EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

EuNetAir

European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

EuNetAir Newsletter

COST Action TD1105 Iss. 8/Sep 2016

Contents

Editorial

by Ralf Moos

Welcome to our loyal readers. This is the eighth and final edition of the "EuNetAir Newsletter", reporting on the over four year-lasting successful history of this COST Action.

Reviewing the past four years, I have to thank at first Dr. Jaroslaw Kita for the layout of this Newsletter, which is one of the success factors of this small journal. Besides the many contributing scientists and researchers who reported on the enormous achieved outcomes of this Action, e.g. of their Special Interest Groups (SIG), their Working Groups (WG), their experiences of Short Term Scientific Mission (STSM), their learning successes during Training Schools and so on, I like to thank greatly Dr. Daniela Schönauer-Kamin for her endurance and her persistence in acquiring articles and editing this journal. Without her, the Newsletter would not have had such a huge success.

It is a must to thank Dr. Michele Penza. Why? Because the entire Action neither would exist nor had it such a great outcome without the commitment and the efforts of Michele. I mean the many nightshifts during the application phase, during the presentation of reports, or during the preparation of meetings like the final one in October 2016 in Prague. Thank you Michele!

I do not want to go more into detail of this final Newsletter, another editorial of Michele Penza will do that. Instead, I hope you enjoyed the past seven Newsletters and I would be happy if you enjoyed this eighth one as well.

Ralf Moos, Editor-in-Chief EuNetAir Newsletter
University of Bayreuth, Germany
September 2016

by Michele Penza

This final eighth issue of Newsletter covers the Action grant period December 2015 - September 2016 to disseminate the networking activities and current research results in environmental science and technology from COST Action TD1105 (www.cost.eunetair.it) European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability - EuNetAir, edited half-yearly in the four years 2012-2016 by an Editorial Board, chaired by Prof. Ralf Moos (University of Bayreuth, DE) with Editorial Board Manager by Dr. Daniela Schönauer-Kamin (University of Bayreuth, DE).

The excellent teams of more than 200 involved international experts such as scientists, researchers, technologists, modellers, SMEs managers from 31 COST Countries, 4 International Partner Countries (IPCs) and 3 Near Neighbour Countries (NNC) have worked hardly to contribute to the work-plan objectives of the COST Action TD1105 in the air quality monitoring including environmental technologies, nanomaterials, gas sensors, smart systems, air-pollution modelling, measurements, methods, standards and protocols.

The concerted COST Action TD1105 is very pleased to present the networking/dissemination results of the national/international research from Action partnership to various international conferences/workshops such as the *Fifth Scientific Meeting* based on Working Groups and Management Committee Meeting focused on *New Sensing Technologies for Indoor Air-Pollution Monitoring and Environmental Measurements* at Bulgarian Academy of Sciences (16-18 December 2015, Sofia, Bulgaria). This EuNetAir event was attended by at least 50 world-class experts and welcomed from Bulgarian Deputy-Minister of Education and Research.

Furthermore, Action has held the *Fourth Workshop on Innovations and Challenges for Air Quality Control Sensors* (25-26 February 2016, Vienna, Austria) at FFG Headquarters hosting Austrian COST Association and welcomed by Austrian COST National Coordinator. More than 50 top-class experts discussed on the recent advances of air quality technologies and modelling.

Moreover, Action has held the *Fourth Training School on Modelling, Methods and Technologies for Air Quality Control* (19-22 April 2016, Copenhagen, Denmark) at Emdrup Campus by Aarhus University. More than 20 Trainees and 8 local and foreign Trainers from 15 COST Countries were involved.

Also, COST Action TD1105 managed the *Symposium X* devoted to *Functional Materials for Environmental Sensors and Energy Systems* at Spring Meeting 2016 of the European Materials Research Society (EMRS) in Lille, France, 2-6 May 2016. This event was well-attended by at least 200 world-class experts.

EuNetAir has financially supported high-level 4 Short Term Scientific Missions (STSMs) in the period of the extended Year 4 (1 July 2015 - 15 November 2016) for visit and exchange of motivated Early Career Investigators from a laboratory to another one in order to start and consolidate new international research collaborations in the whole area of EuNetAir topics for fruitful networking in S&T cooperation.

The COST Action TD1105 (EuNetAir) was officially extended to 15 November 2016.

On behalf of Action Management Committee, I would like to thank ALL Action participants for their valuable scientific work, kind availability and great enthusiasm that have made our Action a very successful COST Top-Story creating an excellent S&T platform to pursue by collaborative research teams the challenges of Horizon 2020.

Michele Penza, Action TD1105 Chair,

ENEA, Italy

September 2016

Focus On

Focus On

Short History of EuNetAir

M. Penza, Action Chair, ENEA, Italy

The COST Action TD1105 (www.cost.eunetair.it) - European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability - EuNetAir aims to establish a top-level Pan-European multidisciplinary R&D platform on a new sensing paradigm for Air Quality Control (AQC) contributing to sustainable development, green-economy and social welfare and to create collaborative research teams in the European Research Area (ERA).

The challenges addressed by COST Action TD1105, composed by 4 Working Groups and 4 Special Interest Groups with leadership by ENEA (Italy), including about 200 international Experts from outstanding 120 Teams (Academia, Research and Industry) of 31 COST Countries (Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, Luxembourg, The Former Yugoslav Republic of Macedonia, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom) are listed as follows:

- Nanomaterials for AQC sensors
- Low-cost gas sensors
- Low-power sensor-systems
- Wireless technology (Environmental Sensors Network)
- Air quality modelling
- Environmental measurements
- Standards and protocols

EuNetAir includes more than 200 experts and is mainly based on 4 Working Groups (WGs) and 4 Special Interest Groups (SIGs), coordinated by a leader:

- WG1: Sensor materials & nanotechnology
- WG2: Sensors, devices & systems for AQC
- WG3: Environmental measurements & air-pollution modelling
- WG4: Protocols & standardisation methods
- SIG1: Network of spin-offs
- SIG2: Smart sensors for urban air monitoring in cities
- SIG3: Guidelines for best coupling air-pollutant and transducer
- SIG4: Expert comments for the revision of the air quality Directive (2008/50/EC)

Focus On

In the period 2012-2016, the COST Action EuNetAir organized about 28 meetings and workshops, 4 training schools and supported about 45 young European investigators to carry out challenging research in the field of environmental sensor technologies and measurements in foreign host institutions of the COST Countries and Associated Countries signing the Memorandum of Understanding EuNetAir.

This has created high impact with the establishing of an international network including about 15 SMEs and spin-offs. Several world-class experts from International Organizations such as European Environment Agency (EEA), World Health Organization (WHO) Europe, United Nations Economic Commission for Europe (UNECE) with group devoted to Long-Range Trans-Boundary Air Pollution - European Monitoring and Evaluation Programme (EMEP), Joint Research Center (JRC) - Institute for Environment and Sustainability, US Environmental Protection Agency (EPA), NASA Ames Research Center, MIT, CSIRO and Queensland University of Technology, have been involved with fruitful discussions and long-term cooperation.

The excellent teams of more than 200 involved international experts such as scientists, researchers, technologists, modellers, SMEs managers from 31 COST Countries, 4 International Partner Countries (IPCs) and 3 Near Neighbour Countries (NNC) have worked hardly to contribute to the work-plan objectives of the COST Action TD1105 in the air quality monitoring including environmental technologies, nanomaterials, gas sensors, smart systems, air-pollution modelling, measurements, methods, standards and protocols.

Some significant results and deliverables:

- Joint-exercise sensors-vs-analyzers in real city environment and related joint-publication
- Report on Innovation in sensor technology for air quality control
- Funded international (>2) and national (>10) research projects in air quality control
- 5 Special Issues of archival papers and conference proceedings
- Organization of international conferences (>3) and symposia (>5)
- Invited Talks (>20) and Plenary Talks (>5) of the EuNetAir members
- Advising of European Commission in the field of sensor-systems

The COST Action TD1105 (EuNetAir) started with the kick-off meeting in Brussels on 16 May 2012 and was officially extended till to 15 November 2016.

At the date of November 2016, 31 COST Countries (Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, Luxembourg, Former Yugoslav Republic of Macedonia, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom) with 123 partner institutions have been involved in EuNetAir. The Action participants are from 55 universities (44%), 39 research centres (32%), 4 environmental agencies (3%) and 25 SMEs (21%) including 9 spin-offs (8%). Additional 8 top-level institutions from 7 Non-COST Countries (Australia, Canada, China, Morocco, Russia, Ukraine, USA) were involved in the Action as well.

The COST Action TD1105 was selected as Top-Story by COST Association and acknowledged officially in the COST Association website (http://www.cost.eu/media/cost_stories/EuNetAir).

On behalf of Action Management Committee, I would like to thank ALL Action participants for their valuable scientific work, high-quality collaboration, kind availability and great enthusiasm that have made our Action a great success.

Kick-off Meeting at COST Office,
16 May 2012, Brussels, Belgium

1st Scientific Meeting at ENEA,
4 - 6 December 2012, Rome, Italy

Focus On

3rd Management Committee Meeting at IREC,
21 June 2013, Barcelona, Spain

2nd Scientific Meeting at Queens‘ College
University of Cambridge,
18 -20 December 2013, Cambridge, UK

5th Management Committee Meeting at EMRS,
30 May 2014, Lille, France

3rd Scientific Meeting at Bahcesehir University
GEBZE Technical University
3 - 5 December 2014, Istanbul, Turkey

4th Scientific Meeting at Linkoping University
3 - 5 June 2015, Linkoping, Sweden

5th Scientific Meeting at
Bulgarian Acedemy of Sciences
16 - 18 December 2015, Sofia, Bulgaria

Spring Meeting 2016
Symposium X
at European Materials Research Society
2 - 6 May 2016, Lille, France

Focus On

Summary on IMCS 2016

D. Schönauer-Kamin, Editorial Board Manager, Functional Materials, Germany

The 16th International Meeting on Chemical Sensors (IMCS 2016) was held from July 10th to 13th, 2016, Ramada Plaza Jeju in Jeju Island, Korea: http://www.imcs2016.org/

With about 500 persons from 34 countries and more than 500 papers (three Plenary papers, 28 Invited papers, 36 Special Session papers, 198 Oral papers, 238 Posters) presented in 47 sessions the IMCS2016 was a great success. Besides sessions on metal oxide gas sensors, topics like emerging gas sensing technologies and sensor systems and applications were presented. Lots of contributions can also be found from EuNetAir participating institutions.

A very interesting and well-attendant session for the sensor community was the Special Session on “Measurement and Standardization”. International Standardization of Gas Sensors, e.g. an ISO-Standard for VOC Detectors, and Standard Gas Sensor Testing Methods are interesting topics for future research on gas sensors.

