Ubiquitous Environmental Monitoring as Decision Tool
MONITAR SENSE: An Environmental Tool

Paulo Pinho[1,3], Sérgio Lopes[1,2,3], Gabriel Rodrigues[3] and Pedro Colaço[3]
[1]*CI&DETS, Center for Studies in Education, Technologies and Health, Polytechnic Institute of Viseu, Campus Politécnico, 3504-510, Viseu, Portugal*
[2]*ADAI/LAETA, Association for the Development of Industrial Aerodynamics, Coimbra University, Rua Pedro Hispano, 12, 3030-289, Coimbra, Portugal*
[3]*MONITAR, Lda, Repeses, Viseu, Portugal*

Keywords: Environmental Monitoring, Web-based Platform, Ubiquitous Monitoring, Decision Tool.

Abstract: Ambient (outdoor) Environmental Quality (AEQ) of urban areas and Indoor Environmental Quality (IEQ) of buildings are recognized as key factors that contribute to improve the position on ranking of smart cities. The challenge is being able to evaluate AEQ and IEQ in large scale, and making the results available, in real-time, so that decision makers can react according to the received information. Monitar started the implementation of an AEQ and IEQ monitoring network based on new environmental sensors and information and communication technologies (ICT), such as a web-based platform, in order to monitor environmental parameters in a large area at a lower cost than conventional environmental monitoring networks and to disseminate information to become available for decision. The data collected are the base for decision support tool to be used by building and district managers and also individual people. In terms of Smart City, in its component Smart Environment, the monitoring network uses different equipment that due to their dimension and price can be placed in several locations. ICT supports Smart Governance and Smart Living, also addressed by accessing information helping changing people's behaviour. This paper describes the Environmental Monitoring Network applied by Monitar (designated MONITAR SENSE) in Central Portugal namely the mainframe and some results.

1 INTRODUCTION

A poor ambient environmental quality (AEQ) is a current problem in urban areas. The continuous exposure to noise has a significant impact on health and well-being resulting, for example, in an increased of cardiovascular disease risk caused by the increase of hypertension and stress (*e.g.* WHO, 2001) and available data shows that 65% of the Europeans living in urban areas are exposed to high noise levels (Decision n. º 1386/2013/EU). Health problems associated with exposure to air pollutants are also an major concern, with particulates (mainly small ones $PM_{2,5}$ and PM_{10}), ozone (O_3) and nitrogen dioxide (NO_2) (*e.g.* EEA, 2015), as main pollutants.

The lack of instantaneous data on environmental parameters such as: air pollutants, noise, temperature, relative humidity, ultraviolet radiation, among others, is due to the fact that most of the measurement techniques and web-based platforms have not yet reached a threshold technological development versus costs, that allow its global spread.

In developed countries there are several convencional AEQ monitoring networks and databases that allow access to historical data, however, usually, they do not measure important environmental parameters such as noise, neither are stable databases nor provide real time data.

European Union obliges member states to have a network of air quality monitoring stations using reference methods and equipment with very strict technical specifications (Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe). These equipments are expensive, need to be in a large conditioned compartment, with great consumption of energy. This type of stations is not expected to increase due to its high cost.

Information produced by this type of network usually does not have the necessary interaction with

Pinho, P., Lopes, S., Rodrigues, G. and Colaço, P.
Ubiquitous Environmental Monitoring as Decision Tool - MONITAR SENSE: An Environmental Tool.
DOI: 10.5220/0006344002740280
In *Proceedings of the 6th International Conference on Smart Cities and Green ICT Systems (SMARTGREENS 2017)*, pages 274-280
ISBN: 978-989-758-241-7

public due to several failures in data communication process, nonfunctional communication platforms, information not updated in real time and limited spacial coverage. Same issues are verified in meteorological stations.

