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

COST Action TD1105

WGs and MC Meeting at ISTANBUL, 3-5 December 2014

Action Start date: 01/07/2012 - Action End date: 30/06/2016

Year 3: 1 July 2014 - 30 June 2015 (*Ongoing Action*)

OFFICAIR:

On the reduction of health effects from combined exposure to indoor air pollutants in modern office buildings (Nov 2010 - Jan 2014)

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OFFICAIR Project Coordinator

On behalf of the OFFICAIR Project Consortium

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EU 7th Framework Programme (FP7)

under the topic:

ENV.2010.1.2.2-1: Indoor air pollution and health risks of modern office buildings

Project Partners

1	**PANEPISTIMIO DYTIKIS MAKEDONIAS (UNIVERSITY OF WESTERN MACEDONIA)**	**UOWM**	**Greece**
2	JRC -JOINT RESEARCH CENTRE- EUROPEAN COMMISSION	JRC	Belgium
3	VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK N.V.	VITO	Belgium
4	DET NATIONALE FORSKNINGSCENTER FORARBEJDSMILJO	NCRWE	Denmark
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6	UNIVERSITA DEGLI STUDI DI MILANO	UMIL	Italy
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10	CENTRE SCIENTIFIQUE ET TECHNIQUE DU BATIMENT	CSTB	France
11	CONSIGLIO NAZIONALE DELLE RICERCHE	CNR-IIA	Italy
12	ACCIONA INFRAESTRUCTURAS S.A.	ACCIONA	Spain
13	EÖTVÖS LORÁND TUDOMÁNYEGYETEM	ELTE	Hungary
14	PANEPISTIMIO IOANNINON (UNIVERSITY OF IOANNINA)	UOI	Greece
15	UNIVERSITA DEGLI STUDI DELL' INSUBRIA	UNINS	Italy