Open session at EUROSENSORS XXX: SENSIndoor presented an overview of its achievements

A. Schütze, WG2 leader & ESSC WG IQ Leader, Saarland University, Germany

With the end of the SENSIndoor project drawing nearer, the project partners organized an open session at EUROSENSORS XXX held in Budapest from September 4-7, 2016. This session, entitled “Nanotechnology-based multi-sensor systems for Indoor Air Quality – Real time monitoring for improved health, comfort and energy efficiency”, demonstrated the main scientific and technological achievements of the project:

- Pulsed Laser Deposition for improved metal-oxide gas sensing layers
- Novel low-cost selective pre-concentrators based on metal organic frameworks
- SiC-FET sensors for selective and quantitative detection of VOCs down to ppb level
- Miniaturized integrated gas sensor systems combining metal oxide gas sensors and pre-concentrators (see images below)
- Dynamic multi-sensor operation and read-out for highly selective gas sensor systems
- System calibration and evaluation under defined lab and real field conditions

The SENSIndoor partners are very proud of these achievements, which have been documented in more than 20 scientific publications so far. We are looking forward to continuing these developments and extending the applications range to other fields.

The pictures show from left to right:

Integrated sensor system with novel low-cost package for micro-pre-concentrator (µPC) and MOS sensor (highlighted); the system also comprises an optional non-dispersive infrared (NDIR) sensor for CO_2 plus temperature and humidity sensors (left)

Integrated sensor system for installation in standard wall mounts. Gas access is through the central holes in the Aluminum cover used to prevent interference by outgassing from plastic housing or PCB (right) (Images: 3S GmbH)

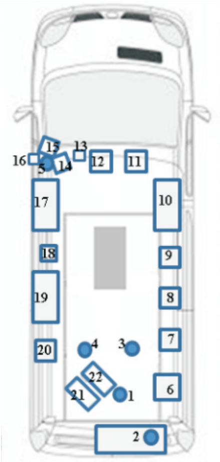
Focus On

Convergence of technologies and people: low-cost sensing for managing air pollution

C. Borrego, J. Ginja, M. Coutinho, IDAD, Portugal

Up to now, air pollution monitoring use complex, expensive and stationary equipment, which limits who gathers data, why data are collected and how data are accessed. The pattern is changing with the development of advanced low-cost, easy-to-use and portable sensor-systems, which will allow expanded use by communities and individuals, new and enhanced applications and increased data availability and access.

A Joint Exercise as Intercomparison Sensors-versus-Analysers was held at the Institute of Environment and Development-IDAD, University of Aveiro, Portugal, during the two-week experimental campaign (13-27 October 2014) at Aveiro city centre. The IDAD Air Quality Mobile Laboratory, equipped with referenced analysers (CO, NO_x, O_3, SO_2, PM10, PM2.5, Benzene, VOC, temperature, humidity, wind velocity/direction, solar radiation, precipitation) was used to host 130 advanced low-cost sensor systems (15 team from research centres, universities and companies coming from 12 countries: Austria, Belgium, Germany, Greece, Italy, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, UK) in order to compare the sensing performance in real scenario.



	Team	Sensor node	Measured parameters
	IDAD	-	CO, NOx, O_3
	IDAD	-	SO_2, CO#2, NOx#2, O_3#2
	IDAD	-	PM10
	IDAD	-	$PM_{2.5}$
	IDAD	-	T, RH, WS, WD, P, Precip., Rad.
	IDAD	-	CO_2
	SGX	-	CO, O_3, NO_2
	NILU	NanoEnvi	CO, NO_2, O_3, T, RH
	Univ.Cambridge	CAM_10	NO_2, NO, PM10, O_3, CO_2, Total VOC, CO, WS, WD, T
	IDAEA-CSIC	AQMesh	NO_2, NO, O_3, CO, T, RH, P
	Siemens AG	Ga_2O_3 microhotplate	VOC, CO
	Siemens AG	GAS86xyB	T, RH, H_2, NO_2
	VITO	AppliedSensor IAQ	VOC
	VITO	AppliedSensor	VOC, NO_2
	VITO	Electrochem	CO, NO, NO2
	IDAEA-CSIC	AQMesh	NO_2, NO, O_3, CO, T, RH, P
	IDAEA-CSIC	AQMesh	NO_2, NO, O_3, CO, T, RH, P
	SenseAir AB		CH_4, CO_2, T, RH
	3S	OdorCheckerOutdoor	VOC, T, RH
	Univ.Cambridge	CAM_11	NO_2, NO, PM10, O_3, CO_2, Total VOC, CO, WS, WD, T
	SenseAir AB		CH_4, CO_2, T, RH
	Univ. Thessaloniki	ISAG Microsensor Box	NO_2, O_3, T, P, RH
	UCL/CCMOSS		T, RH
	IDAEA-CSIC	AQMesh	NO_2, NO, O_3, CO, T, RH, P
	VITO	EveryAware SB	CO, NO_2, Gasoline exh. (CO, H_2, HC), Diesel exh. (NO_2), O_3, VOC, T, RH
	VITO	EveryAware SB	
	VITO	EveryAware SB	
	ENEA	Air-Sensor Box	NO_2, O_3, SO_2, CO, PM10, RH, T
	ECN	Airbox	$PM_{2.5}$, PM10, NO_2
	ECN	Airbox	$PM_{2.5}$, PM10, NO_2

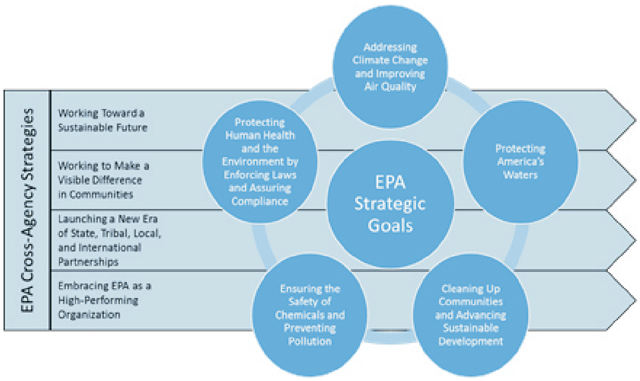
The results have been treated and the paper is under final revision for publication in an international peer-reviewed journal, with a main conclusion: O_3, CO, and NO_2 were the three gases that were measured in a relatively successful way from the tested microsensor platforms, and the gases that were profiled in a satisfactory way. In this case, correlations up to approximately 0.9 were achieved for some sensors. For PM and SO_2, the results show a poor performance with low correlation coefficients between the reference and the available measurements.

United States Environmental Protection Agency (EPA)

T. Watkins, A. Guiseppi-Elie, EPA, USA

The National Exposure Research Laboratory (NERL) was created in 1995, when the Office of Research and Development (ORD) reorganized to better support EPA's mission of protecting human health and the environment. This mission driven reorganization created national laboratories focused on exposure, effects, and risk management research, and, centers focused on risk assessment, and environmental research. NERL was strategically positioned to provide exposure science leadership not only to EPA and across the Federal government, but to the broader scientific community on emerging exposure science challenges. ORD has continued to evolve since 1995, most recently realigning its research programs to focus on conducting research using a systems approach in an integrated and transdisciplinary manner and transitioning to sustainability as an organizing driver. NERL also continues to evolve organizationally and scientifically in driving the development, understanding, and application of exposure science. NERL's multidisciplinary expertise enables the laboratory to bring innovative research and technology to address critical exposure questions and to develop approaches for reducing exposures which are necessary to protect human health and the environment.

The picture shows NERL's Strategic Plan flows from the EPA Goals and Cross-Agency Strategies.



Of particular interest to the EuNetAir community might be air research focused on models, tools and databases at: https://www.epa.gov/air-research/models-tools-and-databases-air-research

News from SIG and Ad-Hoc

News from Special Interest Groups

SIG 1 - Network of spin-offs

M. Alvisi, SIG1 leader, ENEA, Italy

The COST Action EuNetAir has grouped during this last four years, a large and excellent community composed by scientists, companies, spin-off, agencies dealing with low cost sensors for air quality monitoring. This give us the opportunities to assess a state of art of the innovation in this field, in order to produce a scoping with suggested future actions.

So, in order to assess the key factors in sensor technology and the relative state of the art in an effective and exhaustive way, depict, as an excellence and comprehensive community a collective vision in order to define a roadmap of suggested actions, map existing approaches and methodologies and propose new ones, map the strengths and weaknesses factors of the European Technology in sensors for ACQ we are closing the final report on innovation in sensor in Air Quality Monitoring coming from an ad-hoc Focus Group of Innovation in Sensor Technology inside the Action.

The adopted methodology was that of a selected focus group of experts (always open to contributions) with a multidisciplinary composition that, starting from a vision and strategic goals, will present the typical applications, the economical and technical framework, the key challenges/solutions and priorities in the different segments of the AQC “technology value chain” both for indoor and outdoor applications, the educational, societal, industrial and R@D needs. The Report will be closed by some recommendations and the relevant bibliography and will be presented in the final Meeting in Prague.

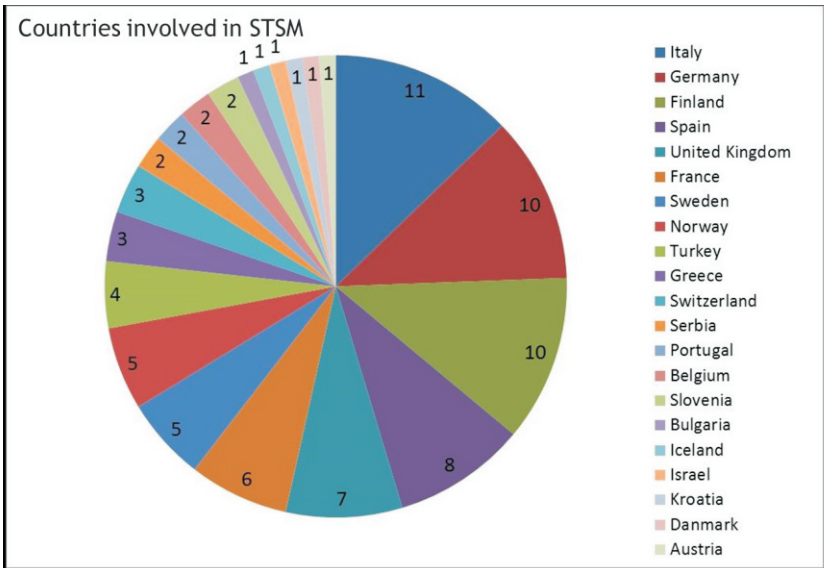
News from Ad-Hoc Groups

Short Term Scientific Missions (STSMs)

J. Theunis, MC member & STSM coordinator, VITO, Belgium

In the fourth year of EuNetAir three Short Term Scientific Missions (STSMs) were carried out, and one more is planned for October. In this newsletter you will find short reports of two of these STSMs.

Over the four years of the action has been very successful in strengthening trans-European scientific collaboration and networking through STSM. A total of 43 researchers (32 male, 11 female) benefited from a grant that allowed them to travel abroad, acquire new skills and enhance collaboration in a host laboratory in one of the participating COST countries. Most of them were Early Stage Researchers (ESR). In total 54 institutes in 21 countries were involved in these exchanges (see figure below). 21 STSMs dealt specifically with development of novel gas sensors, 2 with particle sensors; 10 focused on actual measurements in real world environments; 5 were about air quality modelling, and three others had still other subjects.



