Air Quality Index (AQI)

Methodology & Applications for Public Awareness in Cities

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Sarath Guttikunda

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(UEinfo) was founded in 2007 with the vision to be a repository of information, research, and analysis related to air pollution. There is a need to scale-up research applications to the secondary and the tertiary cities which are following in the footsteps of the expanding mega-cities. Advances in information technology, open-data resources, and networking, offers a tremendous opportunity to establish such tools, to help city managers, regulators, academia, and citizen groups to develop a coordinated approach for integrated air quality management for a city.

UEinfo has four objectives: (1) sharing knowledge on air pollution (2) science-based air quality analysis (3) advocacy and awareness raising on air quality management and (4) building partnerships among local, national, and international airheads.

This report was conceptualized, drafted, and designed by the members of UEinfo.

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Air Quality Index (AQI):
Methodology & Applications for Public Awareness in Cities

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The outdoor air pollution is a growing concern for many cities in developed and developing countries of the world. While the developed and developing countries differ in terms of their ambient standards for various pollutants (the level at which they consider the pollution to be harmful), the general idea behind the standards is to be aware of the damage caused to the public health and the environment.

The urban air pollutants arise from a wide variety of sources, though primarily linked to the combustion processes. The largest sources include the motor vehicles, variety of manufacturing processes (industries) such as brick kilns, cement, metal processing, tanning, etc., residential fuel usage, biomass burning and road dust (especially in the developing country cities). The traffic-generated pollutants include nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs) and particulates (PM). Given the mix of NO_x and VOC emissions, combined with strong sunlight during the day, this leads to a buildup of ozone (O3) through photolysis and aide of numerous radicals[1]. Other pollutants include sulfur dioxide (SO_2) primarily from the coal combustion in industries, power plants, and residential areas (which also contribute to the emissions to above listed pollutants).

Urban air pollution, however, is not a new problem or an easy one to explain. Each of the pollutants is associated with a range of health impacts, partly linked to the source of the pollutant. For example, PM leading to cause of the respiratory illnesses, Ozone pollution leading to eye and lung irritations, SO_2 (with precipitation) leading to acid rain, irritation along the respiratory track and bronchitis, NOx enhancing the symptoms for chronic

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[1] The atmospheric chemistry of ground level ozone in the urban areas is unique compared to the ozone during the long range transport. Because of which the ozone levels are very often lower in urban areas than in the rural areas. A number of well studied chemical mechanisms were established at varying degrees of complexities by the "chemical transport modeling community". These mechanisms cover a wide range of species – direct and indirect, radicals, photolysis schemes, and some even include gas-aerosol interactions in multiple size bins to support the extensive chemical analysis. Commonly known chemical schemes include
1. Statewide Air Pollution Research Center (SAPRC) chemical mechanism @
http://www.engr.ucr.edu/~carter/pubs/#reports
2. Regional Atmospheric Chemistry Mechanism (RACM) @
http://www.agu.org/pubs/crossref/1997/97JD00849.shtml
3. Carbon Bond IV Mechanism (CBM IV) @
http://www.epa.gov/scram001/photochemicalindex.htm
http://www.ccl.rutgers.edu/~ssi/thesis/thesis-node57.html
Also see
"Fundamentals of Atmospheric Modeling" by Dr. Mark Jacobson, Stanford University @
http://www.stanford.edu/group/efmh/FAMbook2dEd/index.html
"Atmospheric Chemistry & Physics" by Dr. Sienfeld and Dr. Pandis @
http://www.amazon.com/Atmospheric-Chemistry-Physics-Pollution-Climate/dp/0471178160

bronchitis, and CO reducing the oxygen supply to the brain (and in some cases fatal). A summary of the consequences to human health and environment is presented in **Box 1**.

Among the pollutants, PM is the primary concern due to its direct linkages to human health aggravating chronic and acute respiratory diseases and in some cases leading to premature death[2]. While the PM pollution is measured as a single entity, the composition of PM pollution is complex, consisting of primary pollution from direct sources such as vehicle exhaust and industries flue gases and secondary pollution due to chemical transformation of other pollutants into aerosol forms such as SO_2 to sulfates, NO_x to nitrates, and VOCs to secondary organic aerosols[3]. Similarly, the contribution to ozone pollution is mixed depending on the amount of NO_x and VOC pollution and meteorological conditions.