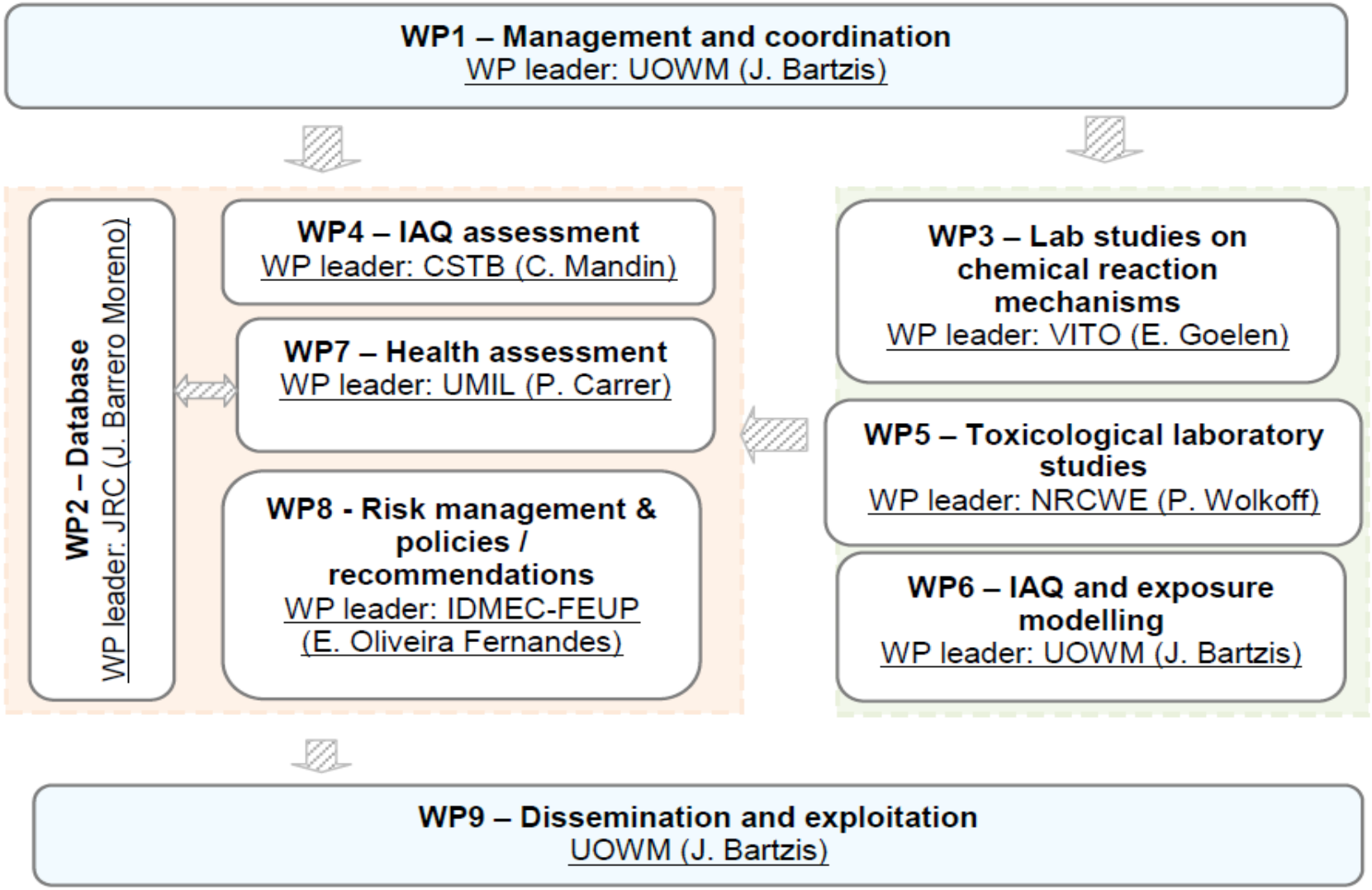
OFFICAIR Overall Objective

- Establish a framework to provide new knowledge, in terms of:
  - *Databases;*
  - *Modelling tools;*
  - *Assessment methods;*

  towards an integrated approach in assessing the health risk from indoor air pollution, focusing on modern office buildings.

- Support current EU policies, e.g.
  - *Thematic Strategy on Air Pollution;*
  - *European Environment and Health Strategy and Action Plan.*

OFFICAIR Main Activities and Organization



Achievements-I

- The indoor air quality in modern office buildings in Europe was monitored for the first time in association with the evaluation of **the workers' performance**, their **perception of comfort**, including **perception of indoor air quality (IAQ)**, and their **self-reported health effects**, including **psycho-social** and **personal** aspects;
- A clearer picture has been generated in terms of **building characteristics** (equipment, types of HVAC systems, cleaning practices, etc.) in modern offices across Europe;
- OFFICAIR provided interesting outputs in terms of IAQ **sampling strategy** in office buildings, which will be useful for the establishment of **harmonized protocols** taking into account the concentration spatial and temporal variabilities.
- The IAQ data set produced by OFFICAIR can now be considered as a reference on indoor concentrations in **recently built** or **recently refurbished** office buildings in Europe.

Achievements-II

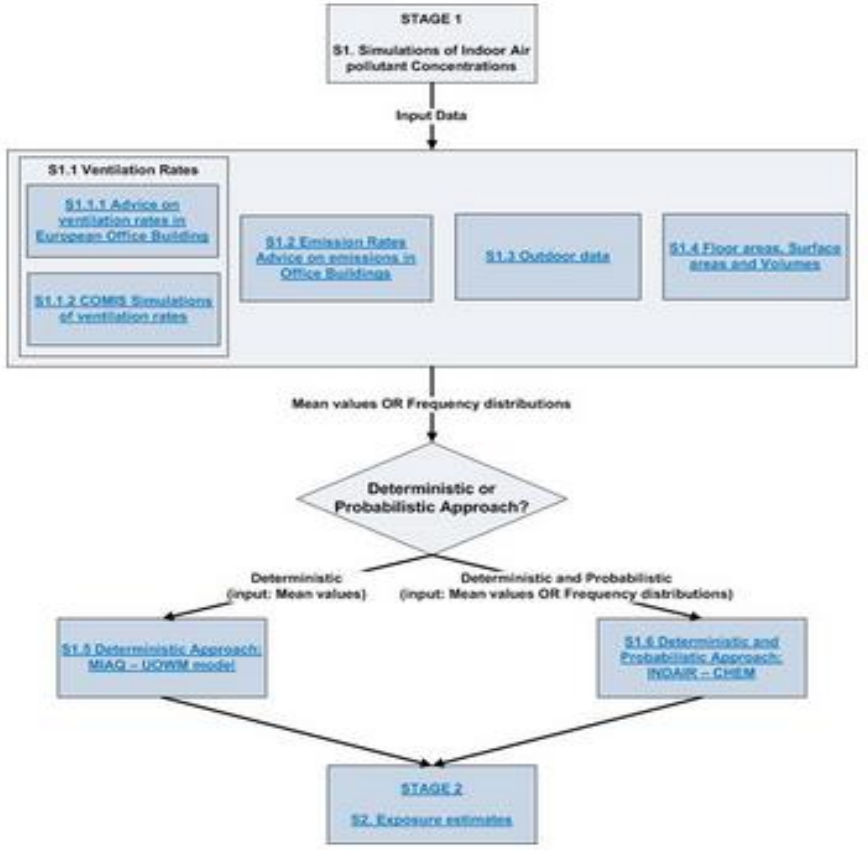
- New insight has been given on **ozone terpene chemistry** in terms of **products identification** and **quantification** and **potential toxicity**;
- A systematic study for evaluating IAQ health effects and health effect reduction via **intervention measures** to **reduce pollutant emissions** under different conditions in modern offices was made;
- Health Risk Assessment was conducted using as target population a group of office workers focusing on their **acute** or /and longer term **inhalation** exposure in the following selected air pollutants: **formaldehyde, acrolein, d-limonene, α-pinene, 6-MHO, 4-OPA , 4-AMCH, ozone and PM2.**5