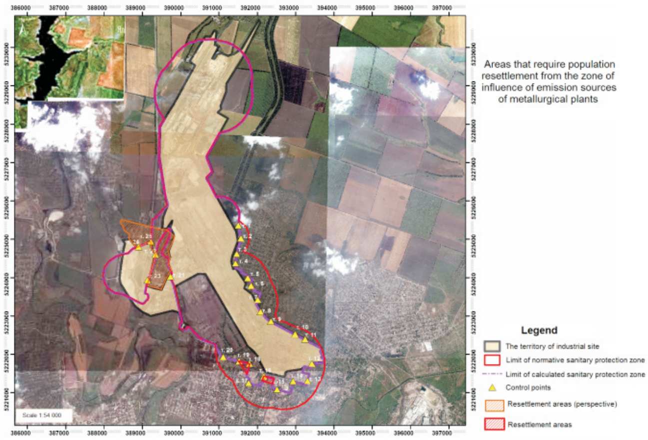
News from NNC and IPC

Incorporation human health risk assessment into system of air quality regulation

O. Turos, A. Petrosian, O. Ananyeva, V. Morhulova,
O.M. Marzeyev Institute for Public Health, Ukraine

Increasing volumes of Ukrainian industrial production have substantially influenced the air quality and led to qualitative changes of toxic emissions. The objective of this study is to substantiate the main principles of regulatory interventions improvement in air protection and to define risk zones for the exposed population of the different cities of Ukraine.

The research revealed that human health risks, where most of the pollution is attributed to combined heat and power enterprises, were within the range $ICR_{total} = 8{,}8\times10^{-6}\div4{,}5\times10^{-4}$. In cities with dominating metal industry estimates were at $ICR_{total} = 1{,}5\times10^{-4}\div2{,}3\times10^{-2}$. Risk levels from chemical industry, coke plants and machine building enterprises were at: $ICR_{total} = 2{,}7\times10^{-5}\div 4{,}6\times10^{-4}$, $ICR_{total} = 1{,}5\times10^{-6}\div9{,}8\times10^{-5}$ and ICRtotal $=1{,}8\times10^{-6}\div2{,}5\times10^{-4}$ correspondingly. The highest probability of negative effects was identified for respiratory, central nervous, cardiovascular and reproductive systems.

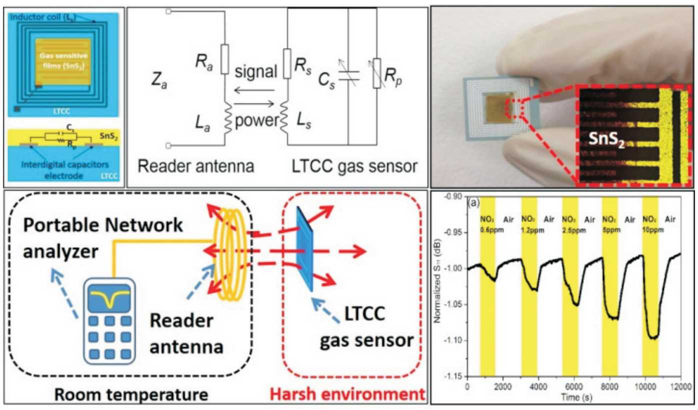


Established that almost 80 % of exposed population of investigated cities living in areas of high risk caused by emissions various groups if industrial enterprises. The carried out study gave the possibility to define zones of the highest risk and provide a prognostic assessment of health adverse effects among the exposed population for medical and conservative interventions on the risk management stage.

Wireless gas sensor based on LTCC technology

Z. Liu, Shanghai Institute of Ceramics, China

Recently, a joint research team of Shanghai Institute of Ceramics, Chinese Academy of Sciences and RMIT University reported a novel wireless gas sensor comprising of LC resonant antenna fabricated using LTCC technology. 2D SnS_2 was chosen as a model gas sensitive film due to its selective and sensitive response to NO_2. The response of the sensor was associated to physisorption based interaction between NO_2 gas and 2D SnS_2 surface that change the resistance and dielectric properties of the sensitive film, affecting the physical response of the LC antenna sensor. The wireless gas sensing experiments under different operation temperatures and NO_2 gas concentrations suggested that the highest response of the sensor could be obtained at 120ºC, and the detection concentration of the LC gas sensor could reach as low as 0.6 ppm. The device's good response and response time demonstrate that it could be a promising gas sensor for wireless gas sensing and analysis for harsh environments such as extreme aeronautical conditions, petroleum industries and aircraft engines.

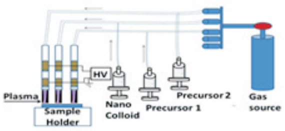


News from NNC & IPC

Activities Related to EuNetAir at NASA Ames

M. Meyyappan NASA Ames Research Center, USA

NASA Ames has been developing nano-chemosensor for over ten years using carbon nanotubes and its variations (doping, functionalization, coating, etc.). At first, the sensors were made on silicon substrates and then on PCB substrates. Interdigitated electrodes were used in both cases and 12-36 sensor arrays were created to create an electronic nose. More recently, the sensor effort has moved to the use of flexible substrates such as paper and cotton. Paper as a platform is green and inexpensive, and cotton platform will lead to wearable sensors. A novel atmospheric pressure plasma jet was developed to deposit the sensor materials (in aerosol form from dispersions) on the flexible substrates. The plasma eliminates the need for post-deposition sintering to obtain a sensor film with good adhesion. This is critical since paper and cotton cannot withstand sintering temperatures. This plasma system is a dry alternative to conventional inkjet printing. Early sensor results on paper and cotton platforms show ~5 ppm detection limit for ammonia, which is the same as in silicon and PCB substrates.



The picture shows the atmospheric pressure plasma jet system for depositing sensor materials on flexible substrates.

Science & Tech Talk

Science & Tech Talk

Real-time monitoring of Indoor Air - Special Session at Indoor Air 2016

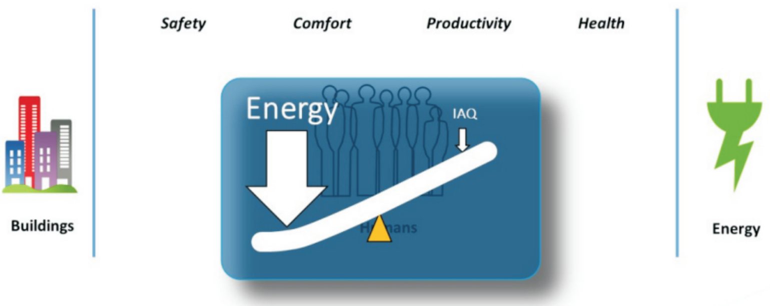
A. Schütze, WG2 leader & ESSC WG IQ Leader, Saarland University, Germany

Together with its partner project IAQSense, the SENSIndoor consortium organized a special session during the Indoor Air 2016, the 14th international conference of Indoor Air Quality and Climate held in Ghent, Belgium, July 3-8, 2016. Indoor Air is the flagship conference of the ISIAQ, the International Society of Indoor Air Quality and Climate (http://www.isiaq.org/), covering a full week of presentations and bringing together more than 1.000 representatives from science, health and industry.

INDOOR AIR 2016

The symposium with the title "Changing the game in the management of Indoor Air Quality – Real time monitoring for improved health, comfort and energy efficiency" aimed at increasing the awareness of novel low-cost sensor solutions for Indoor Air Quality, especially for Volatile Organic Compounds (VOCs). The session discussed key contaminants relevant for indoor air quality assessment and solutions to their reduction to achieve healthy buildings. Six short presentations from highly recognized scientists and leading industrial players have put special emphasis on new developments for VOC sensors developed within the two European projects SENSIndoor and IAQSense and their impact on indoor air quality monitoring and improvement. The session was chaired by Eberhard Seitz, project technical advisor of the European commission for both projects. In contrast to many other presentations focusing on analytical tools for IAQ assessment, this session demonstrated that real time monitoring based on low-cost sensors is becoming increasingly important not only for building management, but also for a better understanding of the causes and effects of pollutants by allowing more comprehensive studies. A summary of the session will be published in the conference proceedings.

The compromise between IAQ and energy in buildings is currently greatly unbalanced favoring reduced energy consumption due to the lack of suitable IAQ sensors is shown in the figure. (Source: Mats Sándor, Systemair AB, Sweden)



Science & Tech Talk

Italian Cluster of national projects on real applications of air quality sensors

M. Penza, Action Chair, ENEA, Italy

A cluster of Italian national projects, funded by Italian Ministry of Education, University and Research (MIUR), devoted to real applications of air quality sensors in various environments such as buildings, smart cities and space remote sensing has been carried out by 3 different Italian consortia, participated and/or led by ENEA.

The Italian national project *BAITAH - Methodology and Instruments of Building Automation and Information Technology for pervasive models of treatment and Aids for domestic Healthcare* - funded by Italian Ministry of University, Research and High Schools (MIUR) in the framework of PON Research & Competitiveness Strengthening Innovation Infrastructures, developed and demonstrated an integrated system of new technologies including indoor air quality sensors for building automation in the context of Ambient Assisted Living.

A mini-network of 4 sensor-nodes composed by CO, NO_2, CO_2, *T* (temperature) and RH (relative humidity) has been implemented for indoor air quality, chemical security and personal comfort.

The BAITAH Consortium (2011-2015) has been participated by ENEA with partners such as large company (STMicroelectronics), small companies (Ingel, Cupersafety, Item Oxygen, Software Engineering Research & Practices, Lab Pignatelli, Dida Network), academia (University of Bari) and private and public research (Cetma, CNR, ENEA).

The Italian national project *RES-NOVAE - Networks Buildings Streets: New Challenging Objectives for Environment and Energy* - funded by Italian Ministry of University, Research and High Schools (MIUR) in the framework of PON Research & Competitiveness Smart Cities, developed and demonstrated an integrated system of new technologies for sustainable development in the green cities (Bari and Cosenza, Italy) to improve environmental sustainability and carbon footprint and to enhance energy efficiency at level of network of buildings, smart district and urban control center.

Reti Edifici Strade Nuovi Obiettivi Virtuosi per l'Ambiente e l'Energia

The final goal of RES-NOVAE is to implement a trust of best available technologies to improve the quality of life of citizens and support the decisions of the policy-makers and city managers in order to plan the urban development with reduced greenhouse gases emissions.

A sensor network, designed and operated by ENEA, based on 10 nodes (9 stationary and 1 mobile on public bus), for air quality monitoring has been deployed in the city of Bari for a long-term experimental campaign since June-2015. Each multiparametric sensor node is composed by at least 9 sensing elements (NO_2, O_3, CO, SO_2, PM10, tVOCs, CO_2, *T*, RH) including data acquisition system and mother board (Raspberry Pi), GPS, GSM modem with standard functionalities of wireless data transmission towards a base station.

Mapping of the targeted air pollutants, expressed as individual Air Quality Index (AQI), has been automatically implemented using sensors data and compared to the referenced data of the city air monitoring stations in order to address the Indicative Measurements of the Ambient Air Quality EU Directive and Cleaner Air for Europe (2008/50/EC).

A typical map of AQI using the sensor network data from the stationary nodes (e.g., airport, port, city office, factories, university, etc.) and mobile node (mounted on city public bus) has been reported in the city of Bari.