> **Box 1: Consequences of being exposed to a mix of pollutants**
>
> **Effects on human health**
> Premature mortality, asthma attacks, respiratory symptoms, chronic bronchitis, oxygen deficiency in blood, eye irritation, and genetic and reproductive damages
> **Effects on vegetation**
> Productivity loss and slower photosynthesis for vegetation
> **Effects on material and structure**
> Corrosion of metal, accelerated erosion on building and monument
> **Effects on comfort and aesthetics**
> Bad smell, reduced vision distance, quick paling of paint on buildings
> **Effects on ecosystem (atmosphere, soil and water body)**
> Local (human health), regional (acid rain), and global (climate change)

Need for a Common Denominator

While all these pollutants exist in any urban environment and the impacts of individual pollutants on human health are well documented and studies routinely, it is not easy to apportion the contribution of each pollutant to each health effect, since the effects do overlap with one another.

For the regulatory purposes, while each of the pollutants is assigned an ambient standard, they do not immediately reflect the strain on the human health or on the surrounding environment.

For a common person, not familiar with the jargon of the pollutants, their compositions, and their impacts, it is difficult to adjudge the combined affects of the pollutants prevalent in the surrounding. Hence, the need for a common denominator called "**air quality index**" which provides a common platform to compare and assess the impact of various pollutants together.

This paper presents the definition, a methodology, and examples across the global cities for air quality index.

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[2] See a list of publications summarizing the impacts of outdoor air pollution on human health based on epidemiological studies conducted across the world and distributed by the Health Effects Institute, USA @ http://www.healtheffects.org/

[3] A detail explanation on the science and composition of the PM pollution is presented in SIM-air Working Paper No.10 "What is Particulate Matter: Composition and Science" and No.16 "Urban Particulate Pollution Source Apportionment - Part 1. Definition, Methodology, and Resources" @ http://www.urbanemissions.info

Air Quality Index (AQI)

The AQI is an "index" determined by calculating the degree of pollution in the city (as an average) or at the monitoring point and includes five main pollutants – PM, O3, SO2, NO_x, and CO. Each of these pollutants has an air quality standard which is used to calculate the overall AQI. Simultaneously, one can also establish the limiting pollutant (the most damaging of the pollutants measured) and estimate the AQI. In numbers (see **Figure 1**), AQI is represented between 0 to 500 with 0 representing good air and 500 representing hazardous air.
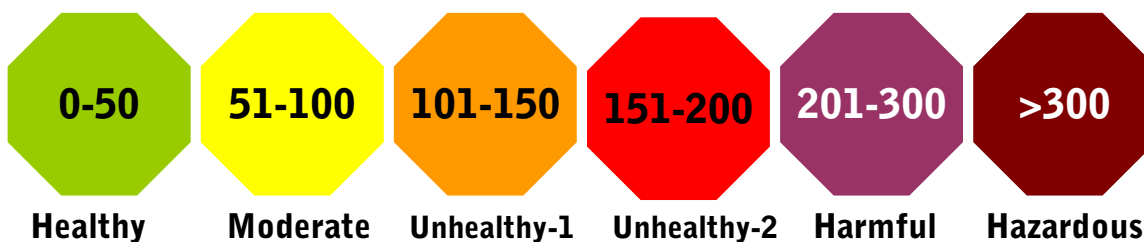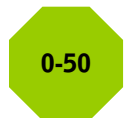
0-50	51-100	101-150	151-200	201-300	>300
Healthy	Moderate	Unhealthy-1	Unhealthy-2	Harmful	Hazardous

Figure 1: The AQI color ranges

For better understanding and presentation, the AQI is broken down into six categories, each color coded with the number scale. To make it easier for people to understand quickly the significance of these air pollution levels, the AQI scale is further divided into six levels of health concern and assigned a specific color to each category:

0-50   "**GOOD** or **HEALTHY**" - This AQI value between 0 and 50 is considered satisfactory and air pollution poses little or no risk. No cautionary actions are prescribed to the general public.

51-100   "**MODERATE**" - This AQI value between 51 and 100 considered is acceptable for general public. However, unusually sensitive people should consider limiting prolonged outdoor stays.

101-150   "**UNHEALTHY FOR SENSITIVE GROUPS**" - This AQI value between 101 and 150 is considered borderline unhealthy, particularly for members of sensitive groups. This means they are likely to be affected at lower levels than the general public. For example, children and adults who are active outdoors and people with respiratory disease are at greater risk from exposure to PM and ozone, while people with heart disease are at greater risk from CO. Some people may be sensitive to more than one pollutant.

