as a distance to a target index. The target being the EU directives (annual air quality standards and objectives):

- If the index is higher than : for one or more pollutants the limit values are not met.
- If the index is below : on average the limit values are met.

The annual index is aimed at better taking into account long term exposure to air pollution based on distance to the target set by the EU annual norms, those norms being linked most of the time to recommendations and health protection set up by World Health Organisation

Air Quality	Index Value
EU Standards are exceeded by one pollutant or more	> 1
EU Standards are fulfilled on average	1
The situation is better than the norms requirements on average	< 1

1 Introduction

1.1 Scope of the document

1.1.1 Daily and hourly indices

The CAQI or Common Air Quality Index has been operational on the website www.airqualitynow.eu since 2006. After an initial proposal the calculation grid was revised to improve the representation of the PM_{10} concentrations. In the first version of the CAQI, the fact that PM_{10} is being measured both on an hourly and daily basis was initially not well covered and the PM_{10} grid was rather strict. This was revised after an analysis of PM_{10} data from Airbase stations. The final CAQI calculation grid is operational since 2007.

In this paper we evaluate the way the CAQI performs on a selection of urban and suburban stations. In addition we propose a calculation grid for $PM_{2.5}$. Since the CAQI was launched the air quality directives have been revised and a limit value for $PM_{2.5}$ was added in the new, so called, CAFE directive (2008/50/EC of 21 May 2008). $PM_{2.5}$ is a health relevant and regulated parameter so it had to be included in the CAQI calculation. However we wanted the new CAQI calculation to be in line with the existing calculation grid to avoid major changes in the outcome. Therefore, we experimented with various calculation grids.

The data used were obtained from Airbase (http://air-climate.eionet.europa.eu/databases/airbase/). We used urban and suburban stations (background and traffic) where the core pollutants of the index were monitored. We used 2006 as the year for which data were analysed. Though in 2007 there are more stations in Airbase monitoring $PM_{2.5}$, 2006 was used as, on average[1], the concentrations observed were slightly higher than in 2007.

See chapter 3 for the evaluation of the CAQI performance and chapter 4 for the revised calculation grid, after inclusion of $PM_{2.5}$.

1.1.2 Previous index document

This document replaces 'Comparing Urban Air Quality across Borders', the first document describing the index. The previous document not only describes the index but also the logic why, at the time, such an index was needed. That discussion won't be repeated here. The old document is currently still available at the project website or via the short published version:

- http://citeair.rec.org/downloads/Products/ComparingUrbanAirQualityAcrossBorders.pdf
- http://dx.doi.org/10.1016/j.envint.2007.12.011

The basic working of the index is also briefly described in chapter 2 of this document.

1.2 Use of the CAQI indices in another context

Potential users of the CAQI must notify the CITEAIR partners (at caqi@airqualitynow.eu) and establish a user agreement (www.airqualitynow.eu/about_copyright.php#legal_agreement). This way, users can be kept informed in case of further developments concerning the index. The use of the CAQI is free of charge for non commercial purposes.

[1] This is not true everywhere. In France the PM monitoring method was modified to include a correction for the loss of volatile material. This leads to higher PM concentrations.

2 Basic concepts of the CAQI

2.1 History of the CAQI

The CAQI was developed in the course of the CITEAIR project (an INTEREG IIIC project, 2004-2007) and has been around since 2006. The index was made for the purpose of easily comparing the air quality in European cities in real-time. At the start of the CITEAIR project we observed that many cities present their air quality in different, hard to compare, ways. Often they use an own (or sometimes nationally prescribed) air quality index but as all indices were different in logic and presentation this didn't help[2]. For the purpose of comparison we developed a new index. The main reason to add yet another index was practical and twofold:

- The index was developed for the purpose of comparing cities on a website and should coexist next to any existing local indices that people might be used to; it was not meant to replace existing indices.
- This way no city in no country willing to participate in the online comparison was forced to use someone else's index.

Whether this has actually contributed to the success of the index is not known but the fact is that what was started as a project proposal by (and an obligation for) five cities has by now (October 2010) grown to a system (www.airqualitynow.eu) where about hundred cities voluntarily submit their data for online comparison purposes.

The CAQI is part of an effort to raise awareness on urban air quality. This purpose has consequences for the design of the index as will be described in the next section. In the past years there have been various publications on the CAQI and the website www.airqualitynow.eu. Some of the publications are mainly descriptive, some focus more on the reasoning behind the choices made in developing the index the way we did. In the next section we provide the reasoning behind the working of the index.

Most of the indices found in literature and on the internet cover the short-term air quality situation (hourly, daily). This applies to the CAQI as well. Indices for the long-term air quality are very rare. We provide a year average CAQI (YAQACI). This index is calculated in a completely different manner and this is described in part 2 of this document (to be published in 2012).

2.2 Description of the CAQI

2.2.1 Introduction

There are many ways of making an air quality index and one way is not necessarily better than the other. Making an index is a pragmatic process of reducing a variety of information on the chemical characteristics of a complex mixture of pollutants observed in the air into a simple (often single) figure on a scale. From a scientific point of view this is a gross generalisation and a tremendous loss of information but for communication purposes this information reduction is considered essential. That is why there are so many indices in use all over the world. However, this assumption has never been tested as far as we know. Shooter and Brimblecombe (2009), in a review article on air quality indices, mention (citing Burden and Ellis, 1996) that in Australia, public confidence in reporting on air pollution fell following the introduction of an index.

How to reduce the complex information largely depends on the purpose for which the index is to be used. The exact formula to transfer concentration readings into index classes is

[2] For an overview of different indices in use see for example Elshout and Léger (2007) and Garcia et al. (2002). Note that index calculations become outdated; the information in these sources might no longer be correct!

another matter of subjective choices though often limit values (for example ensuing form air quality legislation such as Directive 2008/50/EC) are used as guidance.

Shooter and Brimblecombe (2009) mention two reasons for making an index: firstly linking air quality to health effects to inform the public of poor air quality and of possible remedial actions; secondly to condense complex data to provide an information overview e.g. for the development of policy or to check compliance with standards. We formulated a third reason: drawing the public's attention to air quality issues and raising awareness.

- Linking air quality to health effects

Linking air quality information to health effects is potentially a very powerful way of communicating as individual health concerns tend to be very persuasive. However indices strongly based on health effects also have limitations. The relations between air quality and health are many, they interact in still poorly understood ways and their exact nature is hard to quantify. This has several implications:

- the indices need to undergo frequent updates as sciences evolve (e.g. Longhurst, 2005);
- they can become very complex if one tries to capture pollutant interactions (e.g. Cairncross et al., 2007) and usually the simpler approach that the worst pollutant (at a given time) determines the index for that moment is followed;
- health effects occur over different exposure times (both short-term and long-term) and the reported index value usually refers to only one averaging time (usually daily);
- lastly several pollutants that are currently believed to be the main causes of health effects of air pollution (e.g. elemental carbon, ultrafine particles, particle numbers) are not (yet) regulated and are not commonly monitored and included in indices.

The different consequences of different exposure times poses an awkward communication problem. A health-based index meant to warn people for short-term exposure to adverse air quality is mainly in the good part of the index scale, indicating that air quality is not a problem. Though this could be true from the short-term exposure point of view, the long-term exposure (even to low levels of air pollution) is often worrisome. Furthermore, limit value exceedences for long-term exposure (e.g. year averages) are exceeded in many urban areas even if a health-based air quality index is virtually continuously signalling that there are no problems. In this case a health-based index might add to the confusion: visiting the city website there seems to be no problem, yet an air quality action plan is needed to comply to legal standards. The US and UK air quality standards are typical examples of health-based indices[3].

Despite these drawbacks one could argue that it is important to alert people of adverse air quality, and this alone could be a reason to have such an index. Shooter and Brimblecombe (2009) mention this as the principal reason to have an air quality index (and many indices started/are operated with this in mind). However they note (citing Johnson, 2003) that these indices rarely succeed in changing people's behaviour in face of the oncoming poor air quality. They argue that better forecasting, making a timelier alert might improve people's response in the case that the index is signalling adverse air quality. This is obviously an improvement making the index and the displayed information more useful. On the other hand, we doubt that this would considerably change the general public's response to an alert. The air quality has to be extremely poor before it poses an acute danger to the population in general. With busy agenda's it is unlikely that the average person will cancel his sports game, that a school outdoor activity that was planned long ago (involving many volunteers) is postponed at short notice to avoid exposure, etc. The possibilities to adjust one's plans as well as the medical need to do so, are limited for most people. Today there are better, more targeted ways to inform the select group of people that really needs to adapt their activities in the face of pollution episodes than a general index presented on a website.

[3] Note that they differ considerably, reflecting the different appreciation of the health impact of a certain pollutant level.

For example Sussex-air provides a messaging system that those in need of this kind of information can subscribe to (see www.airalert.info/Sussex/Default.aspx). Smartphone applications could play a similar role.

- Providing simple overview information for policy formulation or monitoring

The short-term indices are mainly used for informing or warning the public. However, some authorities report annually the number of days an index was above a certain level. Year average indices are more apt for policy monitoring. See Mayer et al (2008) for the application of the German LAQx. CITEAIR also proposes a year average distance to target type of index. The policy application of an index necessarily has a longer averaging time than the alerting/informing indices. For policy formulating or monitoring one would also need to consider spatial representativeness and averaging, e.g. an index value that is population or area weighted. See for example Bell et al. (2011). The communicative beauty of presenting a single index figure to mark the air quality then hides an increasingly complex calculation analysis and the implications of the index, or its changes, might be hard to interpret. Shooter and Brimblecombe (2009) raise this point as well. On the other hand, we should not forget that the sole purpose of making an index is to arrive at a single, simple (arbitrary) relative parameter that, if applied consistently, gives an indication of progress or stagnation. Hiding information is the purpose of making an index!

- Drawing the public's attention to air quality and raising awareness

The public is both a victim and a source of air pollution particularly in urban areas. Traffic is often the dominant source of urban air pollution. Though in some industrialised cities the tons emitted through high stacks might be higher than the tons emitted by vehicles, the contribution of traffic to the ambient air pollution, the air people breath, often exceeds 50% and can be as high as 80%. This is particularly true for the most health relevant pollutants: the smallest particles (< PM_1) or the Elemental or Black Carbon fraction[4]. This pollution is mainly attributed to diesel vehicle exhaust. From the regulatory perspective, exceedences of the EU regulation along the streets for PM_{10}, $PM_{2.5}$ and NO_2 are of major concern for many cities in Europe[5]. Local authorities therefore have a keen interest in trying to influence the behaviour and the travel choices of the urban population. Raising awareness on the sources of pollution is one way of doing so.

If awareness raising is an objective, the last thing one wants is an index saying that the air quality is good whilst from the long-term exposure and the legal perspective it is not. The short-term index we needed and developed can therefore not be health-based in the sense that the index scales directly related to the extent of health impacts (as is the case in the US for example). It can have alert values for pollution episodes but it also needs to have differentiation of the air quality appreciation at the lower end of the pollution scale. An example of indices without a direct link to health effects and with differentiation at the lower end of the pollution scale are for example the French and Belgium indices. At the opposite, an index that is always "poor" does not help either.

We further assumed that to entice people to visit the air quality websites and check the situation one would need an hourly index, hourly updated. This way people can see how pollution levels evolve throughout the day and can related index readings to physical events: elevated midday ozone peaks, rush-hours, etc. We also assumed that a scale with considerable differentiation (1-100) would lead to a more dynamic (interesting) presentation than a grid from 1 to 5 or 1 to 10. From a scientific point of view it hardly makes sense to

[4] The exact cause of the health effects of traffic pollution or not yet known. Whether it is particle numbers, nano particles, soot, metals, or a combination is not clear. That traffic is a major source is undisputed, as is the fact that it is mainly the smaller particle fraction.