Achievements-III

- **A web based integrated modeling system to link emissions with concentrations and exposure**

- **Development of a European database in terms of concentrations, sources and emissions, exposures and health effects**

OFFICAIR Modelling System



Considered Air Pollutants

- Priority compounds (WHO)

  (benzene, formaldehyde, NO_2, naphthalene)
- Compounds associated with perceived air quality

  (Acetic acid, Hexanal, 2-butoxyethanol, 2-ethylhexanol, Hexanoic acid, Limonene, Phenol, Settled dust on surfaces)
- Compounds associated with sensory irritation

  (Acetic acid, Acrolein, Ammonia, 2-ethylhexanol, Formaldehyde, Glutaraldehyde, Hydrogen peroxide, 6-methyl-5-heptene-2-one (6-MHO), Methacrolein, Methyl-naphthalenes, 1-octen-3-ol, 4-oxopentanal (4-OPA), Ozone, Peroxy-acetic acid, Phenol)
- Compounds associated with performance

  (Carbon dioxide)
- Compounds associated with long-term effects

  (respirable (ultrafine/fine or PM2.5) particles)

OFFICAIR Campaign and Buildings

- **GENERAL SURVEY:** Check-list and Questionnaire
  - 8 countries; 20 buildings/country; 167 buildings; 7500 subjects

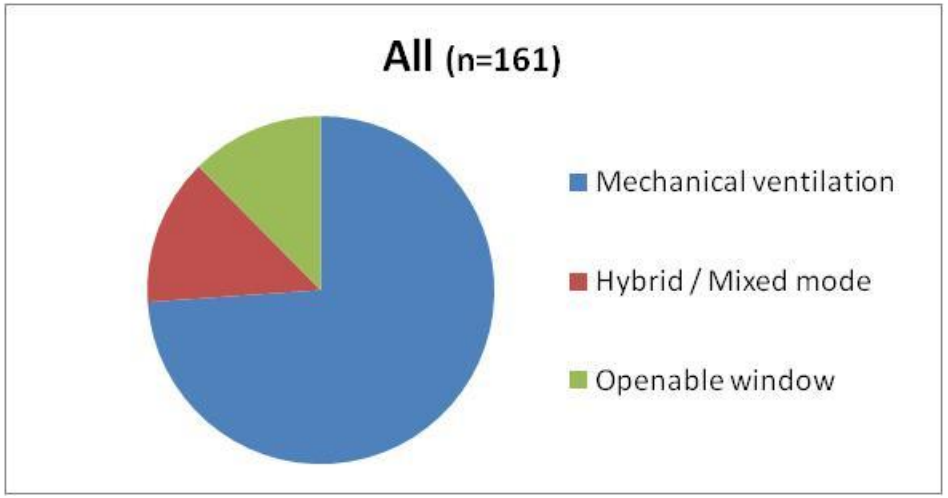
- **DETAILED STUDY:** Check-list, IAQ measurements, Questionnaire-Online tests
  - 8 countries; 3-5 buildings/country; 37 buildings; 30-50 subjects/building; 1400 subjects
  - 2 surveys: summer and winter

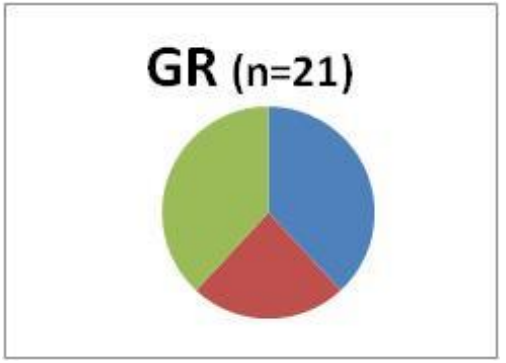
- **INTERVENTION STUDY:** Check-list, IAQ measurements, Questionnaire-Online tests-Health investigations
  - 6 countries; 1-2 buildings/country; 9 buildings; 20-30 subjects/building; 250 subjects
  - 2 surveys: before and after intervention