151-200   "**UNHEALTHY**" - This AQI value between 151 and 200 is considered for most of the public where everyone may begin to experience some level of discomfort. Active children and adults, and people with respiratory disease, such as asthma, should avoid prolonged outdoor stays.

201-300   **"VERY UNHEALTHY"** - This AQI value between 201 and 300 can trigger a health alert, meaning everyone may experience more serious health effects. Active children and adults, and people with respiratory disease, such as asthma, should avoid all outdoor stays.

>300   **"HAZARDOUS"** - This AQI value of over 300 trigger health warnings of emergency conditions. The entire population is likely to be affected. This could be due to a combination of the pollutants or a single pollutant such as PM.

It is important to note that the AQI is an indicative measure of the air pollution levels measured in the city; the AQI is estimated via modeling based on pre-defined methodologies; and the AQI is not direct a measure of the health impacts.

A Methodology to Estimate AQI

An example methodology to calculate the AQI is presented below, along with the supporting data for various ranges.

$$AQI = \frac{AQI_{hi} - AQI_{lo}}{BP_{hi} - BP_{lo}} * (CONC - BP_{lo}) + AQI_{lo}$$

Where

CONC = concentration of the pollutant
AQI = air quality index for the pollutant
BP_{hi} = the breakpoint that is greater than or equal to CONC
BP_{lo} = the breakpoint that is less than or equal to CONC
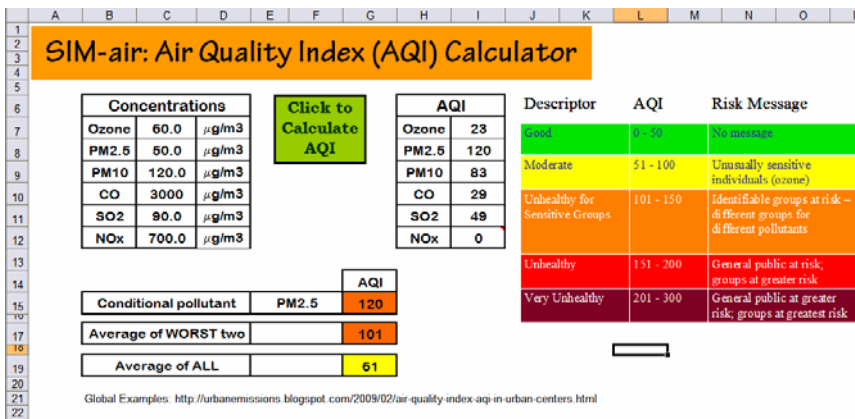AQI_{hi} = the AQI value corresponding to BP_{hi}
AQI_{lo} = the AQI value corresponding to BP_{lo}

Range		Healthy		Moderate		Unhealthy1		Unhealthy2		Very Unhealthy		Hazardous	
Values	AQI-low	0		51		101		151		201		301	
	AQI-hi	50		100		150		200		300		500	
Concentrations		BP_{low}	BP_{hi}	BP_{low}	BP_{hi}	BP_{low}	BP_{hi}	BP_{low}	BP_{hi}	BP_{low}	BP_{hi}	BP_{low}	BP_{hi}
PM_{10} ($\mu g/m^3$)		0	40	40	80	80	120	120	200	200	300	300	
$PM_{2.5}$ ($\mu g/m^3$)		0	25	25	50	50	70	70	100	100	150	150	
SO_2 (ppm)		0	0.01	0.01	0.02	0.02	0.04	0.04	0.10	0.01	0.15	0.15	
NO_2 (ppm)		0	0.02	0.02	0.04	0.04	0.06	0.06	0.10	0.10	0.20	0.20	
O_3 (ppm)		0	0.03	0.03	0.06	0.06	0.10	0.10	0.15	0.15	0.25	0.25	
CO (ppm)		0	2	2	7	7	12	12	15	15	30	30	

An excel version of this methodology is available for the user to plug and play with the measured or modeled air pollution levels of each pollutant[4]. The tool provides the user to input the concentrations of six pollutants – PM_{10}, $PM_{2.5}$, Ozone, SO_2, NO_x, and CO (all in micro-gm/m^3). It is not necessary that the concentrations of all six should be entered. If the

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[4] The tool is available for free @ http://www.urbanemissions.info/model-tools/aqi-calculator.html

data is available only for few, the tool will automatically ignore the cells without numbers and calculate the AQI with the concentrations available.