The RES-NOVAE Consortium (2011-2015) has been leaded by ENEA with partners such as large companies (ENEL, project manager, IBM, GE), small companies (Asperience, Tera), academia (Technical University of Bari, University of Calabria) and research (CNR, ENEA). A strong support from Municipalities of Bari and Cosenza has been received as public end-user of the final output (products and services) of the national project.

The Italian national project *APULIA SPACE - Key Enabling Technologies for Space Remote Sensing* - funded by Italian Ministry of University, Research and High Schools (MIUR) in the framework of PON Research & Competitiveness Strengthening High Technology Districts, developed and demonstrated an integrated system of new technologies including ground-level air quality sensors to complement the environment monitoring by space remote sensing.

A portable sensor system has been designed and fabricated utilizing several sensing elements such as NO_2, O_3, CO, SO_2, PM10, tVOCs, CO_2, *T*, RH, including data acquisition system based on mother board (Raspberry Pi), GPS, GSM modem with standard functionalities of wireless data transmission towards a base station. The ground-level sensor system, located at an airport in Puglia (Italy), has been complemented to the satellite remote sensing of the environment.

The APULIA SPACE Consortium (2012-2016) has been participated by ENEA with partners such as large and small companies (Planetek Italia, Sitael, Enginesoft, IMT, GAP, District of Puglia Aerospace), academia (University of Bari, University of Salento, Technical University of Bari) and public research (CNR, ENEA).

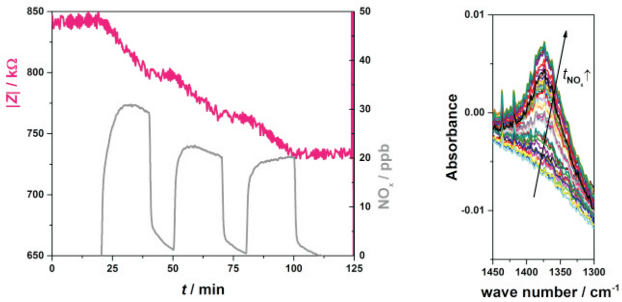
Science & Tech Talk

Gas dosimeter for sub-ppm NO_x detection

I. Marr, D. Schönauer-Kamin, R. Moos, Functional Materials, Germany

In contrast to typical gas sensors, resistive NO_x gas dosimeters measure continuously the amount (or the dose) of NO_x in the test gas. Its complex impedance decreases linearly with the integrated NO_x concentration in the test gas. During NO_x absence, the sensor signal remains constant. To study the sensing mechanism in detail, especially the adsorption processes on the NO_x storage layer of the NO_x dosimeter, diffuse reflectance infrared Fourier transform spectroscopy (DRIFTS) is an appropriate tool.

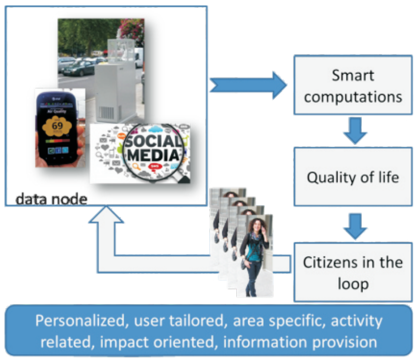
The figure presents the measured complex impedance of a K/Mn-La-Al_2O_3 based sensor at a frequency of 200 Hz and the NO_x concentration analyzed by the CLD during the exposure to three 25 ppb NO_x pulses (each 1200 s) with NO_x pauses in between (each 600 s). During NO_x exposure, the impedance decreases with a concentration dependent slope whereas it stays constant during pauses of NO_x. The absorbance of the in-situ DRIFTS shows a strong absorption band at 1373 cm^{-1} which corresponds to the formation of nitrates on potassium sites. The electrical signal and the nitrate formation agree well. The formation of nitrates is responsible for the measureable conductivity change of the dosimeter during the accumulation of NO_x molecules.



AQ microsensors fueling quality of life services

K. Karatzas, Aristotle University of Thessaloniki, Greece

The Environmental Informatics Research Group is interested in updating its air quality sensor box, taking into account the valuable lessons learned via the participation in the EuNetAir activities and especially in the Aveiro Intercomparison Exercise.



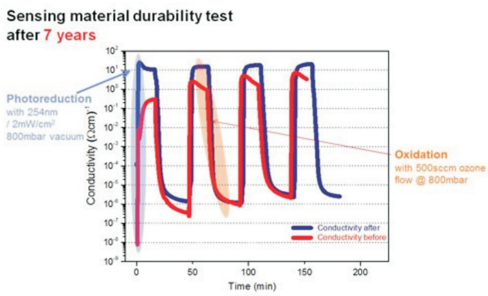
In addition, we are continuously working on the improvement of our data-driven computational methods in order to better analyze and model sensor signals. Our goal is to design and develop microsensor-related information services with high utility and for everyday quality of life (QoL) support. Furthermore, we aim at combining microsensor data with official sensor network information as well as "soft" sensor data (like the ones extracted from social media) in order to deliver high quality spatiotemporal information. The use of user feedback on QoL status via citizen science methods is also of high interest as it will allow the user be "transformed" from a "passive" receiver of environmental information to an actor and to an environmental management participant.

Our work takes into account urban metabolism and we foster research collaborations towards smart ecological cities. Looking back to the experiences gained and to the collaborations resulting from EuNetAir we are grateful to all colleagues for building a unique scientific companionship, and we look forward the continuation of our collaboration, after the EuNetAir action end.

Ageing Resistant Indium Oxide Ozone Sensing Films

G. Kiriakidis, FORTH, Crete

In this work the focus was placed on the remarkable sustainability of the superior sensing properties of our In_2O_3 thin films over a time span of seven years. Structural, optical, electrical and sensing characteristics of the material were re-evaluated following exposure, under no particular conditioning, in dark and ambient (Temperature 12–30 °C, RH = 20% to 60%, Pressure ~1 Torr) long time after deposition date and it is shown that they largely retained their initial properties. In as far as storage conditions were concerned it was noted that as no particular conditioning measures were taken.



Reported results highlighted the capability of the In_2O_3 material to be used as an ageing resistant and reliable long-term ozone sensor.

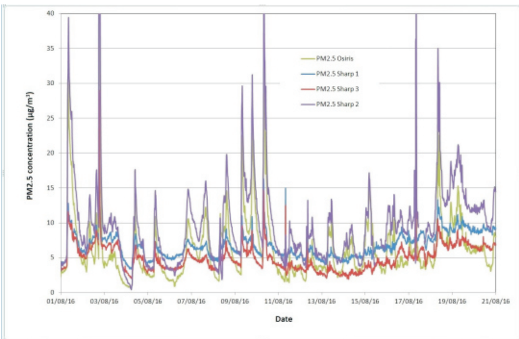
The results of an unique study on Ageing Resistant Indium Oxide Ozone Sensing Films have been recently published by *Sensor Letters* 14 (2016) 563-566.

Science & Tech Talk

Measurement of PM2.5 particles in indoor air using the low-cost Sharp GP2Y1010AU0F sensors

V. Tasić, M. Jovašević - Stojanović, Serbia

In order to investigate the characteristics of Sharp GP2Y1010AU0F sensor, the research was conducted in the period 1 May to 31 August 2016 in the Mining and Metallurgy Institute Bor, Serbia. The measurement systems were formed based on the Arduino Uno microcontrollers. The temperature in the laboratory was maintained in the range of 24-29 °C and relative air humidity within the limits of 50-60% in order to reduce the influences of these parameters on measurements. The results of measurement (simultaneous measurement of three Sharp sensors connected on two Arduino platforms) were compared with readings of the automatic PM monitor (Turnkey Osiris) that was placed in the same lab. Calibration of the Osiris monitor has performed weekly using the reference gravimetric method.



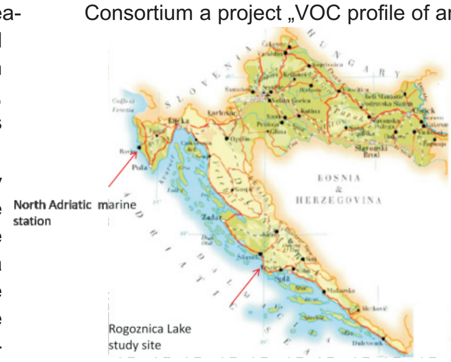
Analysis of the results shows that there is a strong positive correlation between the averaged 15-minute results of Sharp sensors and Osiris ($R_{S1}^2 = 0.71$, $R_{S2}^2 = 0.89$, $R_{s3}^2 = 0.58$). Arduino platform has demonstrated remarkable stability. Further work will be focused on examining the effect of temperature and air humidity on the measurement result.

Characterization of the Adriatic coast Marine Aerosols

I. Ciglenecki-Jusic, Rudjer Boskovic Institute, Zagreb

Croatian group that is actively involved in the TD1105 are working on the Croatian Science Foundation project „The Sulphur and Carbon Dynamics in the Sea- and Fresh-water Environment“ (SPHERE, 1205). The research is focused on sulphur (S) and carbon (C) dynamics between different environmental compartments (atmosphere, water, sediment, biota) of the sea- and fresh-water environment. Physico-chemical characterization of the marine and urban aerosols by electrochemical, chromatographic, microscopic (AFM) and ICPMS methods is important part of the project activities.

As study sites we selected the unique, highly eutrophic, and euxinic (anoxic water with free hydrogen sulphide in the water column) marine lake, Rogoznica Lake in the central Dalmatia (Middle Adriatic, 43°32'N 15°58'E) and site in the area of the transect Po river delta-Rovinj. These sites in the last 25 years were subjected to long-term monitoring of physico-chemical and biological processes in the sea water column. Research is now extended to the influence of atmosphere. Through activities of the TD1105 we extended our research and started collaboration with National Institute of Chemistry (NIC), Ljubljana, Slovenia and Institute of Chemistry, Technology and Metallurgy, Department of Electrochemistry, University of Belgrade, Serbia. Recently under a call of Central European Infrastructure Consortium a project „VOC profile of ambient air samples from East Adriatic coastal marine sites as detected by PTR-ToF-MS" has been approved.



The figure shows the map of Croatia with indicated position of marine aerosols study sites in the northern and middle Adriatic (Rogoznica lake).

Science & Tech Talk

EuNetAir related news from Alphasense

J. Saffell, R. Jones, Alphasense, UK

Alphasense has been working with UNEP and World Bank, setting up an AQ network in Nairobi. Results were reported at UNEA2 in May. These organisations expect to develop urban AQ networks in developing cities, seed funded by the World Bank.

The improved (patent pending) NO_2 and ozone sensor pair have been tested by JRC in Ispra with good results.

A low cost PM sensor module will be introduced in Q1 2017, an electronic diffusion tube (NO_2 or H_2S) will be available Q3 2016 and a modified OPC for high particulate concentrations will become available Q1 2017.

South Coast Science is introducing an interface board for the Raspberry Pi, supporting four gas/ VOC sensors plus temperature/ humidity and a connector for the Alphasense OPC. Beaglebone and potentially Arduino interfaces will also be launched.