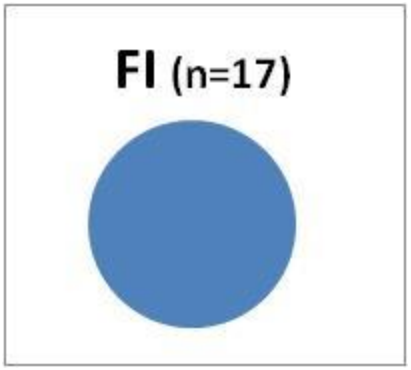
This panel represented the large variety of modern office buildings in Europe.
A clearer picture has been generated in terms of building characteristics (equipment, types of HVAC systems, cleaning practices, etc.) in modern offices across Europe



Ventilation *(provided by TNO, CSTB)*



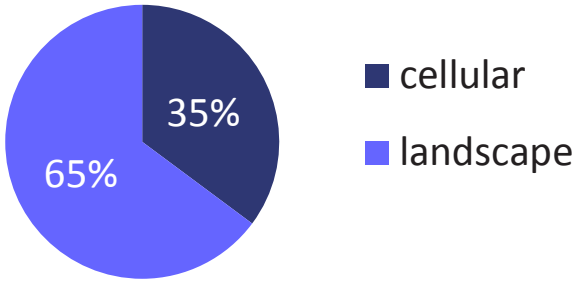




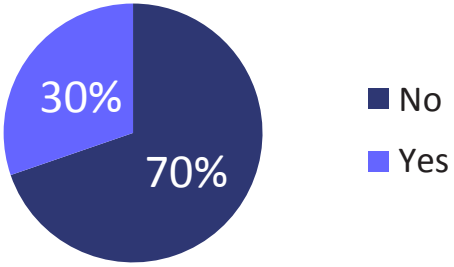