Figure 2: An AQI calculator in plug and play mode

While the AQI is calculated for each of the pollutant, there are different ways of presenting a combined AQI of the pollutants. The tool presents three different ways

1. An average of all AQI calculated using the available information
2. An average of the two worst AQI
3. AQI of the pollutant with the highest value – in which case this pollutant is considered the conditional pollutant.

It is important to note that the AQI is not always calculated based on the monitoring data for these pollutants. The same methodology can be applied to modeled data over a city – gridded or grid average – and estimate AQI.

Worldwide Applications of AQI

At the national and urban scale, in the developed and developing countries, some form of this methodology is employed to estimate AQI and use the same for public alerts on air pollution. The most commonly quoted example is from the United States and Canada, called the "AirNOW" program[5]. Links to various other programs is available @ http://urbanemissions.blogspot.com/2009/02/air-quality-index-aqi-in-urban-centers.html

Recent applications in Asia include Beijing (started during the Olympic Games 2008), Shanghai[6] (started during the Expo 2010), Delhi[7] (starting with the Commonwealth Games 2010) and Hong Kong.

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[5] The AirNOW program covers the geography of US and Canada. AQI and air quality by pollutant information is available by state and city. Details are available @ http://cfpub.epa.gov/airnow/index.cfm?action=airnow.national
[6] This program was developed by the AirNOW International group. Details are available @ http://www.semc.com.cn/expoair/WebFront/default.aspx
[7] Details of the program along with an edited 2 min video is available @ http://www.livemint.com/2010/03/31001807/New-Delhi-to-be-first-Indian-c.html

US AirNOW Program

Environment Canada

Ozone today in Europe

PREV-Air in France
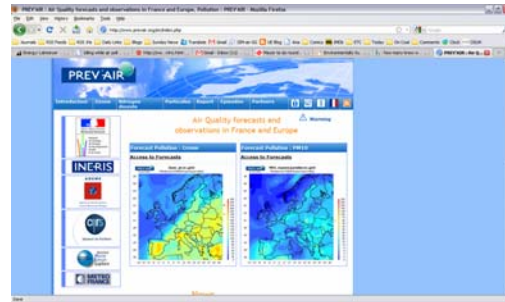
London Air Quality Network

Norway

Bangkok, Thailand

Singapore Environment

Hong Kong

Shanghai, China

Figure 3: Examples of real time AQI data in public domain

AQI for Public Awareness

What we do in the name of science is limited to the scientific and academic communities. Then we have the policy (which is most often consumed by bureaucracy), which tend to be based on either science or because the decision needs to be taken. A most influential step next is the dissemination of the information to the public who have the right to know the harmful nature of the pollution, the public who feel the heat of dirty air pollution on a daily basis, and the public who can put pressure on policy makers to address the right questions and to minimize the air pollution impacts.

The calculation of AQI is science based on monitoring or modeling data for various pollutants, which provide an indication of the level of harmfulness of air pollution. The challenge becomes the dissemination of the information.

How to inform the public about the air quality in an easy to understand manner?

The challenge of public awareness is very intriguing. By awareness we include education about the air quality in specific areas and the associated health effects, understanding the importance of the air quality forecasts and their direct relation to health impacts, which will make the difference between a clean and a polluted air day.

The examples presented so far, in the developed and developing countries, this information is posted on a website, which is updated every day, or via other forms such as Google Earth maps (**Figure 4**) or in some cases local newspapers.
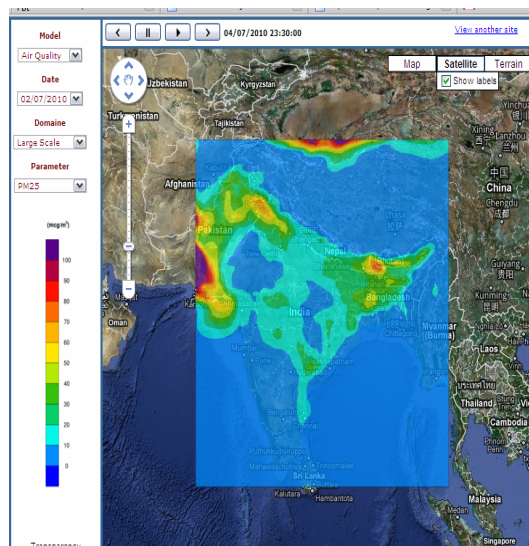

Figure 4: Google Earth interface

Question: *How often does one check AQ forecast on web every day?*

Here are some examples of how artists and citizen groups have used the AQI information to raise awareness among the general public.