The new p-type metal oxide sensor has shown good performance for VOC detection with very stable baseline and humidity performance. Packages include TO-5, FIS/ Figaro plastic housing or ATEX/UL/CSA approved EX housing.

iSCAPE - Improving the Smart Control of Air Pollution in Europe

F. Pilla, University College Dublin, Ireland

Call: H2020-SC5-04-2015 “Improving the air quality and reducing the carbon footprint of European cities”

Funding scheme: Research and Innovation Action

Success rate for this call: 59 submitted, 3 funded

Coordinator and PI for UCD: Dr. F. Pilla

Overall budget: € 5,850,829

Duration: 3 years starting in September 2016

Partners: University College Dublin, Trinity College Dublin, Università di Bologna, University of Surrey, Ilmatieteen Laitos (Finnish Meteorological Institute), Universiteit Hasselt, Technische Universität Dortmund, JRC - Joint Research Centre - European Commission - Institute for Environment & Sustainability, Institut d‘Arquitectura Avancada de Catalunya - FabLab Barcelona, T6 Ecosystems srl, Nanoair Solutions S.r.l., Future Cities Catapult Ltd., Dublin City Council, Agenzia Regionale Prevenzione e Ambiente dell´Emilia-Romagna, European Network of Living Labs.

Test Cities: Dublin (IE), Innovation-City Ruhr (Bottrop - DE), Lazzaretto Bologna (IT), Vantaa (FI), Hasselt (BE), Bologna (IT), Guilford (UK)

Description: The iSCAPE project aims to integrate and advance the control of air quality and carbon emissions in European cities in the context of climate change through the development of sustainable and passive air pollution remediation strategies, policy interventions and behavioural change initiatives. It will tackle the problem of reducing air pollution at target receptors with an innovative SME-led approach, focusing on the use of “Passive Control Systems” in urban spaces. Improvements in air quality, microclimate and behavioural aspects of urban dwellers will be achieved by applying real-world physical interventions on the urban tissue to alter ventilation rates and dispersion patterns in the selected cities assessed for future climate change scenarios and representative of different cultural & life styles in Europe. Through the approach of Living Labs the team will deploy a network of air quality and meteorological sensors (both stationary and mobile) and evaluate through analysis and a suite of up-to-date numerical modelling the benefits expected from the interventions on a neighbourhood and city-wide scale for several aspects ranging from quantification of pollutant concentration to exposure. iSCAPE encapsulates the concept of “smart cities” by promoting the use of low-cost sensors, engaging citizens in the use of alternative solution processes to environmental problems. iSCAPE will support sustainable urban development by promoting the sharing of results with policy-makers and planners using local test-cases, and providing scientific evidence ready-to-use solutions potentially leading to real-time operational interventions. This integrated approach will include the development and assessment of a framework aimed at changing the mobility behaviour of people by studying processes and dynamics that lead to more resilient, healthy, and sustainable cities, by bringing together theory from urban planning, public policy, urban and environmental sociology and urban geography.

Science & Tech Talk

Indoor Air-Quality Improvement Campaign Siemens China

O. von Sicard, R. Pohle, Siemens Corporate Technology, Germany

Air quality has an impact on our everyday wellbeing, comfort and long term health. In work environments it strongly affects our productivity and becomes an economic issue. Aside from pollutants originated within the building, the indoor air quality (IAQ) is strongly affected by outdoor air pollutants. Especially in emerging countries like China the outdoor air pollution can reach hazardous levels. Without extra measures the polluted outdoor air reaches the indoor environment through HVAC systems or through open windows.

In 2015 Siemens launched a campaign to improve IAQ levels in Siemens sites in order to protect employees from unhealthy effects of outdoor air pollution. PM 2.5 was identified as the most important pollution parameter. Siemens is attempting to ensure 95 percent of the time that the self-imposed limits of < 35µg/m^3 of PM 2.5 can be observed.

The measures taken include installation of additional filters in HVAC systems, placement of mobile air purifiers and installation of PM 2.5 sensors on several indoor locations. The data is made available in real time to employees via an app (see figure) and on big screens in the lobbies of the buildings. Currently more than 5000 employees benefit from this system but it is planned to cover more than 100 company sites in the future.

One limitation is still the high cost per sensor (>1000€ + recurring recalibration costs). Cheaper sensors providing additional environmental parameters would greatly improve the benefit of this campaign or similar initiatives.

The mobile app, presented in the figure, shows an outdoor PM 2.5 value of "149µg/m^3", whereas indoor value monitors as "16µg/m^3", hence 9.3 times better inside the building.

Dissertation on mobile air quality monitoring

J. Theunis, VITO, Belgium

Dr. Joris Van den Bossche will defend his doctoral dissertation in public in September 2016. Joris was one of the EuNetAir STSM beneficiaries. During his stay in Norway he worked together with NILU to validate mobile monitoring methods for mapping urban air quality which he developed for Antwerp.

In his work Joris distinguishes between targeted mobile monitoring approaches in which predefined routes are repeatedly monitored at predefined moments, and opportunistic mobile monitoring approaches that make use of existing mobile infrastructure or people's common daily activities to move measurement devices around. He demonstrates that these approaches can be used for mapping urban air quality at a high spatial resolution, when using a carefully developed methodology to collect and process the data. They can provide insight into the spatial variability at a resolution which would not be possible with stationary monitors.

He uses the data further to build LUR models to predict the street-level exposure to black carbon (BC). Different types of models (both linear and non-linear) are compared and evaluated using spatial cross-validation. For the first time, a spatio-temporal model was developed that can predict dynamic trip exposure based on opportunistic measurements. This model is a first step towards a real-time dynamic pollution map that can be updated continuously using real-time measurements from different uncoordinated sources (both targeted and opportunistic).

Joris' PhD was supervised by Prof. Dr. Bernard De Baets (Ghent University-KERMIT), Prof. Dr. Dick Botteldooren (Ghent University-INTEC Acoustics) and Dr. Jan Theunis (VITO).

Science & Tech Talk

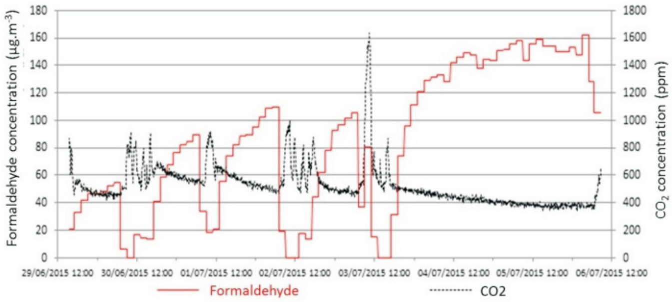
What is the real exposure of children to formaldehyde in schools? Standard reference method versus continuous monitoring

S. Margeridon-Thermet, F. Abedini, R. François, F. Hammel, ETHERA, France
T-H Tran-Thi, NIMBE, CEA, CNRS, France

Formaldehyde (CH_2O) is a carcinogenic, ubiquitous indoor air pollutant. Its toxicity has led the French High Council of Public Health to set public building management requirements: For 30<[CH_2O]<50µg.m^{-3}, the emission source(s) identification and appropriate actions are required to lower [CH_2O] to less than 30µg.m^{-3}.

The present study probes CH_2O exposure of school children. The probed classroom is equipped with a motion capture sensor-controlled ventilation system. The CH_2O measurement reference method sampling over 4.5 days with a 2,4-dinitrophenylhydrazine cartridge is here compared with the ETHERA-NEMO continuous monitoring system. The NEMO device integrates a colorimetric sensor selective to CH_2O and a CO_2 sensor measuring atmosphere confinement.

The average [CH_2O] value obtained with the reference method, is 48,63 µg.m^{-3}. During the same period and up to7 days, the [CH_2O] value obtained with NEMO showed large fluctuations (see figure); during daytime with the ventilation on, [CH_2O] remained low (0 to 17 µg.m^{-3}), while during night and week-end with the ventilation off, [CH_2O] rose, reaching high values (100-150 µg.m^{-3}). This increase is due to CH_2O emission mainly from plywood furniture and insulation materials. This background pollution contributes to the average [CH_2O] increase (to 48,63 µg.m^{-3}), leading to an over-estimate of the children's real exposure (0-17 µg.m^{-3}).



AirSensEUR: An open platform for air quality monitoring

M. Gerboles, JRC, Institute for Environment and Sustainability, Italy

AirSensEUR is a low-cost gas sensor platform for the fixed and mobile monitoring of air pollution. AirSenSEUR aims at reaching the Data Quality Objective of indicative measurements set in the European Air Quality Directive. It has been developed by the EC-Joint Research Centre and LiberaIntentio, an Italian SME specialized in IoT. All development aspects are made freely available through the use of public licenses. AirSensEUR can act as a node within a network of multi sensors, complying with the INSPIRE Directive (Infrastructure for Spatial Information in the European Community), ensuring interoperability and web access to the observation data.

AirSensEUR includes a sensor shield, host board and web server. The shield accommodates electrochemical sensors of many commercial brands and a temperature/humidity/pressure ancillary board. The host is based on a low cost Arietta G25 Linux module. It collects sensor and GPS data into a local sqlite3 database that is periodically pushed to a WEB PostgreSQL database via GPRS or Wi-Fi according to the standard-based transactional Sensor Observation Service (SOS-T). This protocol makes it easy to query data in the WEB AirSensEUR Client and to perform sensor data treatment typically under the "R" statistical environment.

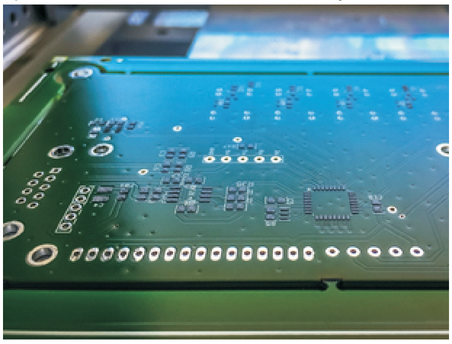
Current update include adding MOx and OPC sensors and to develop automatic calibration methods.

Science & Tech Talk

MSDI Sensor for industrial process monitoring

J. Suisse, University of Burgundy, France

Heterojunctions between a Molecular Semiconductor and a “Doped Insulator” (MSDI) have been successfully used as conductometric gas sensors for oxidizing and electron-donating species ever since their invention by Prof. Marcel Bouvet in 2007. My current research involves fundamental studies of these heterojunctions through ANR OUTSMART [Organic materials for sensing application; DS0901 – Citizen security, fight against crime and terrorism] to gain better knowledge on their inner workings, and applied research targeting air quality and industrial process monitoring. This requires close collaborations with VITAGORA® competitiveness cluster (industrial prototyping project) and with SATT GRAND-EST (technology transfer project). Both projects aim at pushing MSDI sensing technology out of the lab by developing electronic hardware & software to acquire, process and deliver the data through standard analog and digital communication interfaces. Currently, we are on the brink of manufacturing the first commercial batch targeting industrial process monitoring as well as gas sensor research by providing a measurement cell equipped with environmental sensors to study near-real-world conditions in lab, designed to address inter-laboratory reproducibility issues underlined during EuNetAir Linköping meeting.