Room characteristics

- **145 rooms described (information from the detailed study)**

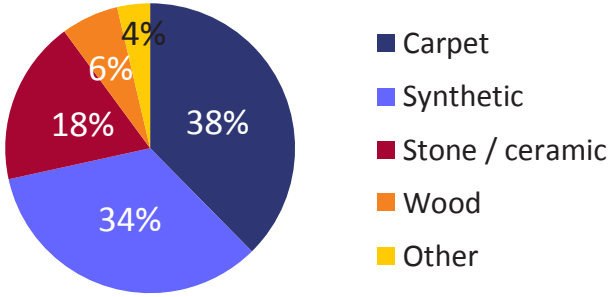
Type of office



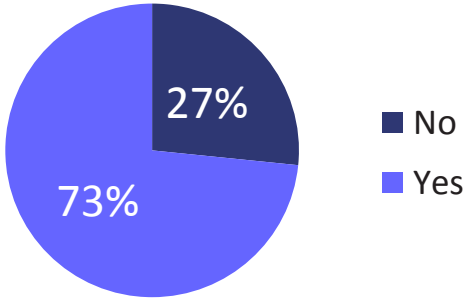
Laser printer in the room



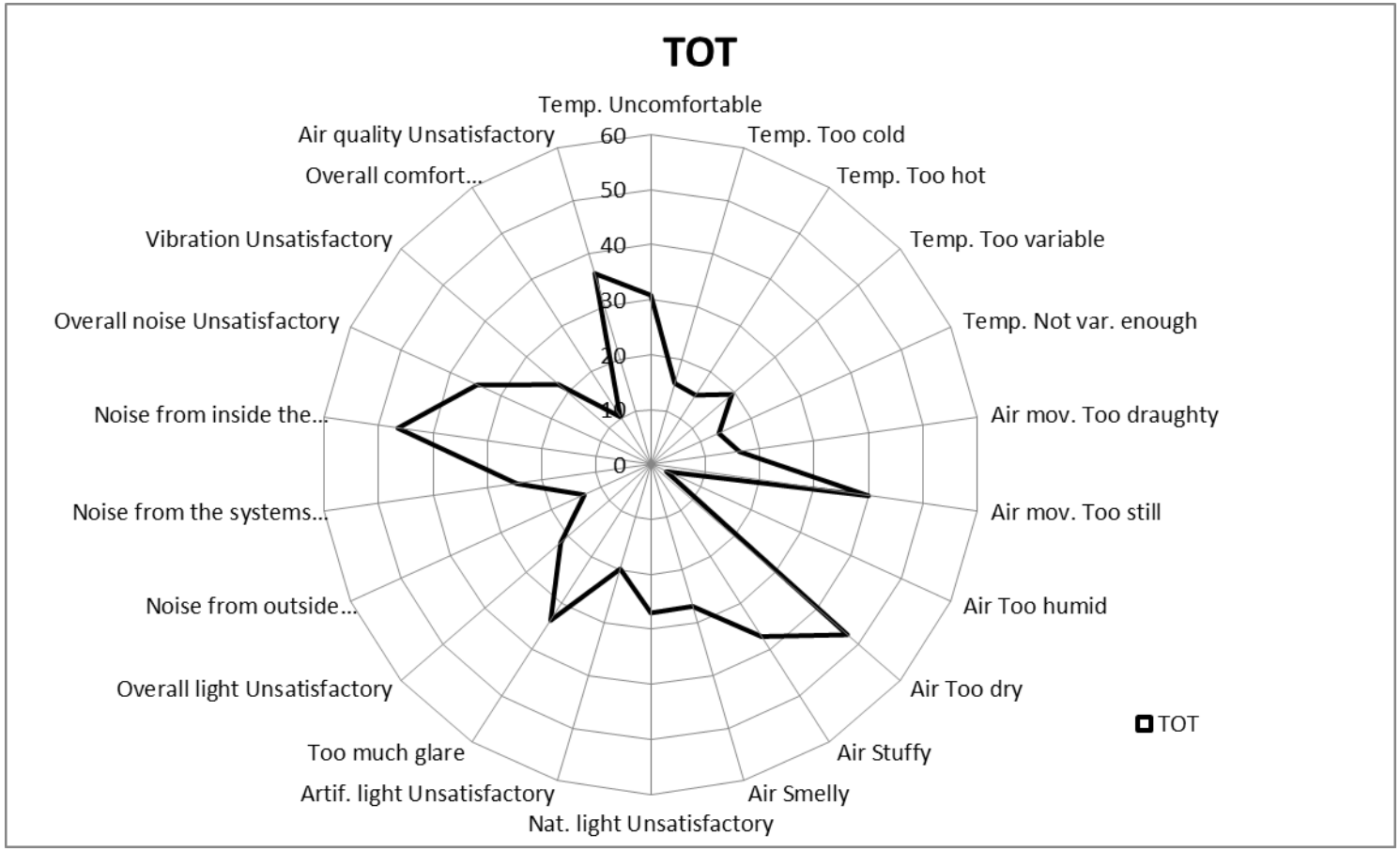
Floor covering



Openable windows



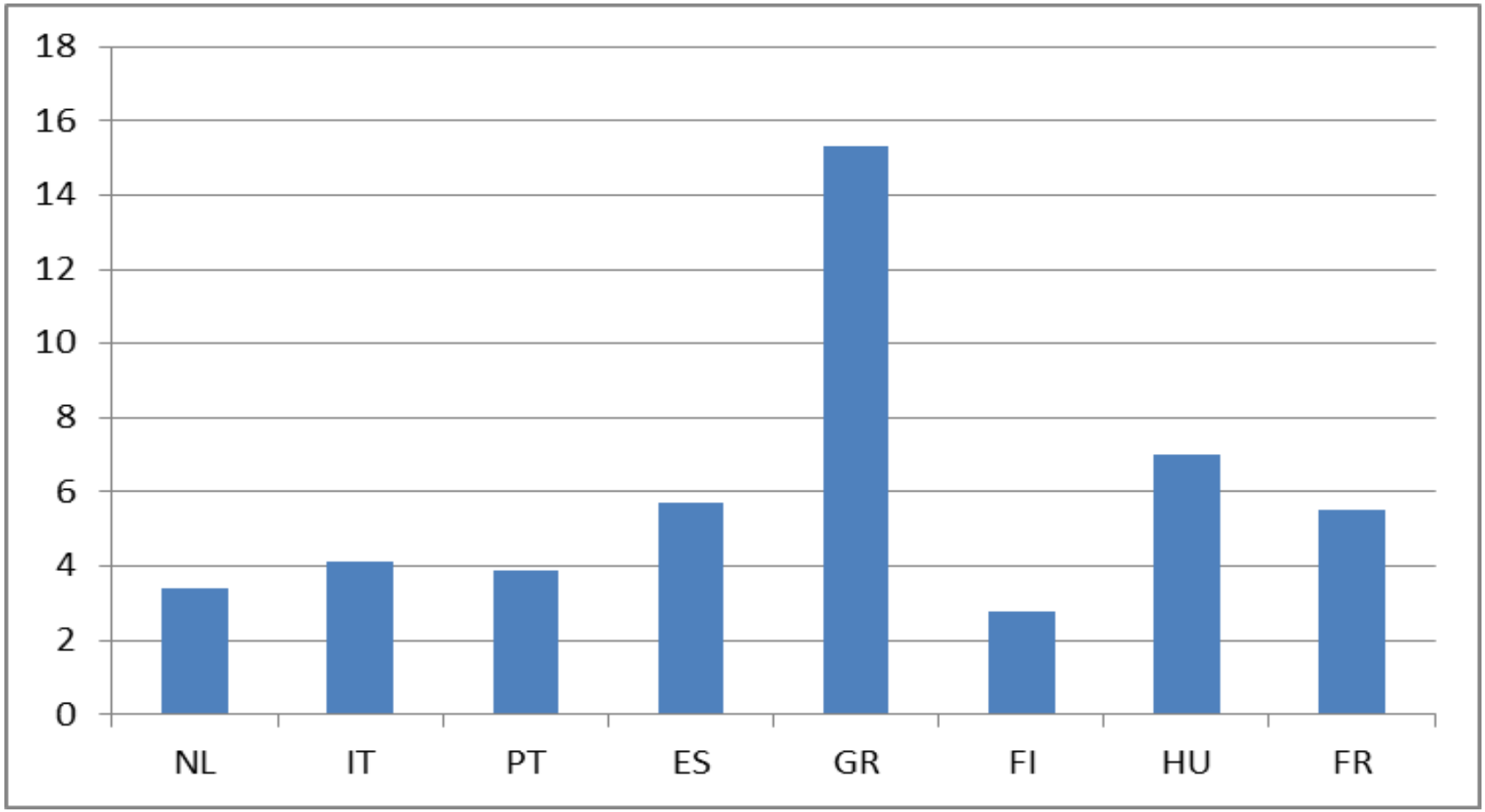
General survey: IAQ perception (156 Buildings; n. 7192 subjects)