Beijing, China

Hosted by the Asia Society[8], this site "Room with a View" is a photo journal of air pollution linked to the daily AQI measured by the State Environmental Protection Administration of China.
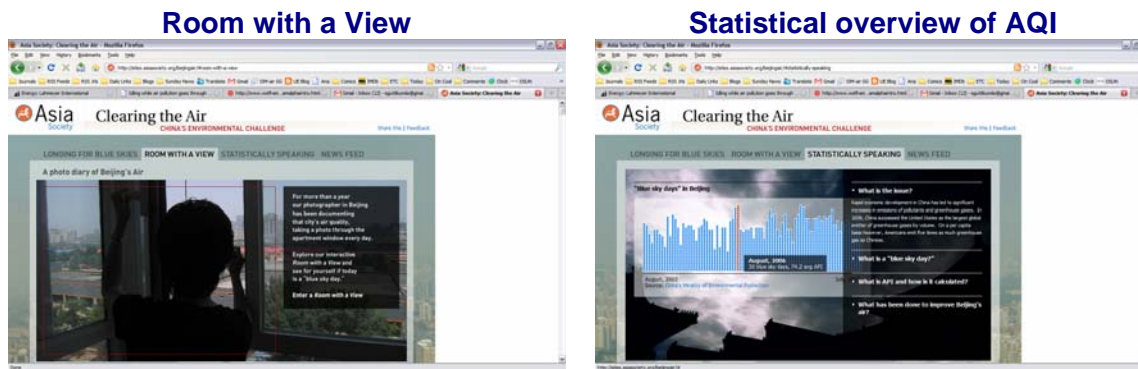
Room with a View   **Statistical overview of AQI**

Figure 5: Photo journal of air pollution in Beijing and AQI data in public domain

The site along with the photo of air pollution, snapped from the same position every day, also provides a statistical overview of the AQI for the day, as displayed by the Ministry of Environment for Beijing and other cities in China[9].

A Clear Day   **A Polluted Day**
September 23rd 2008, AQI = 12   February 9th 2009, AQI = 309

Figure 6: Comparison of AQI and visual observation of pollution in Beijing

This method is very helpful in monitoring and understanding the changes in meteorology and of any policy interventions during the days. For example, Figure 6 presents two pictures (1) from September 23rd, 2008, during the Olympic games, when a number of interventions to control air pollution were in place (2) from February 9th, 2009, when all the restrictions were removed and the AQI shot up from 12 (for a clear day) to 309 (hazardous zone). This is a simple and easy method to visualize the pollution and relate the same to AQI, which can be further used for policy discussions.

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[8] Room with a View – a photo journal of Beijing air pollution
@ http://sites.asiasociety.org/beijingair/#room-with-a-view
[9] AQI for multiple cities in China @ http://www.vecc-mep.org.cn/eng/

Paris, France

This is an artist's way of interpreting and delivering the pollution message to public. Everyday, a balloon is launched near the Eiffel Tower, in the middle Paris, France.

In spring 2008, the balloon took a new dimension by becoming a citizen indicator of air quality. In partnership with AIRPARIF® (approved body to monitor the air quality in France), the new Balloon Air de Paris changes color depending on ambient air quality in Paris (green / red for good / poor through orange / poor). This system is supplemented by an independent perspective showing the same color code the air quality near traffic[10].

Figure 7: Air pollution visualization in Paris, France

The idea is very unique to convey the message of air pollution to the general public, without the fuzz of the opening a website or reading the newspaper, and more importantly at a location which is very central to the city and where people are bound to pass and notice the balloon's color.