Innovative Colorimetric Sensor for Phenol Monitoring in Air

A. Borta, L. Mugherli, G. Le Chevallier, C. Rivront, T.-H. Tran-Thi, NIMBE, France

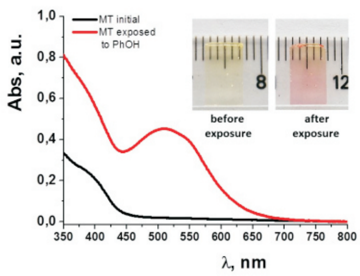
Phenol production ranks in the top 50 in production volumes for chemicals produced with the housing and construction industries accounting for about half of the phenol used. Phenol is suspected to be carcinogenic. In 2009, the individual exposure limit to phenol for workers was set by the European Communities (EC) to 8 mg/m^3 (2 ppm) for 8 hours.

The usual method of detection of phenol in air is based on adsorption-desorption of phenol on activated charcoal cartridges followed by gas chromatography analyses. Although sensitive, it is expensive and require a heavy maintenance. The present work aims at developing an innovative colorimetric sensor, easy to use, for the direct detection of phenol in air.

The solid sensor is synthesized via the sol-gel process, which allows the production of transparent porous monolithic xerogels with tailored pore size. When doped with a specific reactant such as amino-antipyrine, the sensor, initially yellow, undergoes a color change when exposed to a phenol-polluted atmosphere). The intensity rise of the resulting pink product is proportional to the concentration of phenol.

The limit of detection is 15 ppb in air for 30 min of exposure with a flux of 500 mL/min.

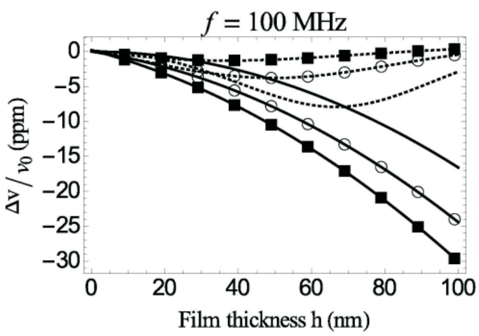
The figure presents the color change and absorption spectra of the sensor exposed to phenol 100 ppb, 500 mL/min, RH: 50%



Soft-film dynamics of SH-SAW sensors

A. Vikström, M. V. Voinova, Chalmers University of Technology, Sweden

We have conducted a theoretical analysis of the propagation of surface acoustic waves with horizontal polarization (SH-SAWs) in a three-layer model consisting of an elastic substrate and two viscoelastic overlayers. The model is applicable to a range of devices, especially within the field of biosensing, where the typical objects of study are soft (bio)polymer materials in viscous or viscoelastic fluids.



We derived analytical expressions for the phase velocity shift and the wave attenuation in the limit of an acoustically thin film in a bulk viscoelastic fluid. The expressions contain the complex shear moduli of both the thin film and the bulk fluid, thus demonstrating the need for considering the effect of viscoelastic coupling when studying biological materials in fluids, or soft multilayers.

Additionally, we introduced a combined Maxwell/Voigt scheme and used numerical calculations to confirm our analytical results and extend the study to thicker films. Interestingly, our calculations showed that it is possible for viscoelasticity to cause SH-SAWs to vanish.

The figure shows the velocity shift for a rigid (solid lines) and a soft film (dashed lines) loaded by bulk glycerol/water (squares), water (circles), or air (none).

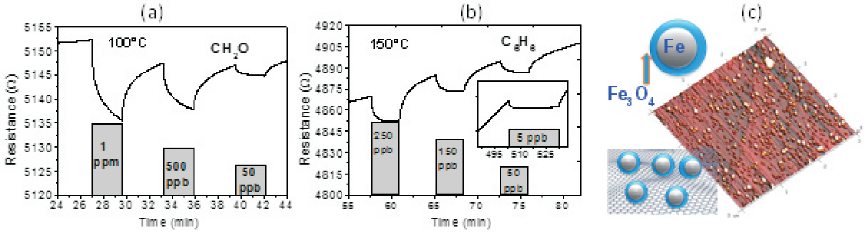
Science & Tech Talk

A flexible platform for extremely sensitive gas sensing: 2D materials on Silicon Carbide

J. Eriksson, Linköping University, Sweden

2D materials offer a unique platform for sensing with extremely high sensitivity, since even minimal chemical interaction causes noticeable changes in the electronic state. However, the sensitivity has to be complemented with selectivity. This has been addressed, for example, by combining graphene (for sensitivity) with metal/oxide nanoparticles (for selectivity). On the other hand, functionalization or modification of the graphene often results in poor reproducibility. We have investigated the gas sensing performance of epitaxial graphene on Silicon Carbide (SiC) decorated with nanostructured metals and metal-oxide nanoparticles deposited using scalable thin-film deposition techniques, like hollow-cathode pulsed plasma sputtering. Under the right deposition conditions the electronic properties of the graphene remain intact, while the surface chemistry can be tuned to improve sensitivity, selectivity and speed of response to gases relevant for air quality monitoring and control, yielding detection at low ppb concentrations of toxic gases such as nitrogen dioxide, benzene, and formaldehyde.

Studies have also been initiated on other monolayer sensing layers like 2D catalytic metals on SiC, which offer additional possibilities like faster response and operation at high temperature and in harsh conditions, while maintaining the promises of 2D materials as extremely sensitive transducers.

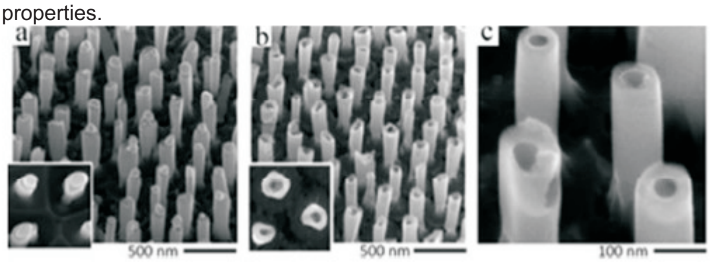


The figure shows: Response of a Graphene on SiC sensor decorate with Fe_3O_4 nanoparticles (about 60 nm in diameter) to (a) CH_2O concentrations from 1 ppm to 50 ppb, and to (b) C_6H_6 concentrations in the range 250-5 ppb (b); (c) shows a 3 µm × 3 µm AFM micrograph of the Fe_3O_4 nanoparticles on EG/SiC.

The MINOS research group

E. Llobet, Universitat Rovira i Virgili , Spain

The MINOS „Microsystems and Nanotechnologies for Chemical Analysis“ research group has published new results on the synthesis of inorganic nanomaterials with excellent gas sensing properties.



In this research, a new structure consisting of large arrays of self-organized tungsten oxide nanotubes (hence, with hollow inner part) have been achieved. In this structure, nanotubes are separated, parallel to each other and perpendicularly aligned to the substrate. This 3-dimensional nanotube array has a very high surface area to react with gases (e.g. hydrogen), which makes it very interesting to develop more sensitive sensors.

The anodization conditions employed to grow tungsten trioxide have been changed to achieve a radically different structure: free-standing nanotubes anchored to a tungsten metal layer, instead of solid nanocolumns or nanorods. The researchers are convinced that this new structure will improve sensor response, because it optimizes the geometry of the devices. On the one hand, the three-dimensional structures enables gases to easily diffuse within a very high specific surface for gas-solid interaction. On the other hand, the fact that electronic charges are confined to the surface (given the small thickness of the nanotube walls) means that the conductivity of tungsten oxide nanotubes will be greatly affected by the presence of gases.

This work is a collaboration between the MINOS group, led by Prof. Eduard Llobet with the group of Dr. Alexander Mozalev at the Technological University of Brno (Czech Republic). Full details can be found in: A. Mozalev et al., Metal-substrate-supported tungsten-oxide nanoarrays via porous-alumina-assisted anodization: From nanocolumns to nanocapsules and nanotubes, *J. Mater. Chem. A*, 4 (2016) 8219-8232.

Science & Tech Talk

LTCC housing for gas and particle sensors as well as device for cell growth monitoring

A. Lloyd Spetz, Linköping University, Sweden

Toxic species in outdoor as well as indoor environment normally includes both gas molecules and (nano)particles. A device that holds both types of sensors is very advantageous and may potentially be realized in LTCC, low temperature co-fired ceramic, technology. This technology provides 3D packaging, sustainable even at high temperature with convenient and flexible processing.

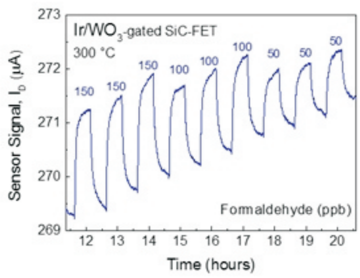
So far one step hermetic packaging of the SiC-FET, silicon carbide field effect transistor, gas sensors in LTCC has been demonstrated. Furthermore, a preliminary version of soot sensor based the SiC-FET with a suspended gate could be realized in LTCC technology. An LTCC device for electrical measurements of cell growth is constructed with the goal to study the influence on cells by nanoparticles and thereby avoiding animal testing.

The picture shows a LTCC mounted SiC-FET gas sensor.

High Performance SiC-FET Gas Sensors for Highly Sensitive Detection of Hazardous Indoor Air Pollutants

D. Puglisi, Linköping University, Sweden

Indoor air pollution is considered one of the top five environmental risks to public health which significantly affects quality of life and economy. In the framework of the EU-project SENSIndoor (2014-2016), metal insulator semiconductor field effect transistors with catalytic metal or metal/metal-oxide gate contacts were fabricated on top of 4 inch n-type 4H-SiC wafers (SiC-FETs). Five different materials for the gate contact, Ir, Pt, WO_3, Ir/WWO_3, and Pt/WO_3, have been processed and characterized. Pure Ir-gate SiC-FETs showed the highest sensitivity to the three target VOCs, formaldehyde, benzene, and naphthalene, with detection limits under the threshold of current legal requirements. Pure WO_3-gate SiC-FETs were not suitable as gas sensors for the target application due to their poor sensitivity and stability, and short lifetime. The addition of a noble metal (Ir, Pt) to the semiconducting oxide (WO_3) has been an effective mean to enhance detection of specific gases because these metal catalysts increase the rate of interaction differently for distinct gases. Ir/WO_3 SiC-FETs were operated for several hundred hours from 180 °C to 300 °C in static and dynamic operation modes. Detection limits below 5 ppb benzene and 5 ppb formaldehyde were demonstrated during several repeated measurements. Ir/WO_3 SiC-FET showed enhanced selectivity to naphthalene in comparison with pure Ir-gate SiC-FET.



The figure shows the repeated sensor response to 150, 100, and 50 ppb of formaldehyde with an Ir/WO_3 SiC-FET.

Operation of air quality sensor networks

C. Hueglin, Empa, Switzerland

Small sensors and dense sensor networks have a vast potential in novel approaches for air quality and exposure assessment, especially in the urban environment where the spatiotemporal variability of air pollutants is largest. However, the requirements for air quality sensors in terms of measurement performance are high. For any intended application of sensors it is essential to ensure that the sensors are fit for purpose. Beside the suitability of the sensors, aspects of sensor network operation are of prime importance: For example, how can the behaviour of individual sensors in a network be supervised and how can a sufficiently high data quality be guaranteed over an extended period of time? In order to address these questions, a small network consisting of six sensor nodes measuring ozone and nitrogen dioxide has been setup in Zurich, Switzerland. The sensor locations have been chosen to represent similar air pollution situations than the air quality monitoring sites run by the federal and municipal authorities. This offered highly useful possibilities for linking the sensors to the measurements at the reference sites. For example, measurements during night time, when the spatial difference in air pollutant levels in the city is small, have been used for continuous adjustment of the sensor data.