In developed societies, most people spend about 90% of their time doing indoors activities and, in most cases, exposed to poor indoor environmental quality (IEQ) associated with health problems, performance decrease and absenteeism (*e.g.* Shendell *et al.,* 2004; WHO, 2010; Mendell and Heath, 2005; Madureira *et al.* 2009; Haverinen-Shaughnessy *et al.,* 2011 and Bakó-Biró *et al.,* 2012).

However, there is no ubiquitous monitoring of indoor environmental parameters for public administration buildings (schools, hospitals, public departments, etc.) or private social services (nursing homes, kindergartens, etc.), neither assessment of workers exposure or building users.

In recent years there has been a substantial development and/or improvement of technologies for measuring environmental parameters. These technologies allow the modular development with several environmental sensors and communication components with lower costs, less space required, good temporal and spatial representativeness and lower energy requirements than traditional equipment. However, it is necessary to develop the equipment and not only the sensor, also auxiliary components and validation and calibration protocols that will guarantee the quality of results (MacDonell *et al.,* 2013; sneider, *et al.,* 2013; spinelle *et al.,* 2013; Jovašević-Stojanovića *et al.,* 2015)

For temperature, relative humidity, ultraviolet radiation, noise and CO_2, low cost sensors have got range and precision required, almost, for their immediate application. For air quality parameters, several recent studies show that low cost technology is already available for reduced concentration ranges and with some stability (*e.g.* Mead *et al.,* 2013 and Ikram *et al.,* 2012; spinelle *et al.,* 2015; spinelle *et al.,* 2017). For pollutants such as O_3 or NO_2, the electrochemical sensors allow determine its concentration in the range observed in ambient air, but there are also other aspects that compromise their use, namely the operating conditions (temperature and humidity) and electronic noise which affects the output signal (Aleixandre *et al.,* 2014, Spinelle *et al.,* 2015 and Spinelle *et al.,* 2017). Therefore, the main challenge for these sensors is to improve its operation sensitivity, stability and longevity (e.g. Kumar *et al.,* 2015).

For measurement fine particles (PM_{10} or $PM_{2,5}$), the low cost sensors are based on counting particles as they interrupt a light beam. Particle concentration is further determined by signal processing (separating size intervals as function of beam interruption time) and on a calculation algorithm that considers particle density, counting efficiency amongst other parameters. The device results depends on the operating conditions and the calculation algorithm used for converting particle count to concentration (Gozzi *et al.,* 2016, Johnson *et al.,* 2016 and Williams *et al.,* 2014).

Several projects of ubiquitous environmental monitoring are being developed (*e.g.* Hwang *et al.,* 2010; Ghobakhlou *et al.,* 2011; Bagula *et al.,* 2012; Yun *et al.,* 2012; Moltchanov *et al.,* 2015) intending to use current communication technologies and equipment to support the decision making of governmental entities, private entities and everyday people's behavior.

2 MONITAR SENSE: AN ENVIRONMENTAL TOOL

Monitar has been developing an environmental monitoring network associated to a web-based platform MONITAR SENSE (sense.monitar.pt) as frame for a decision tool.

In terms of *Smart City*, the components of *Smart Governance*, *Smart Environment* and *Smart Living*, are contemplated. The calculation of indexes based on real-time data that summarize reality (in final development, not implemented yet) will support decision makers and therefore support a Smart Governance. Smart Environment was achivied by increasing temporal and spatial representativeness of environmental data through the use of communication technologies and equipment that due to their dimension and price have been placed in several locations. Smart Living is also addressed by the dissemination of real-time data helping people changing their behaviour in daily life and contributing to improve their health.

In terms of *Citizens' Observatories*, MONITAR SENSE is developing home monitoring equipment that will enable citizens to contribute and participate in environmental information sharing, influencing the rest of the community, social priorities and decision making.

In terms of *IOT*, MONITAR SENSE equipment has real-time communication systems and web-based platform that connects people to real-time equipment data. Most of the environmental monitoring equipment operates on an "*Off-Grid*" or "*Stand-Alone*" logic, collecting data over a long period of time, which are then analysed in backoffice, resulting in reports that reflect a past episode. This time lapse between the monitored episode and the data communication gives rise to an ineffective, or even non-existent decision.