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[10] Aire de Paris @ http://www.ballondeparis.com/fr/ballondeparis

Helsinki, Finland

This is also an artist's way of interpreting and delivering the pollution message to public. This is different from the methodology employed in Paris, France. Unlike the use of AQI, this method is designed to emphasize the intensity of pollution at the source – a power plant in Helsinki, Finland[11].
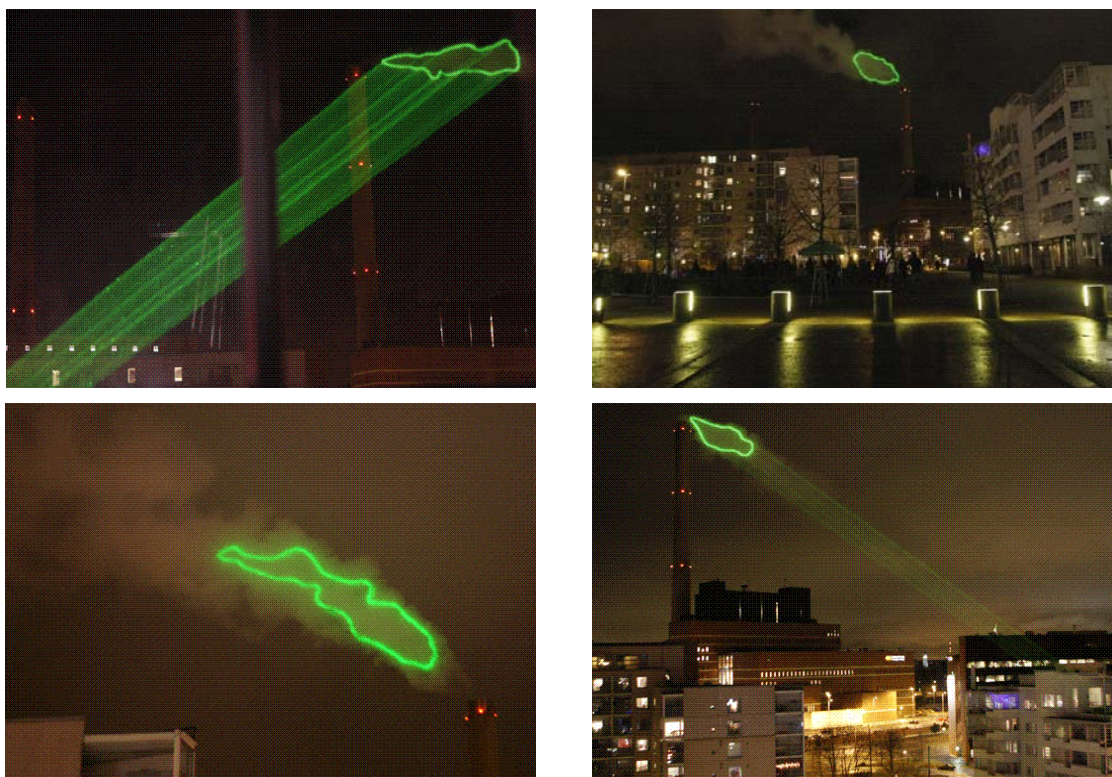

Figure 8: Illuminating emissions in a stack plume in Helsinki, Finland

In this environmental art installation by the French art Duo HeHe (Helen Evans and Heiki Hansen) illuminates the emissions as "Green Cloud" using a range of laser beams, pre-calibrated to illuminate certain range of pollution thickness observed in the plume of the flue gas from the power plant. The size of the ring changes, in real time, depending on the pollution intensity. For example, if the plume is too thick, it is expected to take longer distances to disperse and thin the concentrations within the plume and hence a longer ring. Similarly, if the boilers are not working so hard and the pollution intensity is low; automatically the size of the ring is small, indicating that the emissions are low at that particular moment.

This is an excellent way of raising awareness on air pollution directly at the source and let the general public know about the emissions and their dispersion characteristics in real time. Of course, this method is not applicable for all types or all sizes of sources – most suited for sources like power plants.

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[11] "Green Clouds" in images @ http://www.pixelache.ac/nuage-blog/