General Survey:
Effort/Reward imbalance Index (ERI)

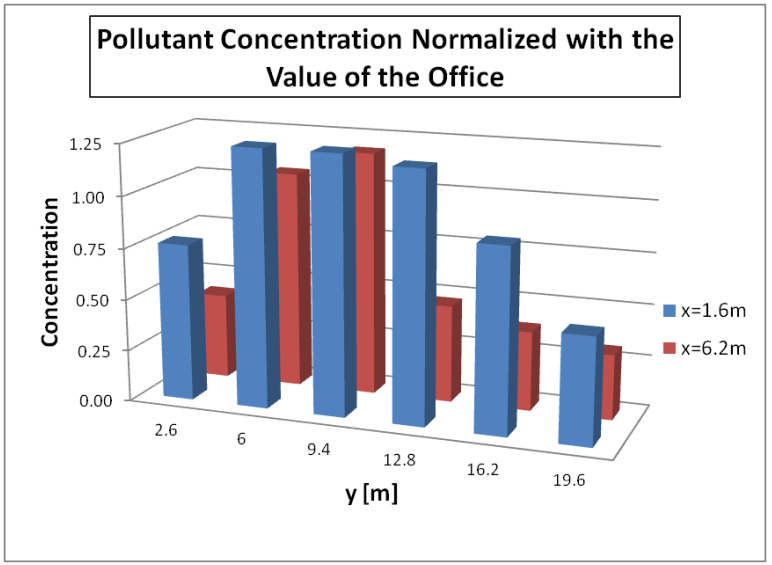
(provided by UMIL)

Stressful Imbalance :ERI> 1

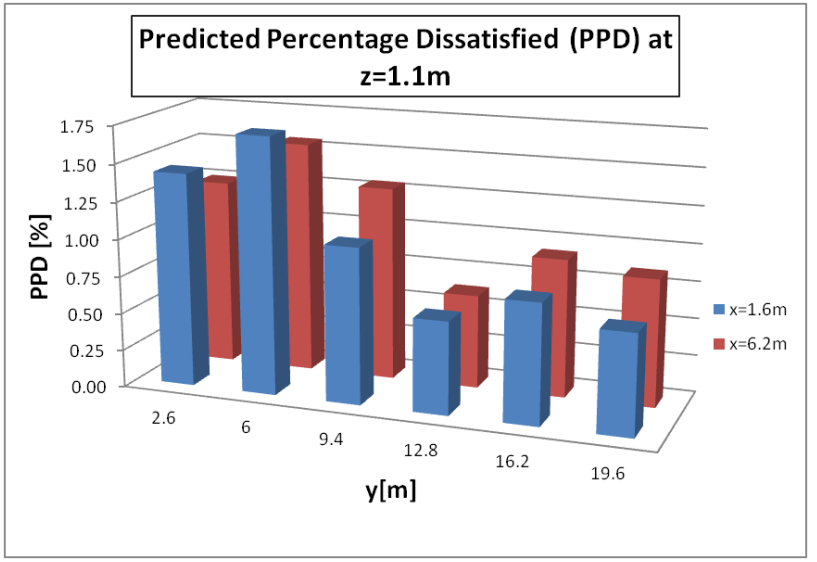


Exposure spatial variation CFD modeling in large modern offices

- The large offices may experience a significant spatial variability both in terms of thermal comfort and pollutant concentrations emitted from the floor and the floor equipment;
- In order not to underestimate the health risks for individual workers, assessments should not be based on the assumption of homogeneous pollutant concentrations within an office;
- The present methodology can be used for ventilation pattern optimization in terms of exposure and/or thermal comfort impact on large offices.