MONITAR SENSE platform, see Figure 2, is a user friendly tool to interact with decision makers and general public allowing visualization of measured parameters in real time, perform historical query, download editable files to data post-processing and view equipment location in a map. Also, enable to create private and public monitoring networks, user management, equipment management and network management.

At a final development stage, not yet implemented, are the possibilities of: configure alerts when exceeded a predetermined value of a measured parameter, calculate in real time several indexes that will be used to support decisions and also statistical treatment and reports of measured data and access to data through the application programming interface (API).

Figure 1: Environmental monitoring network and web-based platform MONITAR SENSE concept.

The network is composed by equipament that measure several environmental parameters. Collected data are transmitted to backoffice to be analysed and become available in a user-friendly frontend.

Concerning ambient environmental quality, as shows Figure 3, equipments that are being installed by MONITAR are: SmartAIRSense for monitoring ambient air quality, measuring parameters such as ozone (O_3) and nitrogen dioxide (NO_2) (using electrochemical sensors) and particle matter (PM_{10} and/or $PM_{2,5}$) (using a particule counter); SmartNOISESense for monitoring noise levels (using an microphone type 2); SmartMETEOSense for monitoring meteorological parameters such as air temperature and relative humidity (using capacitive sensors); ultraviolet and total radiation (using photodiode); wind speed and direction (using a vane anemometer); atmospheric pressure (using a resistor sensor) and rainfall intensity (using a rain collector).

Figure 2: Web-based platform MONITAR SENSE (sense.monitar.pt).

Figure 3: SmartAIRSense, SmartMETEOSense and SmartNOISESense.

Figure 4 shows equipment that are being developed by MONITAR to evaluate indoor environmental quality in schools and homes. SmartHOMESense and SmartSCHOOLSense for monitoring parameters such as CO_2, O_x (O_3+NO_2), PM_{10} and/or $PM_{2,5}$, air temperature and relative humidity, illuminance and noise.

Figure 4: SmartHOMESense or SmartSCHOOLSense.