[5] Elevated background concentrations of particulate matter and particulate pollution due to wood burning in winter are also concerns for member states with difficulties meeting the EU air quality standards.

derive index values with that kind of detail, but from a communication point of view we thought that it will help.

To draw specific attention to traffic as an important source, and roads as an awkward place to be (from the exposure point of view) we calculate the index separately for roadside and city background situations.

2.2.2 The logic of the CAQI

The CAQI has no direct link to short-term health-effects. The methodological disadvantages of a strictly health-based index were discussed in the previous section. Besides, the CAQI was primarily developed to raise awareness and make air quality comparable from one city to another. Warning citizens of adverse air quality was a task best left, according to us, to the cities own web pages with the index (often tailor made to the local circumstances) and communication approach the citizens in the particular city were used to. This doesn't mean that the CAQI cannot be used as a city's sole index, the CAQI resembles a number of other indices (the French and Belgium indices for example) and if a city doesn't have an index, or if the index needs an overhaul, the CAQI could be considered. Otherwise changing local indices is not really advisable as it might confuse the users/the public.

The CAQI has a scale from 1 to 100 with lower rankings representing better air quality. Some of the higher class borders are linked to concentrations mentioned in the EU air quality directives (Directive 2008/50/EC). The large range of the scale assures changes, even at the lower end of the scale.

The CAQI has an hourly time resolution (except for CO). A daily time resolution is also possible for yesterday and for forecasted concentrations. Many indices are on a daily basis because the criteria in the legislation for the different pollutants have different averaging times. E.g. the EU directives assess hourly values of NO_2, daily average values of PM_{10}, 8-hour average values for O_3 and CO (in addition to a range of year average criteria). The hourly calculation is done for reasons of attractiveness outlined above.

A practical problem with the hourly index is that some cities only provide 24-hour average PM data (or moving 24 hour average). The EU has a PM_{10} limit value for 24-hour averaged data and monitoring methods used in Europe rely either on devices providing 24h average data or devices providing hourly data. We have therefore derived two grids for PM_{10} and $PM_{2.5}$ data, one for hourly observations and one for daily observations. This way a city that produces 24-hour (moving average) data can still participate in the index/website by applying the daily grid. The consistency between the daily and the hourly grid is discussed in section 3.3.

Core and other pollutants. There are core pollutants (without those an index value cannot be calculated) and other pollutants. The traffic index comprises NO_2 and PM_{10}, with CO and $PM_{2.5}$ as other pollutants. The background index obligatory comprises NO_2, PM_{10} and O_3, with $PM_{2.5}$, CO and SO_2 as additional pollutants.

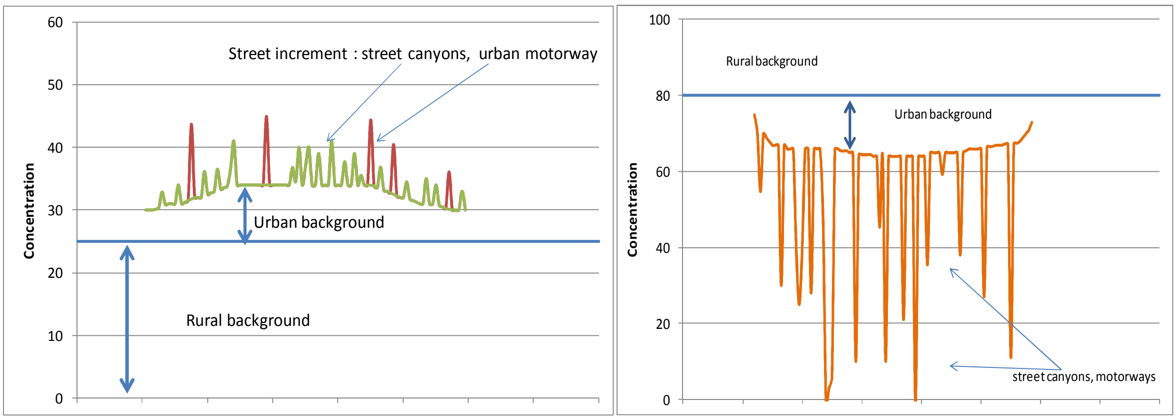
The worst pollutant determines the index. For each pollutant a sub-index is calculated according to a grid that translates concentration measurements into a ranking on a scale from 1 to 100 (see table 1 for the old grid). The highest sub-index value at a given time determines the overall index. This is very common for indices, in particular for indices that have an alerting role to play. Some health based indices claim that interactions between pollutants have to be considered (for proper health assessments) these indices are complicated and less frequently used. If an index is used to monitor air quality policy in terms of health benefits, such an index could be considered.

In the way the CAQI is implemented on the website www.airqualitynow.eu the worst monitoring station in a certain city, at a given moment, determines the index value. The calculation order is: first the sub-indices per monitoring station, the overall index for each station, the highest overall index becomes the city index. This procedure is applied separately for the traffic and the background indices.

Box 2: Two indices to characterise a city and their typical evolution during the day

Two indices to characterise a city

The logic of the two indices is easily visualised by two theoretical pictures of air pollutants in a city. For primary pollutants (often related to traffic) the figure on the left illustrates the situation. For ozone, the right hand picture best describes the concentrations in a city.



Where and when ozone is not dominant the traffic index will likely be higher than the city background index. However if ozone is the dominant pollutant at a given time the background index will be higher.

This can easily be seen from the evolution of the index on a given day (screenshots form www.airqualitynow.eu). In Lyon the evolution in the course of the day is predictable, as soon as the circulation starts to move, the roadside index becomes higher and primary pollutants determine the index. The roadside index is higher than the background throughout the day. In Seville on the same day, the roadside index (note that the peak driving hours are notably different) is lower for a large part of the day. There is an unexplained PM_{10} peak at the background at 07.00h but the point we want to illustrate is visible in the afternoon: the background index is higher than the traffic index due to elevated ozone on a sunny afternoon.

Lyon Yesterday Details

Hour	ROADSIDE INDEX		BACKGROUND INDEX	
	Index value	Pollutant	Index value	Pollutant
0	22	NO2	18	NO2
1	21	NO2	17	NO2
2	27	NO2	17	NO2
3	26	NO2	18	NO2
4	51	NO2	23	NO2
5	60	NO2	24	NO2
6	68	NO2	29	PM10
7	69	NO2	32	PM10
8	70	NO2	25	NO2
9	64	NO2	26	PM10
10	63	NO2	32	O3
11	57	NO2	35	O3
12	56	NO2	35	O3
13	51	PM10	35	O3
14	51	PM10	38	O3
15	44	PM10	40	O3
16	44	NO2	41	O3
17	49	NO2	38	O3
18	41	PM10	38	O3
19	36	PM10	35	PM10
20	37	NO2	41	PM10
21	35	NO2	26	O3
22	32	PM10	29	O3
23	28	PM10	28	O3

NB: the pollutant with the highest value at a certain time determines the overall score of that time

Sevilla Yesterday Details

Hour	ROADSIDE INDEX		BACKGROUND INDEX	
	Index value	Pollutant	Index value	Pollutant
0	37	PM10	30	O3
1	38	PM10	32	O3
2	39	PM10	46	PM10
3	30	PM10	32	O3
4	24	PM10	31	O3
5	27	PM10	28	O3
6	30	NO2	83	PM10
7	34	NO2	> 100	PM10
8	42	PM10	59	PM10
9	22	NO2	60	PM10
10	23	NO2	38	O3
11	29	NO2	46	O3
12	41	PM10	54	O3
13	43	NO2	60	O3
14	53	PM10	63	O3
15	40	PM10	69	O3
16	28	PM10	64	O3
17	59	PM10	48	O3
18	41	PM10	55	PM10
19	76	PM10	41	PM10
20	72	PM10	43	PM10
21	52	PM10	43	PM10
22	49	PM10	48	PM10
23	30	PM10	58	PM10

NB: the pollutant with the highest value at a certain time determines the overall score of that time

It is calculated both for city background and traffic situations. This has two reasons. From a communication point of view this draws specific attention to the role of traffic as a source of pollution. Mostly the traffic index is higher than the background index. This is true for the traffic related primary pollutants NO_2, PM_{10} and $PM_{2.5}$. In many southern cities where ozone plays a major role, the picture is different. The fresh exhaust emission of NO converts O_3 into NO_2 and O_2. Ozone is typically higher in the countryside than the city background and is very low in street canyons. Especially in the afternoon, city background index values often exceed the traffic index in summer.

The second important reason two calculate two indices is to make cities more comparable (one of the CITEAIR objectives and the website www.airqaulitynow.eu). Some cities don't monitor at traffic sites, some cities might focus on traffic as they are often the most polluted sites. If one wanted to compare city average concentrations in cities with completely different monitoring strategies the results would be flawed. By stratifying the sample into background and traffic situations the results become more comparable. See box 2.

2.3 User feedback, acceptance and comments

The CAQI was established after an international review of air quality indices and statistical tests with data from four CITEAIR cities. It is displayed on the website www.airqualitynow.eu. It has been presented at several international conferences and it was published in a journal and several proceedings. It has been subject to peer review: the very first version of the CAQI was reviewed, amongst other indices, by EEA (Leeuw, and Mol, 2005) and Martin Lutz (Senate of Berlin) for the PM_{10} grid. References to the current version of the CAQI are made in recent publications dealing with indices.

The growing participation of cities in the website can be seen as an implicit acceptance of the CAQI as well. The website started with eight cities that were member of, or affiliated to the CITEAIR project. Currently it has over 100 voluntarily participating cities.

The CAQI is used in a environmental website initiative from the EEA called Eye on Earth (http://watch.eyeonearth.org/) and in a GMES downstream service project called obsAIRve (www.obsairve.eu). In short, the CAQI has found several applications outside its original context and it is known to those interested in the field of air quality indexing. Annex 1 shows a list of references to, and publications made on the CAQI.

Questions also continue to exist:

a. having two indices alongside each other (a local one and the CAQI as an international one for comparison purposes) might confuse the public;
b. the index is not well adapted to our local situation;
c. the index is too complicated (too many pollutants);
d. the index is not good in reflecting health effects of the air quality.

Points a. and b. cannot be remedied. In fact they are the essence of the CAQI index: it aims to cater for situations in a vast range of countries and makes air quality presentation comparable across countries. We assumed that most cities interested in comparing their air quality to that of other cities would not be willing to replace their local index and air quality presentation system by another one. And for very good reasons: it is not advisable from a communication point of view. The best way forward, we assumed, was a new neutral index, marketed specifically for international comparison purposes.

Point c. could be tackled by reducing the number of pollutants to the current core pollutants and skipping completely the less relevant pollutants. The index would then be based on PM_{10}, NO_2 and O_3 (the latter not for traffic) and maybe $PM_{2.5}$. CO and SO_2 were included, at the time, because several cities where monitoring these pollutants and occasionally they still play a role. Providing a calculation grid provides a way to compare these pollutants relative to the other pollutants. CO and SO_2 are treated as additional pollutants, they are not needed to calculate the index and in most cities they hardly influence the index calculation.

Point d. is a matter of choice. We have argued in section 2.2 and in the previous CAQI document that a health-based index is complex and its focus on short-term exposure makes it less suitable for raising awareness. The main goal of the CAQI is not to warn people for possible adverse health effects of poor air quality but to attract their attention to urban air pollution and its main source (traffic) and help them decrease their exposure. We believe that awareness on air pollution and its sources adds in (support for) reducing pollution. Health warnings could typically be a purpose of a local city index/warning system.[6]

[6] The index can, if some wishes to do so, be used for alerts, even if there is no well established link between a certain index reading and a corresponding health effect.