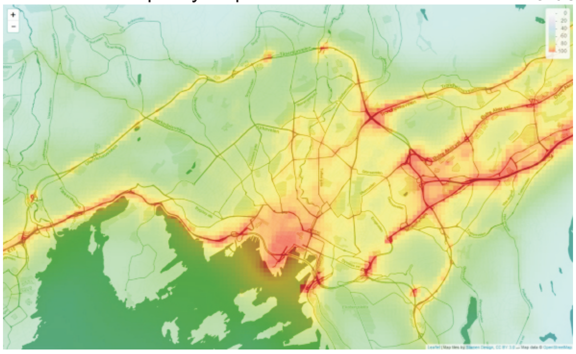
Figure: Location of the six nodes of the air quality sensor network in Zurich, Switzerland (red symbols). The existing air quality monitoring sites operated by the federal and municipal authorities are indicated in blue (image taken from Google Maps).

Science & Tech Talk

CITI-SENSE project: Urban AQ information through mapping

P. Schneider, N. Castell, S. Grossberndt, Al. Bartonova, NILU, Norway

CITI-SENSE is an EU FP7 funded project with the aim to engage and empower citizens to influence community decision-making through so-called Citizens' Observatories. One of the tools that has been developed to serve as information source for citizens are air quality maps.



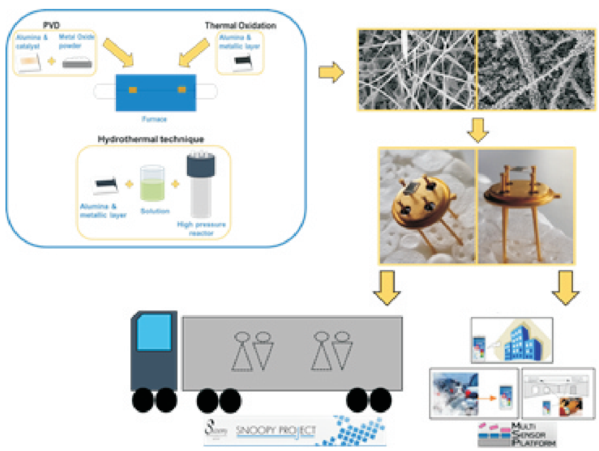
Over various locations in Europe, a network of low-cost sensor nodes is used to acquire hourly observations of various air pollutants (NO_2, PM10, and PM2.5) and meteorological parameters. While such observations provide interesting estimates of air quality at the locations where the instruments are located, many applications require air quality information in areas where no monitoring instruments are available. In order to offer such personalized services, e.g. providing the user with air quality estimates exactly at their home or estimating the exposure to air pollutants on their bicycle commute to work, it is necessary to develop spatially continuous maps of concentrations of the various pollutants. By use of data fusion, hourly average data on NO_2, PM10, and PM2.5 are combined with a detailed map of long-term average air quality, which is derived from either an urban-scale dispersion model or statistical methods such as land-use regression. This combination, or data fusion, is accomplished using geostatistical techniques.

An example of a high-resolution urban air quality map for Oslo, here showing the concentration of nitrogen dioxide (in units of $\mu g/m^3$) on a day in January 2016 is shown in the fugure. The map combines the information from 24 AQMesh sensors deployed throughout the city and additional information coing from the EPISODE urban air pollution dispersion model.

News from Sensor Laboratory

G. Sberveglieri, Brescia University, Italy

Sensor Laboratory, located in Brescia (Italy), was among the first research groups to introduce the use of metal oxide nanowires into a chemical sensing device. The first material investigated, back in 2001, was tin dioxide (SnO_2), enabling the fabrication of the first generation of nanowire-based conductometric gas sensors. Since then, Sensor Laboratory focused research activities on the preparation of many p- and n- type metal oxides, using both physical and chemical bottom-up techniques, like physical vapor deposition, thermal oxidation, hydro- and solvo-thermal methods. All of these nanowires were successfully integrated as sensing element for the next-generation of chemical sensors. To reduce the power consumption, geometry of the devices was scaled down, reaching the milestone of single nanowire devices. To further extend the range of possible applications, metal oxide nanowires were grown on unconventional substrates also, like plastics, MEMS and even paper. Recently, together with some European Partners, we are working on the mass-scale integration of nanowires on wafer level (EU-FP7 MSP project), on the production of low cost system for fast warning against hazardous chemicals, and on the exploitation of these systems for the detection of hidden people in vehicles and close compartments (EU-FP7 SNOOPY project)

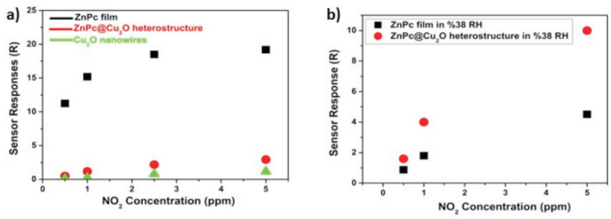


Science & Tech Talk: STSM reports

Investigation of CO and NH_3 sensing of CuO nanowires and their heterostructures with organics

O. Sisman, Gebze University, Turkey

By collaboration of COST Action EuNetAir, I spent great one month in University of Barcelona. My STSM topic was CO and NH_3 sensing properties of organics@CuO nanowires hybrid structures. During STSM, successful integration of measurement systems belongs to Gebze Technical University and University of Barcelona was important to show again the universality of science. Test chamber modification, temperature calibration, using different gas controller systems were unforgettable experiences for me. Although some contact problems of CuO samples, I could get useful and comparable NO_2 sensing results for ZnPc films, Cu_2O nanowires and their hybrid structures (ZnPc@Cu_2O nanowires). The humidity measurements at 150 °C proposed important results.



Evaluation of Low-Cost Air-Quality Monitoring Sensor Nodes at Varying Environments

U. Lerner, Israel Institute of Technology, Israel

In recent years, small, low-cost devices for air quality monitoring are becoming a major focus point for researchers, commercial companies and also legislative bodies throughout Europe. Their small size enables a wider and more flexible deployment of monitoring network and thus enables a better assessment of human exposure to air pollution. However, these devices are limited in their capabilities, and the data they gather is still lacking in nature, compared to reference devices. During my STSM at NILU (Kjeller, Norway), I've focused on working with several types of small sensor nodes being used and deployed, both in NILU's labs (for calibration and data validation) and throughout Oslo. I focused both on improving the means of data acquisition from the Nodes' online web-interface, and on quality assurance of the data gathered by these units. In the latter topic, we focused on inter-node comparison, as a tool to identify erroneous vs. reliable data in real time, for nodes deployed as part of a wide network. We also integrate spatial and temporal characteristics of the network in our validation steps. This in a work in progress, that will hopefully be published early 2017.

Events & Announcements

Overview on EuNetAir Events

Summary of 5th Scientific Meeting 2015 – Sofia, Bulgaria

D. Syrakov, I. Nedkov, Bulgarian Acedemy of Sciences, Bulgaria

The 5th scientific meeting was organized at Sofia and hosted by the Bulgarian Academy of Sciences under local chairing of the Action MC members Prof. Iv. Nedkov and Prof. D. Syrakov. The meeting was focused on the new sensing technologies for air-pollution monitoring and environmental measurements in a multidisciplinary approach including international experts and coordinators of the running FP7 and H2020 research projects. New sensing technologies and gas/PM microsensors were discussed and estimated. The local organizers shared good practices connecting lidar monitoring of large urban areas over Sofia municipality and the synergy with in-situ atmospheric sensors. New results from computer simulations of the atmospheric composition climate in Bulgaria were reported.

During the opening, the participants were welcomed by the Deputy Minister of Bulgarian Ministry of Education and Science and by the Deputy President of Bulgarian Academy of Sciences. The follow-up plenary session was focused on the outdoor and city environment quality applications. In the afternoon, the meeting continued in two parallel sessions, devoted to sensor materials, nanotechnologies, devices and systems and on the environmental measurements and air-pollution modeling. Round table discussion was organized at the end of the day.

The second day started with keynote session related with key technologies for air quality control. H2020 opportunities of funding in air quality monitoring and related topics where presented and discussed. During the poster session a big interest provoked the presence of three private companies from Bulgaria and Germany.

The third day started with analysis of the model estimates of regional climate changes and its impact on the air quality over Bulgaria. The MC meeting discussed in detail the extension of the action at 2016 and the organization of the planed meetings. The Action Chair and Grant Holder Manager presented the analysis of the recent and upcoming action events and financial details.

Overview on EuNetAir Events

Summary of 4th International Workshop 2016, Vienna, Austria

A. Köck, MCL, Austria

The “Fourth International Action Workshop on Innovations and Challenges for Air Quality Control Sensors” was held in Vienna, Austria, 25th – 26th February 2016. The workshop was organized by Materials Center Leoben Forschung GmbH, co-supported by Techkonnex-High-Tech Promotion and was hosted by the FFG – Austrian Research Promotion Agency”. The plenary session started with an impressive overview of the activities in the COST Action TD1105 followed by a presentation on the current air quality status in Europe

Day 1 focused on new strategies for environmental informatics and air quality sensors calibration, use of novel sensor technologies in health and climate change domain, operation of sensor networks in real life measurements, and model simulations. Advanced materials including from carbon nanomaterials, SnO_2 nanowires and other nanostructures were a central topic on Day 2. ams AG presented their environmental sensors for air quality control. CMOS integrated IR emitters and detectors for optical environmental monitoring was presented by CCS. The Key note presentations were dedicated to the project “Air SensEUR – an Open-source Multi-Sensor Platform for Air Quality Monitoring” and the FP7-project “MSP – Multi Sensor Platform for Smart Building Management. 44 participants from 18 countries attended the Action Workshop in Vienna and made it a big success.

4th International Training School 2016, Copenhagen, Denmark

O. Hertel, Aarhus University, Denmark

The fourth EuNetAir training school “Modelling, Methods and Technologies for Air Quality Control” was organized as a 5 ECTS PhD course by Department of Environmental Science, Aarhus University. The training school took place at Aarhus University campus Emdrup in Copenhagen from April 19th to April 22nd, 2016. The training school was attended by 21 trainees (1 local PhD student was added after deadline and two additional guests attending parts of the training) from 13 countries: Bulgaria, Croatia, Denmark, Germany, Hungary, Ireland, Italy, Latvia, Portugal, Russia, Serbia, Sweden, and Turkey. The lectures were given by 11 trainers: 10 local and 1 from Greece.

The trainees were asked to prepare by reading literature on air quality science and management prior to the training school. In addition they had to prepare a poster on their research activities and email the poster to the organizers one week before the training school. The posters were presented by the trainees in two poster session held in the afternoons on the first and third day of the training school. The social dinner took place in the afternoon/evening on the second day.