The equipment uses an electrochemical sensor to

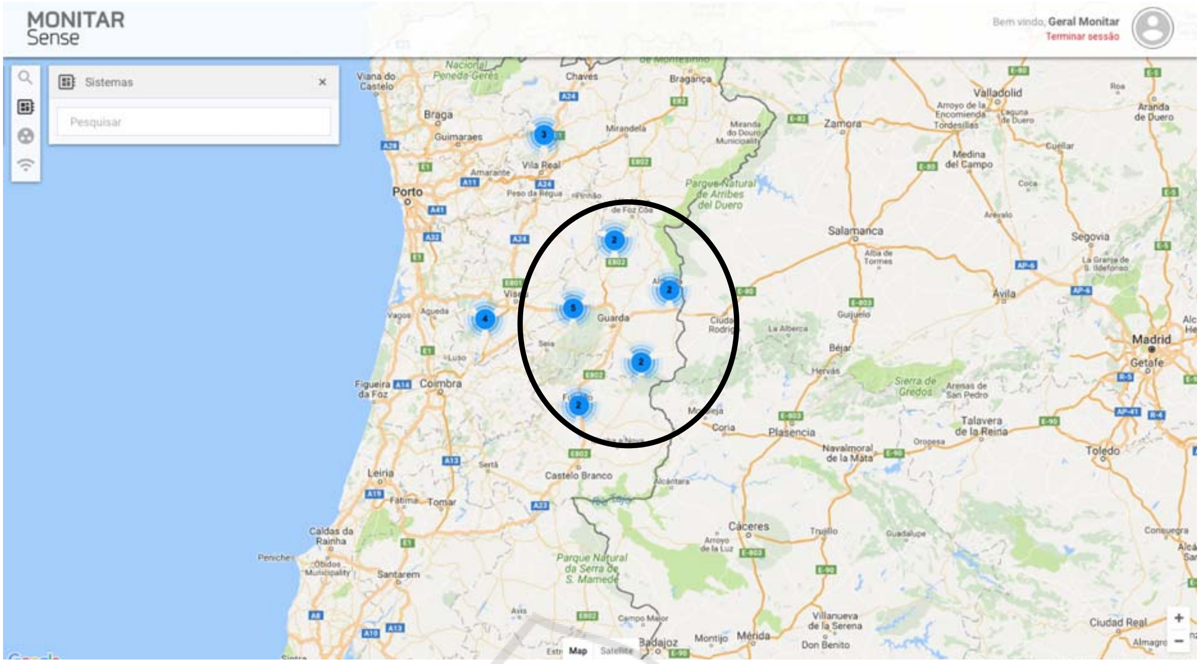

Figure 5: Display of web-based platform MONITAR SENSE (sense.monitar.pt) showing 13 MONITAR environmental monitoring stations located in inland central Portugal.

O_x measurement, a nondispersive infrared sensor for CO_2 measure, microphone type 2 for noise measurement, a particule counter for PM_{10} and/or $PM_{2,5}$, capacitive sensors to measure temperature and relative humidity and photodiode to measure illuminance.

3 MONITAR SENSE APPLICATION - AN ENVIRONMENTAL MONITORING NETWORK IN CENTRAL PORTUGAL

MONITAR SENSE is being applied as a frame of an environmental monitoring network located in central Portugal.

The network has 13 locations. Each location has a SmartAIRSense, a SmartNOISESense and a SmartMETEOSense. Figure 5 presents the web-based platform display MONITAR SENSE (sense.monitar.pt), showing Monitar stations located in central Portugal.

Since early network implementation, not every station worked continuously due to internet availability, stopping data communication, or refrigeration fail in SmartAIRSense equipment compromising liability of air quality data.

MONITAR SENSE platform displays environmental parameters charts measured every 5 minutes, allowing selection of the visible data period, see an example in Figure 6.

The obtained data from SmartNOISESense and SmartMETEOSense are very reliable since sensors are very stable and have good accuracy within a large range of environmental conditions.

Air quality electrochemical sensors (O_3 and NO_2) are very sensible to temperature changes having less accuracy if equipment is not temperature conditioned. SmartAIRSense equipment has conditioned temperature but in extreme environmental conditions (when completely exposed to sun during summer months, for example) cannot always guarantee optimal temperature range. Although this handicap obtained information can still be very useful to decision makers.

In this location area (Inland Central Portugal) only exists two conventional Air Quality Monitoring Stations (AQMS) from the Environmental Portuguese Agency Air Quality National Network (Fornelo do Monte and Fundão, 75 km of distance between them).

When ozone concentration are above 180 $\mu g/m^3$ measured in these stations population should be informed to avoid exposition to breathing air containing ozone including people with asthma, children, older adults, and people who are active