3 Use of current CAQI index

3.1 Calculation grid existing index

The calculation grid as it is in use before the addition of $PM_{2.5}$ is shown in table 1. The grid is inspired on threshold values as they occur in the EU air quality directives, on values used in similar indices and on a number of pragmatic considerations such as frequent changes also at the lower end of the pollution scale. A full discussion is given in the index document of the CITEAIR 1 project.[7] The index was initially tested on a dataset from the CITEAIR 1 project partners. For PM_{10} an additional selection of Airbase data was analysed. In this document we look at frequency distributions for all pollutants to get an impression of the message the index tends to convey (is the air pollution high or low). For this analysis we have only looked at the mandatory pollutants. In Annex 2 a graphical display of the relation between the grid and the concentrations is given.

Table 1: Pollutants and calculation grid for the old CAQI

Index class	Grid	Traffic				City Background					
		Core Pollutant			Pollutant	Core pollutant				Pollutant	
		NO_2	PM_{10} 1-hour	PM_{10} 24-hours	CO	NO_2	PM_{10} 1-hour	PM_{10} 24-hours	O_3	CO	SO_2
Very low	0	0	0	0	0	0	0	0	0	0	0
	25	50	25	12.5	5000	50	25	12.5	60	5000	50
Low	25	50	25	12.5	5000	50	25	12.5	60	5000	50
	50	100	50	25	7500	100	50	25	120	7500	100
Medium	50	100	50	25	7500	100	50	25	120	7500	100
	75	200	90	50	10000	200	90	50	180	10000	300
High	75	200	90	50	10000	200	90	50	180	10000	300
	100	400	180	100	20000	400	180	100	240	20000	500
Very High*	> 100	> 400	>180	>100	>20000	> 400	>180	>100	>240	>20000	>500
NO_2, O_3, SO_2:		hourly value / maximum hourly value in µg/m^3									
CO		8 hours moving average / maximum 8 hours moving average in µg/m^3									
PM_{10}		hourly value / daily value in µg/^{m3}									

* An index value above 100 is not calculated but reported as " > 100"

The calculation grid is used for the hourly index. In addition to the hourly index a daily index is calculated using the maxima of the hourly sub-indices (or, in case of a city reporting PM_{10} only on daily basis, using the PM_{10} daily grid for that subindex). On the website www.airqualitynow.eu this is done for the past day (D-1) and it will be used in the forecast that is being developed. For cities that do deliver hourly PM data the daily index will be calculated based on the maximum of the hourly values. This way the readings between today and yesterday (D and D-1) are consistent.

[7] http://citeair.rec.org/downloads/Products/ComparingUrbanAirQualityAcrossBorders.pdf or (for a short, published version) http://dx.doi.org/10.1016/j.envint.2007.12.011

3.2 Results of the application of the CAQI (hourly data)

Airbase data for 2006 for urban and suburban stations were used to make the analysis. Data from the following countries were used (# background, #traffic): Belgium (3, 3), Czech Republic (13, 6), Germany (4, 4), Finland (1, 3), France (3, 3), Italy (3, 3) Spain (1, 2), Sweden (3, 2), and United Kingdom (0, 1). So, 31 background and 27 traffic stations were available. For 6 cities pairs of traffic and background sites were available. For a list of the Airbase stations used, see annex 3. Note that for France and Italy no hourly values for PM were obtained. In the analysis of the hourly indices and where hourly and daily indices are compared, these stations are left out.

Table 2: Frequency (%) of the occurrence of the index and sub-index classes (hourly data)

Dominant pollutant	Back-ground	Traffic	Index class	Background				Traffic		
				Overall index	Sub-indices			Overall index	Sub-indices	
					PM10	O3	NO2		PM10	NO2
PM10	49	67	0-25	27	55	64	92	35	48	63
O3	45		25-50	51	32	33	8	41	34	30
NO2	6	33	50-75	17	10	3	0	18	14	6
			75-100	4	2	0	0	5	4	0
			" >100"	1	1	0	0	1	1	0

Table 2 shows the average occurrence (of the sample) of the different classes for the sub-indices. As can be seen, the majority of the sub-indices are in the first class, indicating that pollution is very low (NB: sample average). In fact medium or higher pollution occurs in less than 22% (background station) and 24% (traffic station) of the observed hours. In particular NO_2 seems to score very low. The index therefore conveys the messages that air pollution by the individual pollutants is generally low (from the short-term exposure perspective). If we look at different stations in different countries there is some variation around the mean, partly explained by climate differences (e.g. ozone is higher in the southern countries) but the results are reasonably consistent.

How representative the selected stations are for the whole of Europe’s urban agglomeration is not known. However, we don’t have an alternative dataset and there is no prior reason to believe that the sample is not representative. It must be noted that very big cities are scarce in the sample. See Annex 4 for sample calculations per country.

If we look at the total index, based on the principal that the worst sub-index determines the overall index, the outcome is of course different. For the overall hourly index ‘low’ (26-50) is the dominant class. As could be expected, the rating at traffic stations is slightly higher than that at background stations.

At traffic stations PM_{10} is the dominant pollutant for 67% of the time. In background situations PM_{10} and O_3 are equally important. Many countries have difficulties meeting the annual limit value of NO_2. This is not confirmed by the results of this short-term index. As particulate matter is the most important pollutant from a health perspective we are satisfied with the current outcome: the index identifies PM as an important pollutant.

3.2.1 Sensitivity of class borders

To test the sensitivity of the ‘message’ the index conveys we changed the class borders slightly, e.g. 0-20 very low; 21-40 low; 41-70 medium; 71-100 high. The overall picture doesn’t change much. There is a 12% rise in medium pollution cases. See table 3 for the sample of hourly background data.

Overall the index conveys the message that the air quality is fairly good. The pollution qualification is low or very low in 76% of the cases (64% when the class borders are adjusted). We believe that this is a fair message to convey: remember that this index deals with short-term exposure (hourly/daily). The short-term exposure is often, luckily, not a problem. The long-term exposure, and that is where the yearly limit values are meant for, is different of course.

Table 3: Frequency (%) of the occurrence of the index and sub-index classes (hourly data) using stricter, class boundaries (Background)

Index class	Overall index	Sub-indices PM10	O3	NO2
0-20	12	43	49	85
20-40	52	36	41	14
40-70	29	18	9	1
70-100	6	3	0	0
" >100"	1	1	0	0

3.3 Results of the application of the CAQI (daily data)

The daily sub-indices are calculated as the daily maximum of the hourly sub-indices, except for PM_{10}. The daily index therefore leads to higher values than the hourly index. This can be seen when comparing tables 2 and 4. The daily index also seems to attribute more importance to PM_{10}. Especially in the background, PM_{10} as dominant pollutant rises from half of the hours to 2/3 of the days.

Table 4: Frequency of the occurrence of the index and the sub-index classes; daily index as maximum of hourly index (O_3, NO_2 and PM_{10})

Dominant pollutant	Back-ground	Traffic	Index class	Background Overall index	Background Sub-indices PM10	Background O3	Background NO2	Traffic Overall index	Traffic Sub-indices PM10	Traffic NO2
PM10	63	74	0-25	4	17	30	66	6	12	23
O3	34		25-50	51	42	59	32	39	38	54
NO2	3	26	50-75	33	29	11	3	36	33	20
			75-100	11	10	1	0	16	15	3
			" >100"	2	2	0	0	3	3	0

Recall that there are two ways to calculate a daily index for PM_{10} that are meant to give (on average) similar results. To verify this assumption (in this sample) we compared the index based on the daily maximum of the hourly concentration for PM_{10} on the one hand, and the index based on the daily average concentration (with the grid for daily averages) on the other. See Table 5a. for the results. If we compare tables 4 and 5a, there is reasonable agreement between the two approaches. The frequency distribution of the overall index is very similar. The same holds for the frequency distribution of the PM_{10} sub-indices. If we look the dominant pollutant of the overall index it seems that using the daily average PM_{10} concentration makes PM_{10} slightly more dominant (in this sample). Currently most cities deliver hourly PM data to the website so the calculation method using the daily PM grid is hardly used.[8]

To improve the match between the two calculations the calculation grid for PM_{10} will be slightly adapted. The ratio between daily maximum and daily average PM_{10}-concentrations

[8] For maximum consistency between cities, the daily sub-index for PM should be based on the daily average concentration (and using the daily grid) also for cities that deliver hourly PM data. For maximum consistency between today's observation for a city and for yesterday or the forecast that is to be developed the maximum hourly concentration for PM_{10} should be used. The latter is implemented on www.airqaulitynow.eu.

was found to be 0.55 on average (Elshout and Léger, 2007). This ratio was applied at the higher end of the calculation grid but for the “very low” and “low” classes the ratio used was 0.5. If we apply the 0.55 ratio over the whole range the match between the two calculation schemes for the daily averaged data improves.

Table 5a: Frequency (%) of the occurrence of the index and the sub-index classes; daily index as maximum of hourly index (O_3, NO_2) and daily average (PM_{10}); existing grid

Dominant pollutant	Back-ground	Traffic	Index class	Background				Traffic		
				Overall index	Sub-indices			Overall index	Sub-indices	
					PM10	O3	NO2		PM10	NO2
PM10	70	80	0-25	3	11	30	66	4	8	23
O3	28		25-50	48	41	59	32	35	34	54
NO2	2	20	50-75	38	36	11	3	42	40	20
			75-100	10	9	1	0	16	16	3
			" >100"	2	2	0	0	2	2	0

Table 5b: Frequency (%) of the occurrence of the index and the sub-index classes; daily index as maximum of hourly index (O_3, NO_2) and daily average (PM_{10}); improved PM_{10} daily grid

Dominant pollutant	Back-ground	Traffic	Index class	Background				Traffic		
				Overall index	Sub-indices			Overall index	Sub-indices	
					PM10	O3	NO2		PM10	NO2
PM10	56	71	0-25	4	20	30	66	8	15	23
O3	40		25-50	56	44	59	32	41	39	54
NO2	4	29	50-75	28	25	11	3	33	28	20
			75-100	10	9	1	0	16	16	3
			" >100"	2	2	0	0	2	2	0

4 Proposal for integration of $PM_{2.5}$

4.1 The new CAQI calculation grid

Mean $PM_{2.5}/PM_{10}$ ratios in Europe, are shown in table 6. They are derived from Airbase co-located $PM_{2.5}$ and PM_{10} measurements, extracted for the period 2004-2006. In this study by De Leeuw and Horálek (2009) the ratios are in the range of 0.4 to 0.8. They observe a tendency for lower ratios going from rural to urban to traffic sites. This indicates an increasing contribution of locally emitted coarse particles at urban and traffic sites though this phenomenon is absent in North-western and Southern Europe. Drawing firm conclusions is difficult due to the limited number of data. Lack of consistent PM_{10} and $PM_{2.5}$ correction factors for automated equipment could also play a role.

Table 6: Mean $PM_{2.5}/PM_{10}$ ratios in Europe (source: de Leeuw and Horálek)

Region	Urban	Traffic
North	0.55	0.42
North-West	0.63	0.59
Central-East	0.71	0.65
South	0.58	0.53
Europe	0.65	0.58

We want to use as much as possible a fixed ratio between the $PM_{2.5}$ and PM_{10} sub-index calculation grids as it has the advantage that the graphs, as shown in Annex 2, retain the same shape for $PM_{2.5}$ and PM_{10} (and are/remain similar to those for NO_2 and O_3). Looking at the urban data it seems that a ratio between 0.6 and 0.7 would be an appropriate factor to derive the $PM_{2.5}$ sub-index grid from the existing PM_{10} sub-index grid. For traffic the lower of the two seems more appropriate. We therefore derive a $PM_{2.5}$ sub-index calculation grid by multiplying the PM_{10} class borders with 0.6 (and rounding to nearest ‘5’ or ‘0’). These results are shown in Table 8. The sensitivity of the CAQI results to the choice of the class borders was analysed by applying a $PM_{2.5}$ sub-index grid based on PM_{10} sub-index class borders multiplied by both 0.5 and 0.7. These results are shown in Table 9.