Exposure factors at the working positions of the Athens GR22 – Greece at the height of z = 1.1 m.
Volume : 441.015 m^3
Dimensions: 22.26 m (length) x 7.80 m (width) x 2.54 m (height)



Predicted Percentage Dissatisfied (PPD) at the working positions of the Athens GR22 – Greece at the height of z = 1.1 m.
Volume : 441.015 m^3
Dimensions: 22.26 m (length) x 7.80 m (width) x 2.54 m (height)

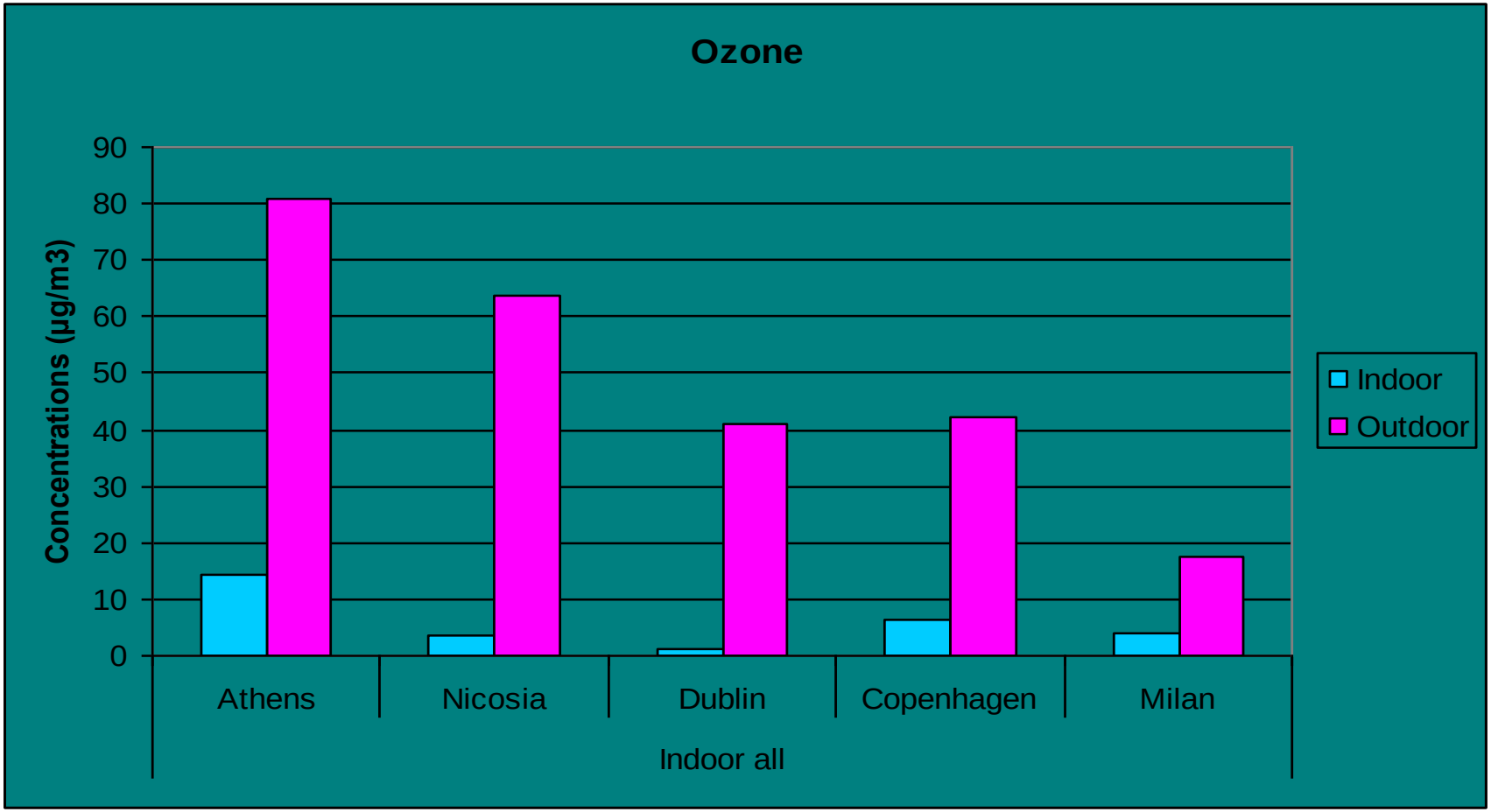
OFFICAIR Focus topic:
Ozone terpene-reaction related studies

- Ozone/terpene reactions result in myriad compounds including reactive intermediates, such as hydroxyl radicals, alkylperoxy radicals, high volatility products such as formaldehyde and semi-volatile products such as carboxylic acids and hydro-peroxides, which may yield Secondary Organic Aerosol (SOA).