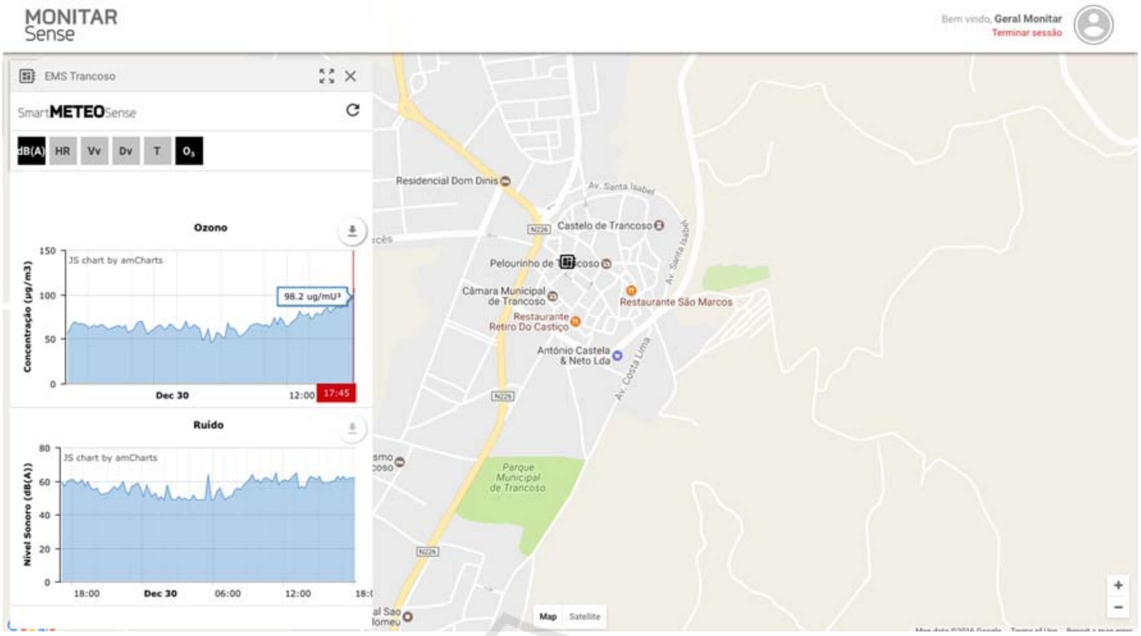

Figure 6: Display of web-based platform MONITAR SENSE showing ozone data and noise data from one of the MONITAR stations.

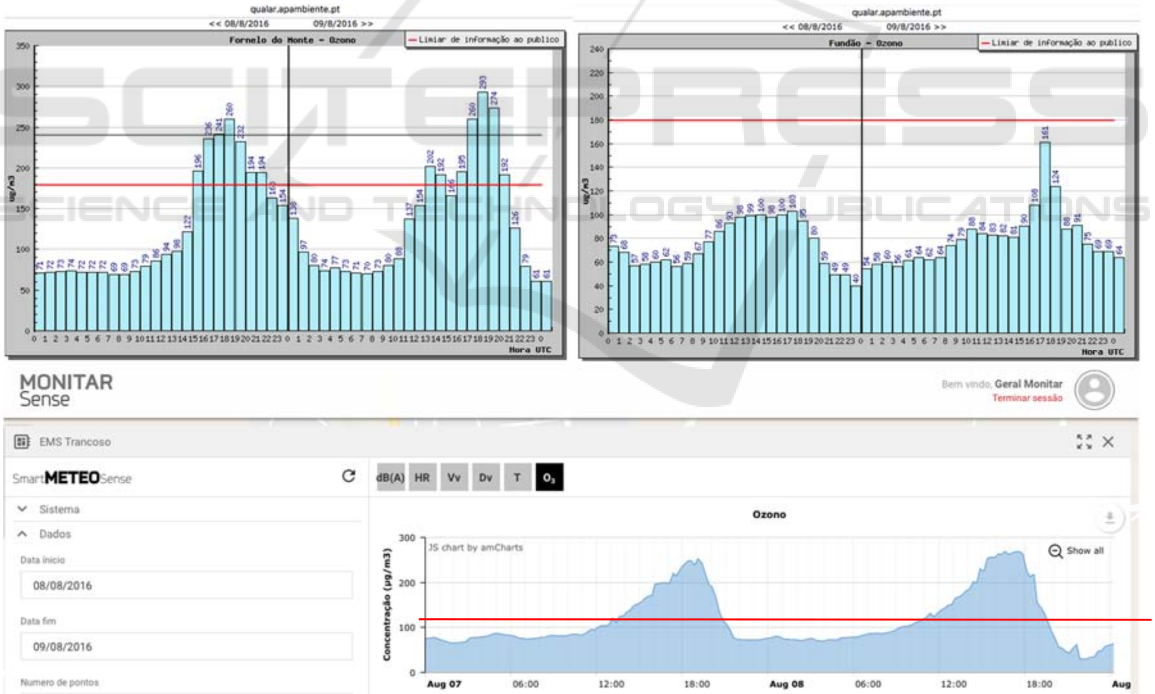

Figure 7: Display of web-based platform MONITAR SENSE (sense.monitar.pt) and the chart obtained in Environmental Portuguese Agency Air Quality Platform showing data from Air Quality Monitoring Station located in Central Portugal concerning to in 8 and 9 of august of 2016.

outdoors. However, it is verified that the informative channels are not working correctly and people are not informed in real time, and usually know only after the exposition occurred.