Applying 0.6 as a multiplier to derive the $PM_{2.5}$ calculation grid from that of PM_{10} leads to a value of 30 µg/m^3 as the border between low and medium index values. WHO has a recommendation[9] for short-term exposure to $PM_{2.5}$ of 25 µgm^3. It was decided not to use this value in the CAQI calculation grid for two reasons: it would lead to unbalanced class boundaries and less internal calculation consistency; secondly WHO (2005) assumes that 50% of PM_{10} is $PM_{2.5}$ and therefore 25 µg/m^3 (0.5 * 50) would be a suitable border. As table 6. shows that 60% would be a better estimate, and using the same WHO-logic one arrives at 30 µg/m^3 (0.6 * 50) as the border between low and medium index values.

Though $PM_{2.5}$ is an important pollutant it is not included as a core pollutant. The latest EU air quality directive (2008/50/EC) allows cities and regions to fulfil their monitoring obligations using a certain mix of PM_{10} and $PM_{2.5}$ stations[10] so it is not evident that smaller cities will be monitoring $PM_{2.5}$ on a large scale in the near future. Making it a core pollutant could hamper a city’s participation to www.airqualitynow.eu. However, for those cities that do monitor $PM_{2.5}$ it will play a role in the overall index as can be seen from the sample calculations shown in

[9] WHO AQG $PM_{2.5}$: 10 µg/m3: annual average; and 25 µg/m3: 24-hour mean, not to be exceeded more than 3 days/year.

[10] The total number of $PM_{2.5}$ and PM_{10} sampling points in a Member State required under Section A(1) shall not differ by more than a factor of 2, and the number of $PM_{2.5}$ sampling points in the urban background of agglomerations and urban areas shall meet the requirements under Section B of Annex V.

the next paragraphs. *The fact that $PM_{2.5}$ is not a core pollutant should not be seen as a sign that it is less important than the mandatory pollutants nor that it hardly determines the overall index.*

Table 7: Pollutants and calculation grid for the revised CAQI (all changes in italics)

Index class	Grid	Traffic						City Background							
		core pollutants			pollutants			core pollutants				pollutants			
		NO2	PM10		PM2.5		CO	NO2	PM10		O3	PM2.5		CO	SO_2
			1-h.	24-h.	1-h.	24-h.			1-h.	24-h.		1-h.	24-h.		
Very low	0	0	0	0	*0*	*0*	0	0	0	0	0	*0*	*0*	0	0
	25	50	25	*15*	*15*	*10*	5000	50	25	*15*	60	*15*	*10*	5000	50
Low	25	50	25	*15*	*15*	*10*	5000	50	26	*15*	60	*15*	*10*	5000	50
	50	100	50	*30*	*30*	*20*	7500	100	50	*30*	120	*30*	*20*	7500	100
Medium	50	100	50	*30*	*30*	*20*	7500	100	50	*30*	120	*30*	*20*	7500	100
	75	200	90	50	*55*	*30*	10000	200	90	50	180	*55*	*30*	10000	*350*
High	75	200	90	50	*55*	*30*	10000	200	90	50	180	*55*	*30*	10000	*350*
	100	400	180	100	*110*	*60*	20000	400	180	100	240	*110*	*60*	20000	500
Very High*	> 100	> 400	>180	>100	*> 110*	*>60*	>20000	> 400	>180	>100	>240	*> 110*	*>60*	>20000	>500

NO_2, O_3, SO_2: hourly value / maximum hourly value in $\mu g/m^3$
CO 8 hours moving average / maximum 8 hours moving average in $\mu g/m^3$
PM_{10} hourly value / daily value in $\mu g/m^3$

* An index value above 100 is not calculated but reported as " > 100"

NB: the PM_{10} 24-h grid was slightly revised; see discussion in section 3.3.

4.2 Results of the revised CAQI including $PM_{2.5}$

4.2.1 The hourly CAQI calculation

The frequency distributions in table 7 shows that when $PM_{2.5}$ is included in the CAQI calculation this pollutant is dominant roughly one third of the time. The hours that PM_{10} was dominant are being reduced. Looking at the occurrence of the different sub-index classes, $PM_{2.5}$ exhibits a similar behaviour as PM_{10}.

Table 8: Frequencies (%) of the index and sub-index classes for a CAQI that includes PM2.5 (hourly data – assumed ratio between $PM_{2.5}$ and PM_{10} sub-index grid is 0.6)

Background							
Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence			
				PM10	O3	NO2	PM2.5
PM10	18	0-25	27	55	64	92	53
O3	39	25-50	51	32	33	8	30
NO2	4	50-75	17	10	3	0	12
PM2.5	38	75-100	4	2	0	0	4
		" >100"	1	1	0	0	1
Traffic							
Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence			
				PM10	O3	NO2	PM2.5
PM10	40	0-25	34	48		63	55
		25-50	41	34		30	31
NO2	27	50-75	19	14		6	11
PM2.5	33	75-100	5	4		0	3
		" >100"	1	1		0	1

The relevance of $PM_{2.5}$ as the dominant pollutant is strongly affected by the choice of the ratio between the two PM calculation grids as can be seen by comparing tables 8 and 9. The choice doesn't affect the overall index calculation but mainly determines which PM fraction is more dominant.

Table 9: Frequencies (%) of the index and sub-index classes for a CAQI that includes PM2.5 hourly data with alternative grid: assumed ratio between PM2.5 and PM10 grid is 0.5 and 0.7

Background										
Dominant pollutant	Occurrence		Index class	Occurrence		Sub-index Occurrence				
	0.5	0.7		0.5	0.7	PM10	O3	NO2	PM2.5	
									0.5	0.7
PM10	11	27	0-25	27	27	55	64	92	43	59
O3	35	42	25-50	51	51	32	33	8	33	28
NO2	4	5	50-75	17	17	10	3	0	17	9
PM2.5	51	26	75-100	4	4	2	0	0	6	3
			" >100"	1	1	1	0	0	1	1
Traffic										
Dominant pollutant	Occurrence		Index class	Occurrence		Sub-index Occurrence				
	0.5	0.7		0.5	0.7	PM10	O3	NO2	PM2.5	
									0.5	0.7
PM10	30	48	0-25	34	35	48		63	44	62
O3			25-50	41	41	34		30	35	28
NO2	23	30	50-75	19	19	14		6	15	8
PM2.5	47	22	75-100	5	5	4		0	5	2
			" >100"	1	1	1		0	1	0

4.2.2 Results of the CAQI revised with $PM_{2.5}$ (daily data)

The results of the frequency distribution of the index values when applying the proposed CAQI with $PM_{2.5}$ included and assuming a ratio of 0.6 between the PM_{10} and $PM_{2.5}$ sub-index grids are shown in table 10. The shift observed when one changes from hourly to daily data with $PM_{2.5}$ included is very similar to same shift in the existing situation (CAQI without $PM_{2.5}$). The frequency distribution of the daily index, due to the way of calculating it (maximum of hourly values), works out slightly higher than the frequency distribution of the hourly index (same as with the original CAQI).

Table 10 is based on those stations where hourly data are available to be able to compare hourly and daily index calculations for the same data set. It follows the same calculation as table 4. But this time with $PM_{2.5}$.If the daily index is calculated using the daily average grids for the PM data six additional stations are available (from France and Italy). The results are shown in Annex 5. The results are virtually identical.

Table 10: Frequencies (%) of the index and sub-index classes for a CAQI that includes PM2.5 (daily data – all sub-indices calculated as maximum of hourly sub-indices: see table 4)

Background							
Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence PM10	O3	NO2	PM2.5
PM10	25	0-25	2	17	30	66	17
O3	25	25-50	43	42	59	32	38
NO2	2	50-75	35	29	11	3	30
PM2.5	48	75-100	17	10	1	0	13
		" >100"	3	2	0	0	2
Traffic							
Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence PM10	O3	NO2	PM2.5
PM10	44	0-25	5	12		23	18
O3		25-50	35	38		54	39
NO2	20	50-75	37	33		20	29
PM2.5	36	75-100	19	15		3	12
		" >100"	3	3		0	2

4.3 Comparing traffic and background stations in the same city

In our sample we had 6 cities that were simultaneously monitoring both at a traffic and an urban or sub-urban site. The cities were Brussels, Mechelen, Prague, Helsinki, Nantes and Stockholm. In Stockholm and Prague more than one traffic station was available. In that case the traffic stations were averaged. Table 11 shows the results of the average comparison over the six cities.

Table 11: Frequencies (%) of the index and sub-index classes for a CAQI comparing traffic and background indices in the same cities (sample of 6) using hourly data

Background							
Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence PM10	O3	NO2	PM2.5
PM10	18	0-25	28	54	60	86	58
O3	47	25-50	54	36	36	14	29
NO2	6	50-75	14	8	3	1	10
PM2.5	29	75-100	3	1	0	0	2
		" >100"	0	0	0	0	0
Traffic							
Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence PM10	O3	NO2	PM2.5
PM10	38	0-25	31	43		43	43
O3		25-50	43	38		38	38
NO2	21	50-75	21	16		16	16
PM2.5	41	75-100	5	4		4	4
		" >100"	1	0		0	0

If we compare these results to the ones in table 7 we see a much more pronounced difference between traffic and background sites. In table 7 the background and traffic index readings above 50 represented 22 respectively 25 % of the sample. In this case with 'paired' stations in the same city the index class over 50 occurs 17% and 27% of the time for background and traffic respectively. The ranges are quite wide. If we look at the occurrence of index class over 50 for traffic it ranges from 12% of the time in Helsinki to 49% in Nantes. For background it ranges from 5% of the time in Helsinki to 26% in Prague.

5 Revision of the YACAQI

5.1 Introduction

Like the hourly and daily index, the Year Average Common Air Quality Index (YACAQI) is calculated for traffic and city background sites. The www.airqualitynow.eu website will accept whatever a city submits as their city year average concentration for each pollutant for traffic and city background situations (or for one of the indices if they don't have data or don't want to supply both). This implies that the resulting indices do not necessarily reflect the complete and balanced picture a city reports under the EU-guidelines. Inferences on city compliance should therefore be based on the official city report and not on the index values on www.airqaulitynow.eu. The website indices are generalised data for comparison purpose, between cities in the same year or for a city from year to year.

The sub-indices are calculated as shown in table 12 and as explained in Elshout and Léger (2007). The $PM_{2.5}$ sub-index is added to the grid. The sub-index for the maximum number of days with PM_{10} concentrations above 50 was modified.

Table 12: Calculation scheme for the year average index

Pollutant	Target value / limit value	Calculation
NO_2	Year average is 40 µg/m^3	Year average / 40
PM_{10}	Year average is 40 µg/m^3	Year average / 40
PM_{10} daily	Max. number of daily averages above 50 µg/m^3 is 35 days	Log(number of days+1) / Log(36)
Ozone	25 days with an 8-hour average value >= 120 µg/m^3	# days with 8-hour average >=120 / 25
$PM_{2.5}$	Year average is 20 µg/m^3	Year average / 20
SO_2	Year average is 20 µg/m^3	Year average / 20
Benzene	Year average is 5 µg/m^3	Year average / 5
CO	-	Not calculated

The need for changes:

- For PM_{10} two criteria are used: the year average and the number of days with a daily average concentration >= 50 µg/m^3. The number of days criterion produces much steeper sub-index changes than the year average sub-index as one extra exceedence day corresponds roughly to approximately 0.19 µg/m^3 (see annex 5 in Elshout and Léger - 2007).
  To avoid this imbalance in the behaviour of the different sub-indices we used the empirical evidence that equates a year average (YA) concentration of 31 µg/m^3 to approximately 35 days of exeedences. The sub-index was thus calculated as year average/31. Though this works quite well on average it was impossible to calculate the index in reverse. E.g. going from a certain index value back to the number of exceedence days, the results were not exactly consistent with the actual number of days observed. The new calculation scheme allows exact reverse calculation. It is presented in section 5.2.1.
- The sub-index for $PM_{2.5}$ is newly added. It is calculated as the observed year average concentration divided by 20 µg/m^3. The value of 20 µg/m^3 is based on the so-called average exposure indicator (AEI). In Directive 2008/50/EC AEI is determined as a 3-year running annual mean $PM_{2.5}$ concentration in urban background locations. We felt that this urban exposure based value was a better criterion than the annual limit value of 25 µg/m^3 that is also introduced in Directive 2008/50/EC.