The first one and a half day of the training school was dedicated to basic lectures on atmospheric chemistry and physics governing air pollution, but also introduction to health effects of air pollution. This was followed by lectures on air pollution tools: monitoring, field experimental work, emission inventories and local scale and long-range transport modelling. The training school continued with a lecture on pollen and fungal spore research and monitoring, a lecture on agricultural air pollution and impact of atmospheric nitrogen on nature, and a lecture on episodic events like the pollution following the eruption from the Icelandic volcano in 2010. The fourth and final day of the training school was devoted to data control/data analyses and air quality management. After the training school the trainees have been asked to solve a number of exercises and forward these to the organizers for evaluation. When the exercises have been approved, the trainees will receive a diploma with a mark based mainly on the exercises. The diploma will confirm that they have received 5 ECTS for the participation in the training school.

During the closing session the trainees were asked to fill in an anonymous evaluation scheme that they had received at the arrival at the training school. In the evaluation scheme the trainees were asked to score each lecture on a scale from 1 to 5 (with 5 as maximum) and provide guidance to the trainers on how to improve the training school. The trainees expressed overall high satisfaction with the training course and gave the lectures at the training school an average score of 4.5. The main criticism was that the intense program of the training school did not allow allocating time for the exercises. In a follow up the training school should therefore either be extended to a full week, or the number of lectures should be reduced. During the closing session, the students organized a Facebook group to keep the contact after the training school.

http://phd.au.dk/gradschools/scienceandtechnology/courses/scientificcourses/modelling-methods-and-technologies-for-air-quality-control/

Overview on EuNetAir Events

View from trainees: 4th International Training School 2016

J. Palmisani, University of Bari, Italy

The 4th Training School "Modelling, Methods and Technologies for Air Quality Control" was organized at Aarhus University Campus Emdrup in Copenhagen on 19-22 April 2016.

Objective of the Training School was to provide attendants both a general introduction to the physical and chemical processes governing air pollution and knowledge regarding methodologies and technologies applied for air quality control. The course consisted of 23 lectures given by Professors and highly trained researchers focused on measuring techniques and mathematical models used in research and management of air quality. Attention was paid also to air pollution effects on human health and environment. The four-days school included a poster session and stimulating discussions among attendants on several research topics. It represented a great experience of communication among students and experts in the field and an opportunity to establish a useful network among students and early-stage researchers coming from all over Europe and neighbouring countries.

European Materials Research Society EMRS 2016, Lille, France

M. Penza, Action Chair, ENEA, Italy

A.Lloyd Spetz, Action Vice-Chair, Linkoping University, Sweden

The Symposium X - Functional Materials for Environmental Sensors and Energy Systems - chaired by Michele Penza, Action TD1105 Chair, Anita Lloyd Spetz, Action Vice-Chair, Albert Romano-Rodriguez, Action MC Substitute and Meyya Meyyappan, IPC Member, has been organized as parallel Open Event inside to EMRS Spring Meeting 2016 Conference (http://www.european-mrs.com/2016-spring-symposium-x-european-materials-research-society), chaired by the General Chairs among other Prof. Juan Ramon Morante, IREC, Spain, Action MC Member, and Prof. George Kiriakidis, FORTH, Greece, Action MC Substitute.

The Symposium X was composed by 5-day workshop including the Invited Talk of the Action Chair on New Sensing Technologies for Air Pollution Control and Environmental Sustainability and other 20 Invited Speakers, 58 contributed speakers and 79 posters, mainly from EuNetAir. This Symposium was top-8 ranked using the number of the submissions (about 160 abstracts) and was well-attended by at least 150 international experts in room during the overall symposium.

Two Grant Student Awards were assigned on competitive basis to Caroline Schultealbert, PhD student from Saarland University (Germany) and Ferry Anggoro Ardy Nugroho, PhD student from Chalmers University of Technology (Sweden).

Very good visibility for the COST Action TD1105 EuNetAir was provided by the EMRS Spring Meeting 2016 as show-case to disseminate the achieved Action results. The EMRS Spring Meeting 2016 Conference was attended by about 2500 delegates.

Overview on EuNetAir Events

Joint dissemination event at SENSOR fair 2016: EuNetAir and ESSC joined forces with EU projects MSP, IAQSense and SENSIndoor

A. Schütze, WG2 leader & ESSC WG IQ Leader, Saarland University, Germany

We proudly look back to a very successful joint dissemination event at the Sensor+Test Fair held in Nuremberg, Germany, May 10-12, 2016. EuNetAir and the European Sensor Systems Cluster ESSC joined forces with three EU-funded projects: MSP, IAQSense and finally the SENSIndoor project, which was originally initiated from the EuNetAir community. The joint booth attracted many interested visitors from both industry and science. Prototypes of four ultra-sensitive sensors and sensor systems were presented leading to various contacts to potential clients from the HVAC industry and other branches. Thus, the conference offered a perfect chance for networking, as the projects are moving towards their completion and yield many interesting results.

To complement the booth, a special presentation session entitled “Novel sensor solutions for Indoor Air Quality – Real time monitoring for improved health, comfort and energy efficiency” was organized on the final day of the fair. This session covered the full scope from “(Indoor) Air Quality: impact on health and the role of sensors”, presented by our chairman, Michele Penza, to “Smart building integration for green and healthy buildings” by Martin Zimmermann, Siemens Building Technologies, and “Indoor Air Quality based on smartphone integrated sensor technologies” by Foysol Chowdhury, Cambridge CMOS Sensors. The three projects were presented by Tilman Sauerwald, Saarland University (SENSIndoor), Mathias Holz, Nanoanalytik GmbH (IAQSense) and Anton Köck, MCL (MSP). The session offered the possibility to present the projects in-depth and to focus on the main results and scope of applications. All partners were very happy to welcome many visitors to this session.

Joint booth at the Sensor+Test 2016. Two experimental demonstrations, the discrimination of alcoholic and non-alcoholic beer and the in-field calibration of sensors illustrated the principle of the sensors and showed their high usability.

Announcements

Upcoming Events

TCM 2016 - International Symposium on Transparent Conductive Oxides
October 9-13, 2016, Crete, Greece
www.tcm2016.org/

ISES Meeting - International Society of Exposure Science
October 9-13 , 2016, Utrech, The Netherlands
www.ises2016.org/

IEEE SENSORS 2016
October 30 – November 2, 2016, Orlando, FL, USA
www.ieee-sensors2016.org/

MRS Fall Meeting and Exhibit 2016
November 27-December 2016, Boston, Massachusetts.
http://mrs.org/fall2016/

IMCS 2018 - International Meeting on Chemical Sensors
July 15-19, 2018, Vienna, Austria
http://www.imcs2016.wien/

Publications of EuNetAir participants

List of publications related to EuNetAir

D. Puglisi, J. Eriksson, J. Huotari, M. Bastuck, A. Lloyd Spetz, M. Andersson
Exploring the gas sensing performance of catalytic metal/ metal oxide 4H-SiC field effect transistors
Mat. Sci. Forum 858 (2016) 997-1000

J. Huotari. J. Lappalainen, R. Bjorklund, E. Heinonen, I. Miinalainen, J. Puustinen, A. Lloyd Spetz
Synthesis of Nanostructured Solid-State Phases of V_7O_{16} and V_2O_5 Compounds for ppb-Level Detection of Ammonia
J. Alloys and Compounds, 675 (2016) 433-440

J. Huotari, W. Cao, Y. Niu, J. Lappalainen, J. Puustinen, V. Pankratov, A. Lloyd Spetz, M. Huttala
Separation of valence states in thin films with mixed V_2O and V_7O_{16} phases
J. Electron Spectroscopy and Related Phenomena 211 (2016) 47-54

M. Bastuck, D. Puglisi, J. Huotari, T. Sauerwald, J.Lappalainen, A. Lloyd Spetz, M. Andersson, A. Schütze
Exploring the selectivity of Wo_3 with Iridium catalyst in an ethanol/naphthalene mixture using multivariate statistics
Thin Solid Films, Special Issue SGS 2015

D. Puglisi, J. Eriksson, M. Andersson, J. Huotari, M. Bastuck, C. Bur, Jy. Lappalainen, A. Schütze, A. Lloyd Spetz
Exploring the Gas Sensing Performance of Catalytic Metal/Metal Oxide 4H-SiC Field Effect Transistors
Materials Science Forum 858 (2016) 997-1000

M. Leidinger, M. Rieger, T. Sauerwald, C. Alépée, A. Schütze
Integrated pre-concentrator gas sensor microsystem for ppb level benzene detection
Sens. Act. B: Chem. 236 (2016) 988-996

J. Huotari, V. Kekkonen, T. Haapalainen, M. Leidinger, T. Sauerwald, J. Puustinen, J. Liimatainen, J. Lappalainen
Pulsed Laser Deposition of Metal Oxide Nanostructures for Highly Sensitive Gas Sensor Applications
Sens. Act. B: Chem. 236 (2016) 978-987

M. Leidinger, J. Huotari, T. Sauerwald, J. Lappalainen, A. Schütze
Selective Detection of Naphthalene with Nanostructured WO_3 Gas Sensors prepared by Pulsed Laser Deposition
J. Sens. Sens. Syst. 5 (2016) 147-156

O. Monereo, S. Illera, A. Varea, M. Schmidt, T. Sauerwald, A. Schütze, Al. Cirera, J. D. Prades
Localized self-heating in large arrays of 1D nanostructures
Nanoscale 8 (2016) 5082-508

J. Huotari, J. Lappalainen, J. Puustinen, T. Baur, C. Alépée, T. Haapalainen, S. Komulainen, Ju. Pylvänäinen, A. Lloyd Spetz:
Pulsed laser deposition of metal oxide nanoparticles, agglomerates, and nanotrees for chemical sensors
Procedia Engineering 120 (2015) 1158–1161

E. Dilonardo, M. Penza, M. Alvisi, C. Di Franco, F. Palmisano, L. Torsi, N. Cioffi
Evaluation of gas-sensing properties of ZnO nanostructures electrochemically doped with Au nanophases
Beilstein J. Nanotechnol. 7 (2016) 22-31

E. Dilonardo, M. Penza, M. Alvisi, C. Di Franco, R. Rossi, F. Palmisano, L. Torsi, N. Cioffi
Electrophoretic deposition of Au NPs on MWCNT-based gas sensor for tailored gas detection with enhanced sensing properties
Sens. Act. B: Chem. 223 (2016) 417-428

A.Kumar, A. J. Brunet, C. Varenne, A. Ndiaye, A. Pauly, M. Penza, M. Alvisi
Tetra-tert-butyl copper phthalocyanine-based QCM sensor for toluene detection in air at room temperature
Sens. Act. B: Chem. 210 (2015) 398-407

S. Öztürk, A. Kösemen, Z. A. Kösemen, N. Kılınç, Z. Z. Öztürk, M. Penza
Electrochemically growth of Pd doped ZnO nanorods on QCM for room temperature VOC sensors
Sens. Act. B: Chem. 222 (2016) 280-289

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Action Chair Dr. Michele Penza, ENEA, IT - michele.penza@enea.it
Editor-in-Chief Prof. Ralf Moos, University of Bayreuth, DE - functional.materials@uni-bayreuth.de
Editorial Board Manager Dr. Daniela Schönauer-Kamin, University of Bayreuth, DE
Graphic design Dr. Jaroslaw Kita, University of Bayreuth, DE