Seoul, South Korea

This "Living Light" program aims to combine real-time data about the environment with dynamic lighting to create an interactive façade that displays air quality and public interest in the environment[12]. It is a permanent outdoor pavilion in Peace Park, across from World Cup Stadium in Seoul, Korea. The air quality data is supported by Air Korea[13].
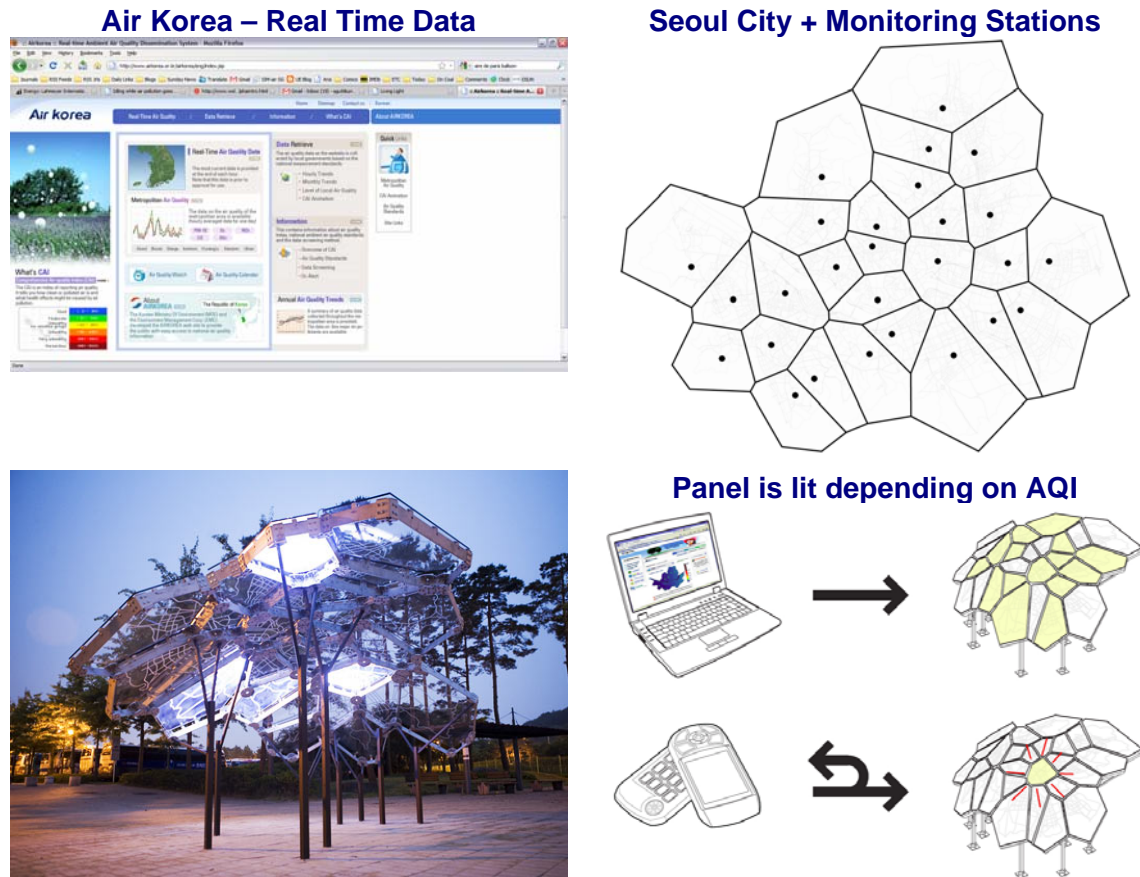
Air Korea – Real Time Data

Seoul City + Monitoring Stations

Panel is lit depending on AQI

Figure 8: Illuminating emissions in a stack plume in Helsinki, Finland

The general public can send a text message with a zip code to the "Living Light" Hotline and receive a text message reply with the neighborhood's current air quality. At the same time, the panel of the requested zip code blinks and the facade becomes a register of collective interest.

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[12] Living Lights - Public awareness of air pollution using lighted panels for the geography of Seoul, South Korea. Details of the program @ http://www.livinglightseoul.net

[13] Air Korea – Real time data on air quality across South Korea @ http://www.airkorea.or.kr/airkorea/eng/index.jsp

In Conclusion

While monitoring air quality and developing a common denominator for all the pollutants is one side of the coin, the dissemination of the information to the public and policy makers (alike) is the other side and a crucial one. From the examples presented in this paper, the importance of this index to the policy makers and the public is very obvious.

The environmental regulations might not be effective, if there are no simultaneous efforts for public awareness to accept the regulation and for capacity building to implement those regulations. An important co-benefit of increased public awareness of air pollution is (1) public demanding cleaner air (2) stakeholders looking for opportunities in cleaner production, particularly with government officials, shifting the emphasis from emissions regulations to health exposure (pollution related) indicators.

As part of the integrated air quality management, the combination of regulations, awareness and capacity building, and partnerships between stakeholders (including artists, in this case) contribute equally towards improving air quality in a city. This approach where each instrument (e.g., information) supports the other instrument (e.g., awareness) yields quicker and better results.