The overall city index is the average of the sub-indices for NO_2, PM_{10} (both year average and the number of days >=50 µg/m^3 sub-index) and ozone for the city background index. For the traffic year average index the averages of the sub-indices for NO_2 and PM_{10} (both) are being used. The other pollutants (including $PM_{2.5}$) are used in the presentation of the YACAQI if data are available, but do not enter the calculation of the city average index. They are treated as additional pollutants like in the hourly and daily indices. The main reason is that not every city is monitoring this full range of pollutants.

5.2 Relative importance of the sub-indices

Using the 2006 airbase data we analysed the relative importance and the behaviour of the various sub-indices. This was necessary to assure that the index update would not cause major changes in the outcome. For $PM_{2.5}$ this is not an issue as it doesn't affect the overall outcome of the YAQACI calculation. Nevertheless the results should fit in the overall trend of the calculation. For the revision of the PM_{10}-daily sub-index the continuity in the results was a major issue hence we studied the relative importance of the various calculation schemes.

For all stations used in the previous chapters where we had sufficient data to calculate a reliable year average concentration we calculated all of the sub-indices. The sub-indices where each sorted from low to high. This gives an impression of the occurrence of the sub-indices in the sample of cities studied. The results of the old calculation scheme are shown in figure 1 for the background stations, for the core pollutants.

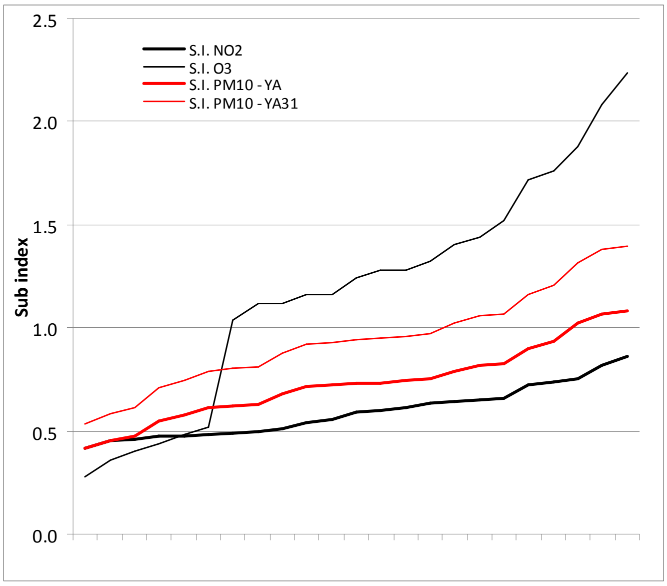


Figure 1: The sorted occurrence of the sub-indices over a sample of 23 background stations (NB 'PM10-YA31' is the old calculation scheme of the sub-index for the PM_{10}-daily limit value.)

- The graph shows that in background situations NO_2 is the lesser problem in the sample studied. In traffic stations this is different (see figure 3, right hand side.)
- PM_{10} year average concentration has slightly higher sub-index values but the range of values that occurs in the sample shows almost identical behaviour.
- The PM_{10} number of days with an average concentration >=50 µg/m^3 is a similar curve as the PM_{10} year average curve, but slightly higher. Recall that in the old sub-index calculation for the PM_{10} daily limit value the observed year average (YA) was simply

divided by 31 to obtain this sub-index so it is obvious that this produces higher sub-index values than the year average sub-index (YA/40).

- The ozone sub-index is based on count data rather than concentration data and this leads to a much steeper curve. This different behaviour is somewhat awkward but unavoidable. However, these exeedence days represent the higher percentiles of the concentration distribution, so a steeper response curve is expected. Moreover, ozone is a secondary pollutant that responds more indirectly to air quality policy than the primary pollutants.

5.2.1 The new calculation of the PM10 daily sub-index

If the PM10-YA31 calculation is simply replaced by the number of days with a daily average concentration above 50 µg/m^3 divided by the target number of 35 days, the situation in the left hand side of figure 2 is obtained. This implementation of the sub-index is completely different from the previous one and would lead to a disruption of the trend. Secondly, like the ozone sub-index, this sub-index based on counts gives a steep response to changes in the air quality and hence different behaviour than the other pollutants. This is particularly awkward compared to the PM_{10} year average sub-index as it is the same pollutant that is being considered.

The shape of this sub-index curve can be modified to correspond better to the previous calculation scheme and to the general sub-index behaviour by taking the logarithm of the number of days observed. The only difficulty is the situation with 0 days for which no logarithm can be calculated. This is overcome by adding 1 to both the observed number of days and the target value. The formula hence becomes[11]:

$$S.I._{\text{PM10-daily}} = \text{Log(number of days+1) / Log(35 +1)}$$

The results are shown in the right hand side of figure x. The log-approach yields virtually the same results as the previous sub-index calculation (thin red line) so it is a suitable replacement. The same applies to traffic situations (graph not shown here).

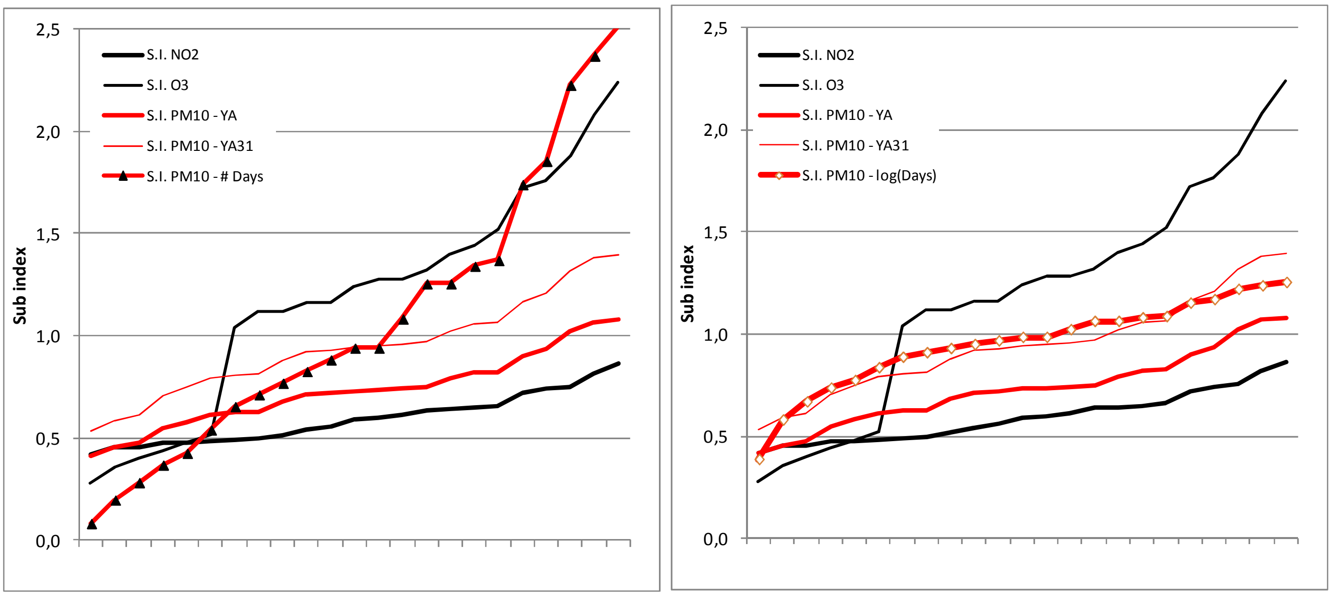


Figure 2: The sorted occurrence of the sub-indices over a sample of 23 background stations: two new ways of calculating the PM_{10}-daily sub-index.

[11] And the inverse formula: # days = 10^(log(36) * SI $_{\text{PM10-daily}}$)

5.2.2 Adding PM2.5 sub-index

The calculation of the $PM_{2.5}$ sub-index is straightforward. It is the observed year average concentration divided by 20 µg/m^3. If we analyse the behaviour of this sub-index compared to the other indices we see that the $PM_{2.5}$ sub-index results in quite similar results as the PM_{10} daily sub-index in background situations. In traffic stations the PM_{10}-daily sub-indexproduces higher results (probably due to the fact that resuspension of road dust plays a significant role). See figure 3. The figure also shows that, as expected, the NO_2 sub-index plays a much more prominent role at traffic stations.

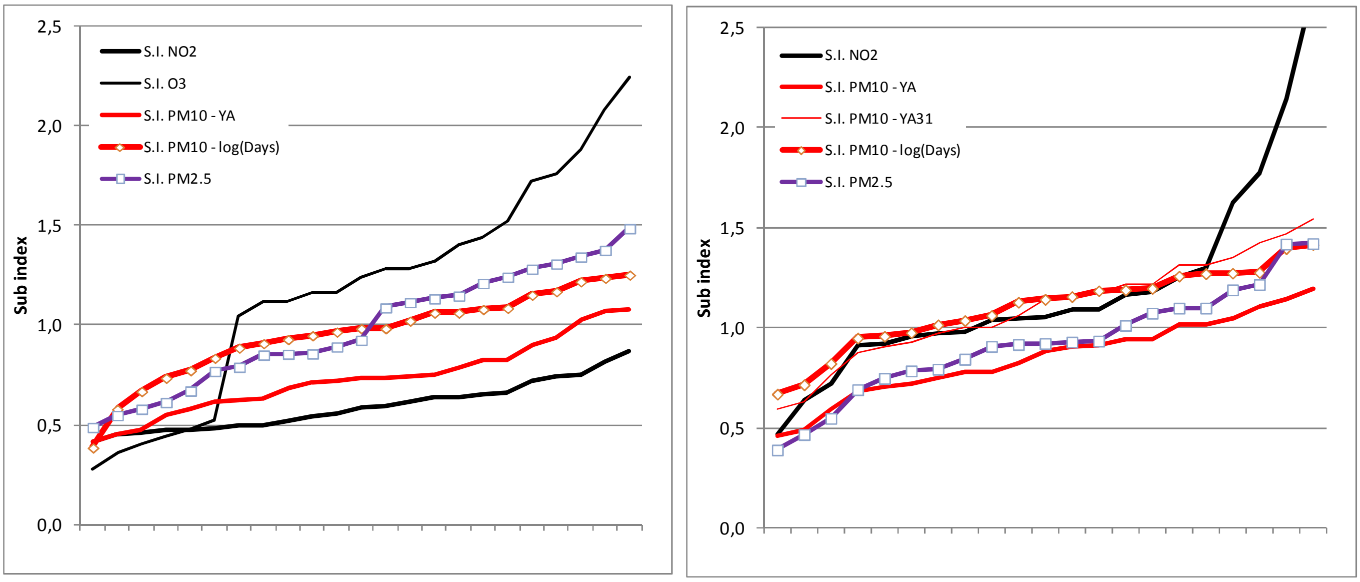


Figure 3: The sorted occurrence of the sub-indices over a sample background (left) and traffic (right) stations: the new PM_{10} daily sub-index, the new $PM_{2.5}$ sub-index and the unchanged sub-indices for NO_2, PM_{10} and Ozone.