As it can be seen in Figure 7, on August 8 and 9, 2016, two ozone episodes occurred in Central Portugal detected by the Fornelo do Monte station (AQMS from Environmental Portuguese Agency) but not detected in the other Central Portugal AQMA (Fundão). These episodes were also detected in the MONITAR SENSE station located approximately in the middle location between these two stations. Information from MONITAR SENSE station, even less accurate, can be very useful for decision makers that after receiving alert can confirm the values in the National Network and act in real time.

4 CONCLUSIONS

Ubiquitous environmental monitoring starts being a reality since the technology become available and affordable. However, for some parameters like air quality pollutants (O_3, NO_2, PM_{10} and $PM_{2,5}$) the technology is not available in a ready-to-use way, needing to be tested and calibrated before use.

Also, some steps need to be done before this ubiquitous environmental monitoring starts being a decision tool.

MONITAR SENSE is already a real environmental tool although it needs some improvements.

ACKNOWLEDGEMENTS

The authors acknowledge the support from the Polytechnic Institute of Viseu, namely the CI&DETS – Center for Studies in Education, Technologies and Health (Project I&D CI&DETS/IPV/CGD), from ADAI/LAETA - Association for the Development of Industrial Aerodynamics and from Monitar, LDA and Associação de Munícipios da Cova da Beira.

REFERENCES

Aleixandre M., Matatagui D., Santos J. P., Horrillo M. C., 2014. *Cascade of Artificial Neural Network committees for the calibration of small gas commercial sensors for NO_2, NH_3 and CO*. IEEE SENSORS 2014 Proceedings.

Bagula, A., Zennaro, M., Inggs, G., Scott, S., & Gascon, D. 2012. Ubiquitous Sensor Networking for Development (USN4D): An Application to Pollution Monitoring.Sensors(Basel,Switzerland),12(1),391–14.

Bakó-Biró Z, Clements-Croome D.J., Kochhar N., Awbi H.B., Williams M.J., 2012. *Ventilation rates in schools and pupils performance*. Building and Environment 48:215-23.

Decisão n. º 1386/2013/UE do Parlamento Europeu e do Conselho de 20 de novembro de 2013 relativa a um *programa geral de ação da União para 2020 em matéria de ambiente "Viver bem, dentro dos limites do nosso planeta*".

EEA (European Environment Agency), 2015. *Air quality in Europe*. Report. EEA Report n. º 5/2015.

Ghobakhlou A., Zandi S., Sallis P., 2011. Development of Environmental Monitoring System with Wireless Sensor Networks. 19th International Congress on Modelling and Simulation, Perth, Australia.

Gozzi, F., Ventura, D.G., Marcelli, A., 2016. *Mobile monitoring of particulate matter: State of art and perspectives*. Atm. Pollution Research 7, 228-234.

Haverinen-Shaughnessy U., Moschandreas D.J., Shaughnessy R.J., 2011. *Association between substandard classroom ventilation rates and students academic achievement*. Indoor Air, 21:121-31.

Hwang, J., Shin, C., Yoe, H., 2010. Study on an Agricultural Environment Monitoring Server System using Wireless Sensor Networks. Sensors, 10(12), 11189–11211.

Ikram J., Tahir A., Kazmi H., Khan Z., Javed R., Masood U., 2012. *View: implementing low cost air quality monitoring solution for urban areas*. Environmental Systems Research, 1:10.