5.3 Sample application of the YAQACI

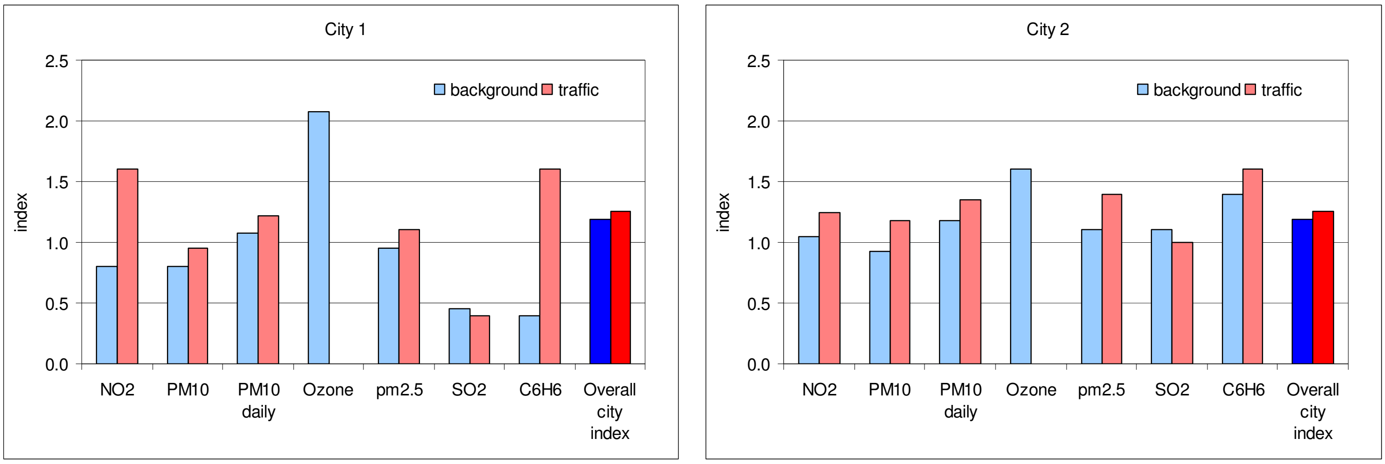
Table 13 presents an imaginary example for two cities. The two cities in the example have the same YACAQI but different air quality problems. This can be seen from the bar charts shown in figure 4. The presentation provides valuable additional information when comparing two cities or the same city over two years). It is instantly evident what the main problems are and/or where progress of the concentrations is satisfactory. Note that:

- the overall index is the same in both cities despite the fact that SO_2 and benzene are very different: they don't enter into the calculation of the average index.
- City 1 has a specific NO_2 problem for traffic and an ozone problem for background; and city 2 has overall higher concentrations leading to the same overall city indices.

Table 13: An example of the results of the YACAQI calculation

	NO_2		PM_{10}-year average		PM_{10}-exceed. daily av.		Ozone days with 8h av. >120		$PM_{2.5}$		SO_2		Benzene		**Index = average of sub-indices**	
Target value	40		40		35		25		20		20		5			
	B	T	B	T	B	T	B	T	B	T	B	T	B	T	**B**	**T**
year average city 1	32	64	32	38	46	78	52		19	22	9	8	2	8		
year average city 2	42	50	37	47	68	125	40		22	28	22	20	7	8		
Target index	1	1	1	1	1	1	1		1	1	1	1	1	1	**1**	**1**
Index city 1	0.80	1.60	0.80	0.95	1.07	1.22	2.08		0.95	1.10	0.45	0.40	0.40	1.60	**1.19**	**1.26**
Index city 2	1.05	1.25	0.93	1.18	1.18	1.35	1.60		1.10	1.40	1.10	1.00	1.40	1.60	**1.19**	**1.26**

Figure 4: Graphic display of the YAQACI results in table 13



Literature

Bell, Michelle L., Luis A. Cifuentes, Devra L.Davis, Erin Cushing, Adriana Gusman Telles and Nelson Gouveia. 2011.Environmental health indicators and a case study of air pollution in Latin American cities. Environmental Research 111, 57-66.

Burden, F.R., Ellis, P.S., 1996. Air pollution indices for Victoria. Clean Air 30, 26-30.

Cairncross, E.K., John, J. and Zunckel, M. 2007. A Novel Air Pollution Index Based on the Relative Risk of Daily Mortality Associated with Short-term Exposure to Common Air Pollutants. Atmos. Environ. 41: 8442-8454.

De Leeuw, Frank, and Jan Horálek. 2009. Assessment of the health impacts of exposure to $PM_{2.5}$ at a European level, ETC/ACC Technical paper 2009/1.

Leeuw, de Frank, and Mol, Wim. 2005. Air quality and air quality indices: a world apart? ETC/ACC Technical paper 2005/5.

Shooter, David and Peter Brimblecombe. 2009. Air quality indexing. International Journal of Environment and Pollution. Volume 36, Number 1-3 / 2009.

Elshout, Sef van den and Léger, Karine. 2007. Comparing Urban Air Quality Across Borders.A review of existing air quality indices and the proposal of a common alternative. DCMR, Schiedam. www.airqualitynow.eu/download/CITEAIR-Comparing_Urban_Air_Quality_across_Borders.pdf

EU.2008. Directive 2008/50/EC. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32008L0050:EN:NOT.

Garcia, J., Colossio, J. and Jamet, P., 2002. Air-quality indices. Elaboration, uses and international comparisons. Les presses de l'Ecole des Mines, Paris.

Johnson, B.B., 2003. Communicating air quality information: Experimental evaluation of alternate formats. Risk Analysis 23, 91-103.

Longhurst, James. 2005. 1 To 100: Creating an Air Quality Index in Pittsburgh. Environmental Monitoring and Assessment. Vol. 106, 2005

WHO. 2005. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005.Summary of risk assessment. http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf (Accessed 29-12-2010).

Annexes

Annex 1: publications on and references to the CAQI (until 2011)

References to the CAQI
NB: reverse order and not necessarily exhaustive

Bell, Michelle L., Luis A. Cifuentes, Devra L.Davis, Erin Cushing, Adriana Gusman Telles and Nelson Gouveia. 2011.Environmental health indicators and a case study of air pollution in Latin American cities. Environmental Research 111, 57-66.

Lee, Duncan, Claire Ferguson and E. Marian Scott. 2011. Constructing representative air quality indicators with measures of uncertainty. J.R.Statist. Soc. A, 174, part 1, 109-126.

Venegas, L.E. and N.A. Mazzeo. 2009. Indice de calidad del aire en la ciudad de Buenos Aires. *In* Contaminación Atmosférica en Argentina. PROIMCA.

Di Menno di Bucchianico A., G. Cattani, R. Aceto, S. Bartoletti, A. Gaeta and A.M. Caricchia. 2009. The use of air quality indices to evaluate atmospheric pollution in urban areas. Abstract at European Aerosol Conference 2009, Karlsruhe.

Papanastasiou, Dimitris K., Dimitris Melas, Thomas Bartzanas and Constantinos Kittas. 2009. Temperature, comfort and pollution levels during heat waves and the role of sea breeze. International Journal of Biometeorology.

Mayer, H. and Fritz Kalberlah. 2009.Two impact related air quality indices as tools to assess the daily and long-term air pollution. International Journal of Environment and Pollution.Vol. 36. 2009.

Shooter, David. and Peter Brimblecombe. 2009. Air quality indexing. International Journal of Environment and Pollution. Volume 36, Number 1-3 / 2009.

D. Deniz Genc , Canan Yesilyurt and Gurdal Tuncel. 2009. Air pollution forecasting in Ankara, Turkey using air pollution index and its relation to assimilative capacity of the atmosphere. Journal Environmental Monitoring and Assessment.

Bishoi, B., Prakash, A., Jain, V.K. 2009. A comparative study of air quality index based on factor analysis and US-EPA methods for an urban environment. Aerosol and Air Quality Research 9 (1), pp. 1-17.

Aleksandra M. Žujić, Bojan B. Radak, Anka J. Filipović and Dragan A. Marković. 2009. Extending the use of air quality indices to reflect effective population exposure. Environmental Monitoring and Assessment. Vol. 156, 2009.

Antonella Plaia, Mariantonietta Ruggieri, Anna Lisa Bondì. 2009. An aggregate air quality index considering combined effects of pollutants.TIES 2009 conference. http://www2.stat.unibo.it/ties2009/slides/Plaia.pdf. (Accessed September 2009).

Mayer, H., J. Holst, D. Schindler, D. Ahrens. 2008. Evolution of the air pollution in SW Germany evaluated by the long-term air quality index LAQx. Atmospheric Environment, Volume 42, Issue 20, Pages 5071-5078.

Normander, Bo, Tim Haigh, Jesper S. Christiansen and Trine S. Jensen. 2008. Development and Implementation of a Near-Real-Time Web Reporting System on Ground-Level Ozone in Europe. Integrated Environmental Assessment and Management 4(4):505-512. 2008.

Campos, A. R. Gómez, L. Licon, J. Carrillo, E. Ramírez y E.F. Herrera. 2008. Monitoreo de contaminantes atmosféricos en la ciudad de Chihuahua (Norte de México) como una herramienta para la gestión de la calidad del aire. Revista Latinoamericana de Recursos Naturales, 4 (3): 357-366, 2008.

Leeuw, de Frank, and Mol, Wim. 2005. Air quality and air quality indices: a world apart? ETC/ACC Technical paper 2005/5.

Shooter, David and Brimblecombe, Peter. 2005. Air quality indexing. http://www.uea.ac.uk/~e490/msc/m566fdl/AQI.pdf (Accessed 2007/02/24)

Publications on the CAQI
NB: Reverse chronological order. CITEAIR conferences, workshops and documents are not included.

Karine Léger, Sef van den Elshout, Anthony Ung, Laure Malherbe, Frederik Meleux, Charlotte Songeur, Cecile Honoré and Delphine Pernot. 2010. Www.airqualitynow.eu, a common website and air quality indices to compare cities across Europe. Proceedings, 13th Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes.

Jan Macoun, Maria Kazmukova, Karin Léger, Sef van den Elshout. 2009. Comparison of air quality by CITEAIR and CHMU index in Paris, Prague and Rotterdam. Air quality 2009, Istanbul.

Karine Léger, Sef van den Elshout, Hermann Heich, Fabio Nussio. 2009. Www.airqualitynow.eu, a common website and air quality indices to compare cities across Europe. TOWARDS *e*ENVIRONMENT, Prague 2009.

Elshout S van den, Léger K, Nussio. 2008. Comparing urban air quality in Europe in real time a review of existing air quality indices and the proposal of a common alternative. Environ Int. 2008;34(5):720-6.

S. van den Elshout, K. Léger, H. Heich, N. Hodges & F. Nussio. 2007. Www.airqualitynow.eu, a common website and air quality indices to compare cities across Europe. Pollution Atmosphérique, 196.

S. van den Elshout, K. Léger, H. Heich, N. Hodges and F. Nussio. 2007. Facilitating the comparison of urban air quality – a new set of common air quality indices. Proceedings 6th International Conference on Urban Air Quality, Cyprus, 2007.

S. vd. Elshout, K. Léger, H. Heich, N. Hodges & F. Nussio. 2007. Www.airqualitynow.eu, a common website and air quality indices to compare cities across Europe. In: Borrego and Brebbia (editors). Air Pollution XV, Wessex Institute of Technology, UK.

Elshout, Sef van den, Léger, Karine, Paassen, Annemarie van and Heich, Hermann. 2007. Communicating Air Quality. 6th International Symposium on Environmental Software Systems (ISESS'07). Prague.