Johnson, K.K., Bergin, H.M., Russell, G.A., Hagler, W.S.G., 2016. *Using Low Cost Sensors to Measure Ambient Particulate Matter Concentrations and On-Road Emissions Factors*. Atmospheric Measurement Techniques, amt-2015-331.

Jovašević-Stojanovića, M., Bartonovab, A., Topalovićc, D., Lazovića, I., Pokrićd, B., Ristovskie, Z., 2015. *On the use of small and cheaper sensors and devices for indicative citizen-based monitoring of respirable particulate matter*. Envir. Pollution, V. 206, 696–704.

Kumar P., Morawska L., Martani C., Biskos G., Neophytou M., Sabatino S. D., Bell M., Norford, Britter L.R., 2015. *The rise of low-cost sensing for managing air pollution in cities*. Environment International, Volume 75, 199-205.

Madureira J., Alvim-Ferraz M., Rodrigues S., Gonçalves C., Azevedo M.C., Pinto E., Mayan O., 2009. *Indoor Air Quality in Schools and Health Symptoms among Portuguese Teachers*. Human and Ecological Risk Assessment: An Int. Journal, 15:159-69.

MacDonell M., Raymond M., Wyker D., Finster M., Chang Y., Raymond T., Temple B., Scofield M., 2013. Research and Development Highlights: Mobile Sensors and Applications for Air Pollutants. Argonne National Laboratory Environmental Science Division (EVS) Argonne, IL, EPA/600/R-14/051.

Mead M.I., et al., 2013. *The use of electrochemical sensors for monitoring urban air quality in low-cost, high-density networks*. Atmospheric Environment, Volume 70, 186–203.

Mendell M.J., Heath G.A., 2005. *Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature*. Indoor Air, 15:27-52.

Shendell D.G., Prill R., Fisk W.J., Apte M.G., Blake D., Faulkner D., 2004. *Associations between classroom* CO_2 *concentrations and student attendance in Washington and Idaho*. Indoor Air, 14:333-41.

Snyder, E., P. Solomon, M. MacDonell, R. Williams, E. Thoma, D. Vallano, M. Raymond, AND D. Olson. Next generation air monitoring-a review of portable air pollution sensors. Presented at 2013 32nd annual AAAR, Portland, OR, September 30, 2013.

Spinelle L., Aleixandre M., Gerboles M., 2013, Protocol of evaluation and calibration of low-cost gas sensors for the monitoring of air pollution, EUR 26112.

Spinelle L., Gerboles M., Villani M. G., Aleixandre M., Bonavitacola F., 2017. *Field calibration of a cluster of low-cost commercially available sensors for air quality monitoring. Part B: NO, CO and* CO_2. Sensors and Actuators B: Chemical, Vol. 238, Pages 706-715.

Spinelle L., Gerboles M., Villani M. G., Aleixandre M., Bonavitacola F., 2015. *Field calibration of a cluster of low-cost available sensors for air quality monitoring. Part A: Ozone and nitrogen dioxide*. Sensors and Actuators B: Chemical, Volume 215, Pages 249-257.

WHO (World Health Organization), 2010. WHO *Guidelines for Indoor Air Quality: Selected Pollutants*. WHO Regional Office for Europe.

WHO (World Health Organization), 2001. *Occupational and community noise*. Fact sheet N.258. Feb. 2001.

Williams, R., Kaufman, A., Hanley, T., Rice, J., Garvey, S., 2014. *Evaluation of Field-deployed Low Cost PM Sensors*. United States Environmental Protection Agency. EPA/600/R-14/464.

Yun, J. , Baek, J. , Kang, B. , Park, P. 2012. 'Development of Workplace Environmental Monitoring Systems Using Ubiquitous Sensor Network'. World Academy of Science, Engineering and Technology, International Science Index 70, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, 6(10), 2210 - 2214.

Moltchanov S., Levy I., Etzion Y., Lerner U., Broday D.M., Fishbain B., 2015. On the feasibility of measuring air pollution at dense urban areas by wireless distributed sensor networks. Science of the Total Environment. 502:537–547.