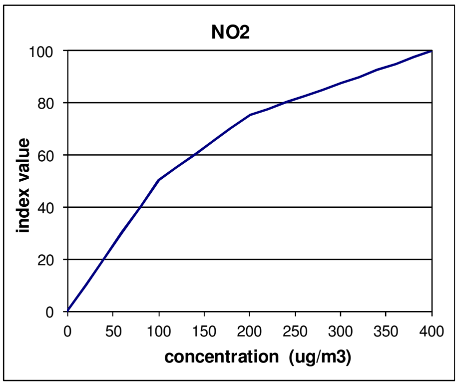
Sef vd Elshout, Karine Léger, Hermann Heich, Nick Hodges and Fabio Nussio. 2006.Near real-time comparison of air quality data across European cities and regions. Poster at Enviro Info, 2006.

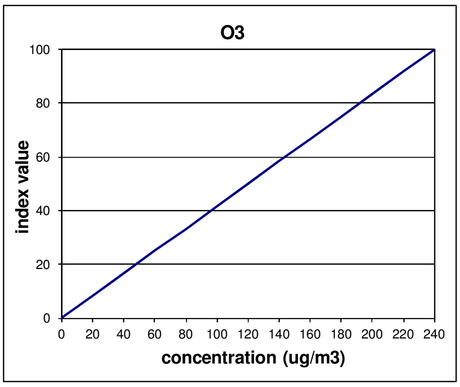
Elshout, Sef van den, Léger, Karine and Nussio, Fabio. 2005. Comparing urban air quality in Europe in real time – a review of existing air quality indices and the proposal of a common alternative. Third International Symposium on Air Quality Management at Urban, Regional and Global Scales. Turkey. (In: http://www.umad.de/infos/aqm2005/UrbanAndRuralAirQuality.pdf)

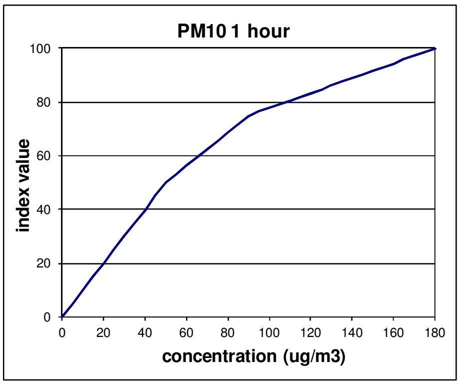
Nick Hodges, Sef van den Elshout, Hermann-Josef Heich, Chetan Lad, Karine Léger, Fabio Nussio and Maria Kazmukova.2005.Comparing Urban Air Quality in EU in Real Time. EU project CITEAIR – Common Information to European Air. EnviroInfo 2005.

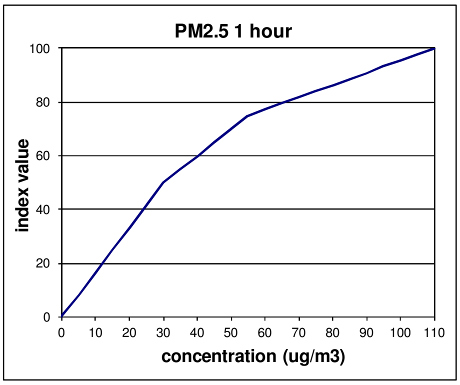
Annex 2 Graphical display of the CAQI

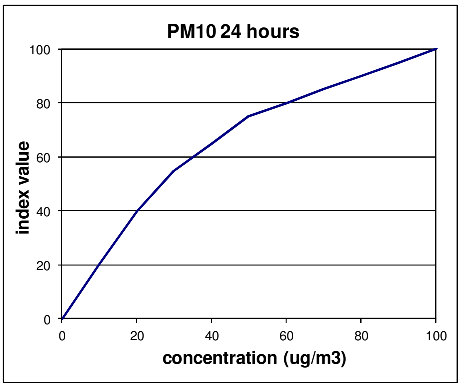
Ozone has a completely linear relation and NO_2 and PM_{10} have relations that are steep at the lower end of the concentration range and become flat at the top end. This is in line with the objective of making the index interesting ('active') also in the lower end of the concentration range. The patterns of SO_2 and CO are slightly less form-consistent but the same overall principal applies.

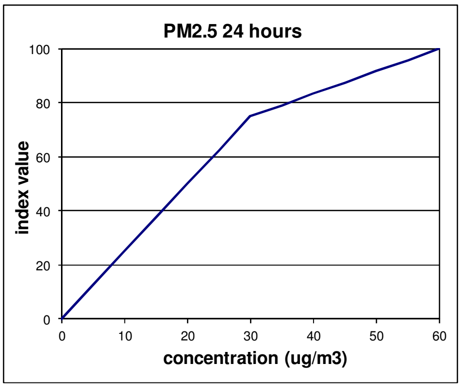


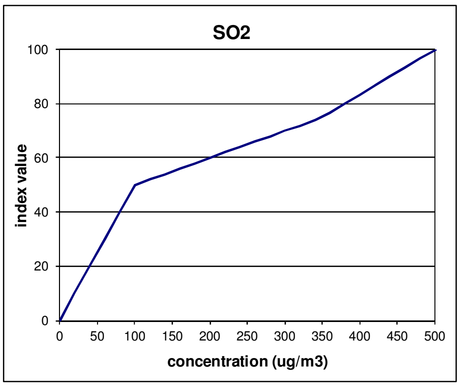


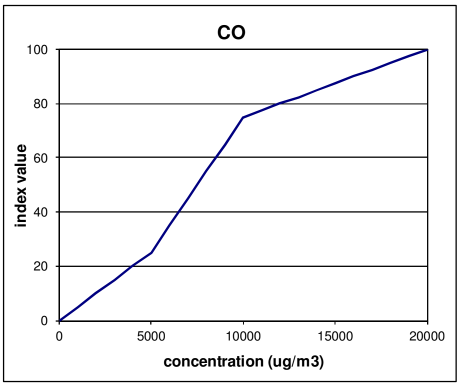












Annex 3 Air base stations used in this study

List of airbase stations used in the analysis (2006 data)

Background		31	Traffic		27
BE0186A	Brussels	3	BE0184A	Brussels	3
BE0296A	Hasselt		BE0228A	Antwerp	
BE0404A	Mechelen		BE0415A	Mechelen	
CZ0020A	Prague	13	CZ0011A	Prague	6
CZ0022A	Ústí nad Labem		CZ0068A	Beroun	
CZ0024A	Teplice		CZ0082A	Prague	
CZ0029A	Most		CZ0083A	Prague	
CZ0034A	Sokolov		CZ0086A	Hradec Králové	
CZ0042A	Brno		CZ0112A	Plzeň	
CZ0046A	Třinec				
CZ0059A	České Budějovice				
CZ0071A	Liberec				
CZ0073A	Pardubice				
CZ0075A	Zlín				
CZ0088A	Jihlava				
CZ0089A	Kladno				
DEHH008	Hamburg	4	DEHE037	Wiesbaden	4
DEHH021	Hamburg		DERP009	Mainz	
DEST002	Burg		DERP032	Neuwied	
DEST072	Halle (Saale)		DEST075	Halle (Saale)	
ES1193A	Madrid	1	ES0116A	Madrid	2
			ES0123A	Madrid	
FI0124A	Helsinki	1	FI0126A	Vaasa	3
			FI0131A	Oulu	
			FI0148A	Helsinki	
FR0351A*	Paris	3	FR0812A*	Dunkirk	3
FR0832A*	Strasbourg		FR1286A*	Saint-Étienne	
FR1376A*	Nantes		FR1377A*	Nantes	
			GB0682A	London	1
IT0466A*	Milan	3	IT1079A*	Palermo	3
IT0554A*	Turin		IT1360A*	Ancona	
IT1650A*	Saronno		IT1552A*	Palermo	
SE0001A	Malmö	3	SE0003A	Stockholm	2
SE0004A	Gothenburg		SE0027A	Stockholm	
SE0022A	Stockholm				

*: Only daily PM data

Annex 4: Sample index calculations using hourly data and the revised grid

A4.1 Traffic data country averages

BE	Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence		
					PM_{10}	NO_2	$PM_{2.5}$
	PM_{10}	33%	25	32%	45%	67%	48%
	NO_2	18%	50	45%	42%	31%	32%
	$PM_{2.5}$	48%	75	18%	12%	1%	15%
			100	5%	2%	0%	4%
			" >100"	0%	0%	0%	0%
CZ	Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence		
					PM_{10}	NO_2	$PM_{2.5}$
	PM_{10}	47%	25	30%	42%	75%	49%
	NO_2	13%	50	41%	35%	23%	30%
	$PM_{2.5}$	41%	75	20%	17%	2%	14%
			100	7%	5%	0%	5%
			" >100"	2%	1%	0%	2%
DE	Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence		
					PM_{10}	NO_2	$PM_{2.5}$
	PM_{10}	25%	25	37%	56%	60%	56%
	NO_2	37%	50	45%	33%	36%	31%
	$PM_{2.5}$	38%	75	15%	9%	4%	10%
			100	3%	1%	0%	3%
			" >100"	0%	0%	0%	0%
ES	Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence		
					PM_{10}	NO_2	$PM_{2.5}$
	PM_{10}	45%	25	15%	31%	24%	41%
	NO_2	46%	50	43%	36%	52%	40%
	$PM_{2.5}$	9%	75	33%	25%	23%	16%
			100	9%	8%	1%	2%
			" >100"	0%	0%	0%	0%
FI	Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence		
					PM_{10}	NO_2	$PM_{2.5}$
	PM_{10}	49%	25	61%	68%	82%	83%
	NO_2	27%	50	30%	21%	16%	13%
	$PM_{2.5}$	23%	75	6%	5%	1%	2%
			100	2%	2%	0%	0%
			" >100"	0%	0%	0%	0%
GB	Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence		
					PM_{10}	NO_2	$PM_{2.5}$
	PM_{10}	31%	25	9%	16%	15%	35%
	NO_2	66%	50	36%	44%	34%	50%
	$PM_{2.5}$	3%	75	45%	36%	43%	14%
			100	10%	4%	8%	1%
			" >100"	0.16%	0%	0%	0%
SE	Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence		
					PM_{10}	NO_2	$PM_{2.5}$
	PM_{10}	41%	25	37%	50%	63%	58%
	NO_2	27%	50	44%	31%	33%	35%
	$PM_{2.5}$	33%	75	15%	13%	3%	7%
			100	4%	6%	0%	0%
			" >100"	0%	1%	0%	0%

A4.2 Background data country averages

BE	Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence PM10	O3	NO2	PM2.5
	PM_{10}	34%	25	27%	45%	76%	85%	56%
	O_3	32%	50	51%	40%	21%	15%	29%
	NO_2	6%	75	19%	13%	3%	0%	12%
	$PM_{2.5}$	28%	100	4%	2%	0%	0%	3%
			" >100"	0%	0%	0%	0%	0%

CZ	Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence PM10	O3	NO2	PM2.5
	PM_{10}	15%	25	19%	48%	59%	93%	41%
	O_3	35%	50	51%	34%	37%	7%	34%
	NO_2	2%	75	22%	13%	4%	0%	17%
	$PM_{2.5}$	48%	100	6%	4%	0%	0%	6%
			" >100"	2%	1%	0%	0%	1%

DE	Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence PM10	O3	NO2	PM2.5
	PM_{10}	17%	25	36%	63%	71%	93%	58%
	O_3	37%	50	50%	30%	27%	7%	31%
	NO_2	6%	75	12%	7%	2%	0%	8%
	$PM_{2.5}$	39%	100	3%	1%	0%	0%	2%
			" >100"	0%	0%	0%	0%	0%

ES	Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence PM10	O3	NO2	PM2.5
	PM_{10}	28%	25	29%	57%	58%	81%	66%
	O_3	49%	50	52%	31%	35%	17%	30%
	NO_2	12%	75	17%	10%	7%	2%	4%
	$PM_{2.5}$	12%	100	2%	2%	0%	0%	1%
			" >100"	0,00%	0%	0%	0%	0%

FI	Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence PM10	O3	NO2	PM2.5
	PM_{10}	10%	25	48%	83%	65%	92%	81%
	O_3	56%	50	47%	14%	33%	7%	15%
	NO_2	15%	75	5%	2%	1%	0%	3%
	$PM_{2.5}$	19%	100	0%	0%	0%	0%	1%
			" >100"	0.02%	0%	0%	0%	0%

SE	Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence PM10	O3	NO2	PM2.5
	PM10	18%	25	41%	75%	61%	95%	79%
	O3	56%	50	54%	22%	38%	4%	18%
	NO2	6%	75	5%	3%	1%	0%	3%
	PM2.5	20%	100	0%	0%	0%	0%	0%
			" >100"	0%	0%	0%	0%	0%

Annex 5: Daily index calculation including $PM_{2.5}$, including French and Italian Airbase stations

Table A5.1: Frequency (%) of the occurrence of the index and the sub-index classes; daily index as maximum of hourly index (O_3, NO_2) and daily average (PM_{10} and $PM_{2.5}$); improved PM_{10} daily grid.

Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence PM10	O3	NO2	PM2.5
Background							
PM10	24%	0-25	3%	20%	30%	66%	27%
O3	35%	25-50	52%	44%	59%	32%	39%
NO2	4%	50-75	27%	25%	11%	3%	19%
PM2.5	38%	75-100	15%	9%	1%	0%	13%
		" >100"	3%	2%	0%	0%	3%
Traffic							
PM10	35%	0-25	5%	15%		23%	13%
O3		25-50	35%	39%		54%	38%
NO2	21%	50-75	38%	28%		20%	36%
PM2.5	45%	75-100	19%	16%		3%	11%
		" >100"	2%	2%		0%	2%

Table A5.2: Frequency (%) of the occurrence of the index and the sub-index classes; daily index as maximum of hourly index (O_3, NO_2) and daily average (PM_{10} and $PM_{2.5}$); improved PM_{10} daily grid.

Dominant pollutant	Occurrence	Index class	Occurrence	Sub-index Occurrence PM10	O3	NO2	PM2.5
Background							
PM10	23%	0-25	3%	18%	32%	58%	24%
O3	33%	25-50	49%	43%	56%	36%	38%
NO2	4%	50-75	29%	25%	11%	6%	21%
PM2.5	40%	75-100	16%	11%	1%	0%	13%
		" >100"	4%	3%	0%	0%	4%
Traffic							
PM10	35%	0-25	4%	12%		21%	12%
O3		25-50	33%	37%		53%	36%
NO2	18%	50-75	39%	32%		23%	36%
PM2.5	47%	75-100	21%	17%		2%	14%
		" >100"	3%	2%		0%	2%

Adding an additional six stations (three French and three Italian) to a subset of 21 (traffic) or 25 (background) stations hardly affects the outcome of the average index calculation.

Annex 6: Daily maximum and daily average indices for PM_{10} and $PM_{2.5}$

As we described in section 3.3, the two ways of calculating the daily PM_{10} sub-index and the daily overall index are quite similar if we look at the average of all monitoring sites in the sample. However if we look at different sites the results can be substantial. Here we show the frequency distribution of the sub-indices for PM_{10} and $PM_{2.5}$ calculated in both ways: as a Daily Average (DA) or a Daily Maximum (DM), each with its appropriate grid. We focus on those instances where the index or the sub-index is higher than 50. On average both calculation methods should give similar results but in reality the DM method leads to higher Sub-Indices (SI) and hence higher overall Index (I) values.

The table shows the parameters "ratio SI >50" and "ratio I >50":

ratio SI >50 = days with SI>50, method DA / days with SI>50, method DM and

ratio I >50 = days with I>50, method DA / days with I>50, method DM

If the ratio is > 1 it means that the Daily Average method produces higher index or sub-index values. The results show that in this sample of background data the daily average calculation leads to slightly lower index values.

Summary table (city background)[12]

		Average	Min.	Max.
Ratio SI>50	PM10	0.9	0.4	1.3
Ratio SI>50	PM2.5	0.8	0.6	1.0
Ratio I>50	Index	0.8	0.5	1.0

Frequency distribution and ratio's for city background data comparing two ways of determining the PM sub-indices.

	BE0186A				BE0296A				BE0404A			
	PM10		PM2.5		PM10		PM2.5		PM10		PM2.5	
	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM
25	0,12	0,21	0,32	0,24	0,06	0,03	0,36	0,23	0,04	0,02	0,28	0,14
50	0,54	0,48	0,38	0,43	0,53	0,51	0,39	0,45	0,42	0,46	0,34	0,35
75	0,26	0,27	0,18	0,24	0,31	0,38	0,15	0,25	0,34	0,39	0,20	0,33
100	0,08	0,04	0,11	0,09	0,10	0,08	0,09	0,08	0,19	0,12	0,18	0,17
" >100"	0,00	0,00	0,01	0,00	0,01	0,00	0,01	0,00	0,01	0,01	0,01	0,01
Ratio SI>50	1,12		0,90		0,90		0,77		1,03		0,77	
Ratio I>50	0.9				0.9				1.0			
	CZ0020A				CZ0022A				CZ0024A			
	PM10		PM2.5		PM10		PM2.5		PM10		PM2.5	
	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM
25	0,19	0,13	0,29	0,18	0,19	0,06	0,13	0,01	0,06	0,02	0,13	0,02
50	0,40	0,43	0,35	0,36	0,51	0,27	0,46	0,26	0,37	0,19	0,35	0,15
75	0,28	0,33	0,18	0,29	0,21	0,42	0,24	0,50	0,35	0,50	0,26	0,46
100	0,10	0,08	0,12	0,12	0,07	0,23	0,14	0,19	0,16	0,23	0,20	0,30
" >100"	0,03	0,02	0,06	0,04	0,02	0,02	0,03	0,04	0,06	0,06	0,06	0,08
Ratio SI>50	0,95		0,78		0,45		0,57		0,72		0,62	

12 The results for traffic data are not shown. For the overall index they are virtually identical.

Ratio I>50	0.9				0.5				0.7			
	CZ0029A				CZ0034A				CZ0042A			
	PM10		PM2.5		PM10		PM2.5		PM10		PM2.5	
	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM
25	0,13	0,12	0,22	0,08	0,28	0,22	0,29	0,09	0,12	0,10	0,12	0,04
50	0,31	0,25	0,29	0,33	0,45	0,46	0,40	0,41	0,33	0,38	0,30	0,29
75	0,33	0,36	0,24	0,33	0,20	0,26	0,18	0,36	0,38	0,38	0,27	0,41
100	0,18	0,21	0,18	0,19	0,06	0,05	0,12	0,13	0,14	0,10	0,25	0,22
" >100"	0,05	0,06	0,06	0,07	0,01	0,01	0,02	0,02	0,02	0,03	0,07	0,04
Ratio SI>50	0,88		0,82		0,84		0,63		1,06		0,87	
Ratio I>50	0.9				0.7				0.9			
	CZ0046A				CZ0059A				CZ0071A			
	PM10		PM2.5		PM10		PM2.5		PM10		PM2.5	
	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM
25	0,05	0,04	0,11	0,04	0,25	0,16	0,17	0,06	0,14	0,12	0,12	0,03
50	0,33	0,30	0,33	0,30	0,42	0,47	0,39	0,32	0,48	0,47	0,44	0,36
75	0,38	0,37	0,30	0,38	0,21	0,27	0,23	0,40	0,28	0,32	0,25	0,42
100	0,18	0,23	0,23	0,25	0,09	0,08	0,16	0,18	0,08	0,08	0,16	0,15
" >100"	0,06	0,07	0,03	0,03	0,03	0,02	0,05	0,04	0,01	0,02	0,02	0,04
Ratio SI>50	0,93		0,85		0,89		0,73		0,91		0,71	
Ratio I>50	0.9				0.8				0.8			
	CZ0073A				CZ0075A				CZ0088A			
	PM10		PM2.5		PM10		PM2.5		PM10		PM2.5	
	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM
25	0,09	0,04	0,14	0,10	0,14	0,14	0,09	0,05	0,22	0,18	0,15	0,10
50	0,33	0,34	0,40	0,34	0,39	0,44	0,30	0,29	0,41	0,42	0,33	0,29
75	0,36	0,44	0,23	0,36	0,30	0,29	0,30	0,37	0,25	0,28	0,30	0,42
100	0,18	0,14	0,19	0,16	0,13	0,09	0,25	0,23	0,11	0,12	0,20	0,16
" >100"	0,04	0,04	0,04	0,04	0,04	0,04	0,07	0,06	0,02	0,00	0,02	0,02
Ratio SI>50	0,94		0,84		1,15		0,94		0,92		0,85	
Ratio I>50	0.9				0.9				0.9			
	CZ0089A				DEHH008				DEHH021			
	PM10		PM2.5		PM10		PM2.5		PM10		PM2.5	
	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM
25	0,10	0,07	0,03	0,01	0,06	0,07	0,26	0,14	0,34	0,33	0,32	0,20
50	0,53	0,36	0,48	0,31	0,57	0,56	0,48	0,52	0,50	0,51	0,44	0,47
75	0,23	0,40	0,27	0,37	0,28	0,31	0,17	0,27	0,10	0,13	0,15	0,25
100	0,10	0,14	0,16	0,25	0,09	0,06	0,08	0,07	0,05	0,03	0,08	0,07
" >100"	0,03	0,04	0,06	0,06	0,00	0,00	0,01	0,01	0,01	0,01	0,01	0,01
Ratio SI>50	0,63		0,71		0,99		0,76		0,95		0,72	
Ratio I>50	0.7				0.9				0.7			
	DEST002				DEST072				ES1193A			
	PM10		PM2.5		PM10		PM2.5		PM10		PM2.5	
	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM
25	0,24	0,30	0,19	0,17	0,26	0,27	0,38	0,31	0,26	0,18	0,35	0,25
50	0,54	0,52	0,52	0,54	0,45	0,44	0,41	0,43	0,36	0,34	0,49	0,47
75	0,18	0,15	0,19	0,23	0,23	0,23	0,14	0,20	0,31	0,33	0,15	0,25
100	0,04	0,04	0,08	0,05	0,06	0,06	0,07	0,06	0,07	0,15	0,01	0,03
" >100"	0,01	0,00	0,01	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00
Ratio SI>50	1,21		1,00		0,99		0,83		0,80		0,57	
Ratio I>50	0.9				0.9				0.9			

	FI0124A				SE0001A				SE0004A			
	PM10		PM2.5		PM10		PM2.5		PM10		PM2.5	
	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM	DA	DM
25	0,57	0,50	0,67	0,50	0,42	0,48	0,47	0,39	0,19	0,15	0,53	0,45
50	0,35	0,42	0,25	0,35	0,49	0,44	0,44	0,49	0,63	0,61	0,39	0,48
75	0,05	0,06	0,06	0,12	0,08	0,07	0,07	0,11	0,15	0,19	0,07	0,08
100	0,03	0,02	0,02	0,02	0,01	0,01	0,02	0,01	0,04	0,04	0,01	0,00
" >100"	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00
Ratio SI>50	0,91		0,56		1,27		0,78		0,78		1,00	
Ratio I>50	0.7				0.7				0.8			

	SE0022A			
	PM10		PM2.5	
	DA	DM	DA	DM
25	0,41	0,38	0,53	0,42
50	0,46	0,47	0,37	0,46
75	0,11	0,13	0,07	0,11
100	0,02	0,02	0,03	0,01
" >100"	0,00	0,00	0,00	0,00
Ratio SI>50	0,87		0,79	
Ratio I>50	0.8			