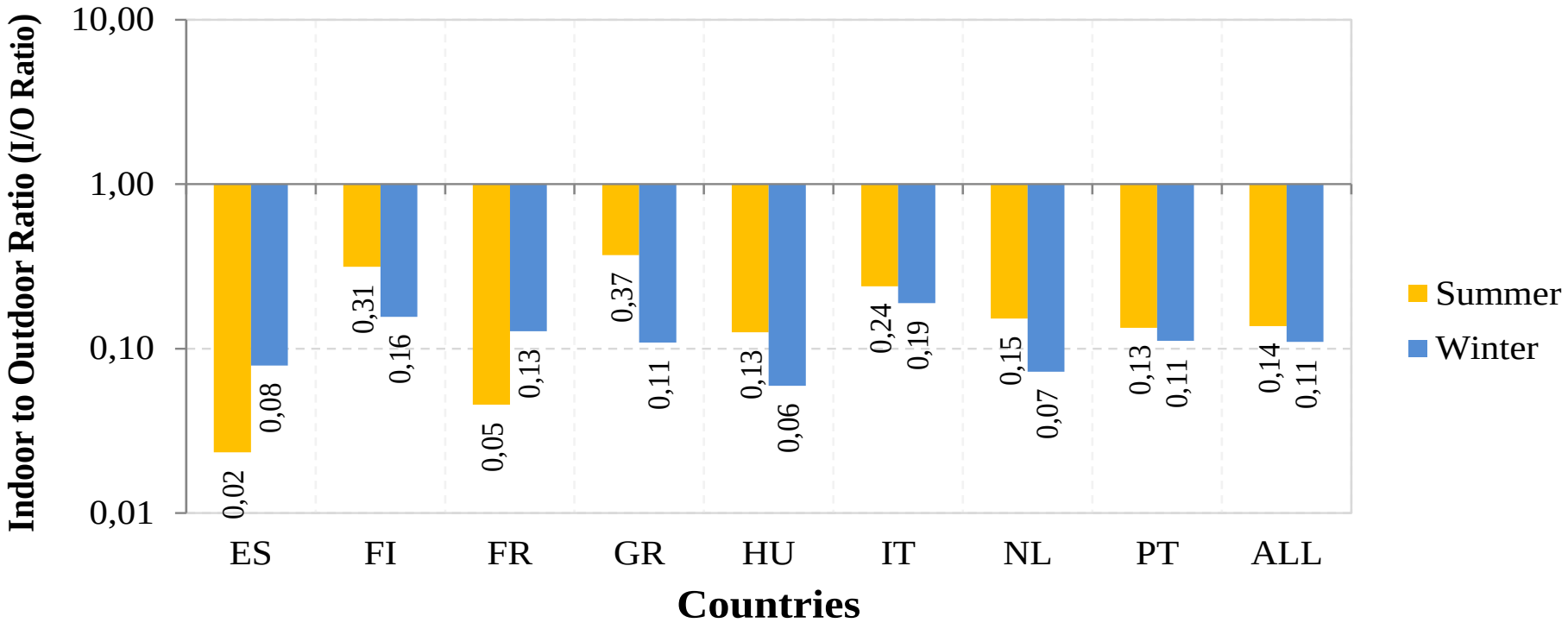
- Relatively strong presence of terpenes in the **indoor air** and **indoor surface-sorbed.**

- Evidence for significant outdoor ozone **consumption indoors**

BUMA Project : Indoor vs Outdoor mean levels of O_3 (residential)



OFFICAIR Median I/O ratios for ozone in European offices (CSTB)



OFFICAIR :
Ozone terpene-reaction integrated approach
Emphasis on limonene

- **Lab Chemical Measurements studies**
- **Targeted Toxicological studies**
- **Field studies**
- **Modeling studies**
- **Health Risk Assessment studies**

Lab Chemical Measurements Studies – New Method (VITO)

- The new innovative thermal desorption GC MS method for SVOC sampling and analysis including PM/SRP (secondary reaction products) showed to be applicable for **selected SRPs such as e.g. 4-OPA (4-oxopentanal), 6-MHO (6-methyl-5-heptene-2-one), 4-AMCH (4-acetyl-1-methylcyclohexene), 3-IPOH (3-isopropenyl-6-oxo-heptanal) [**and other substances such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) and phthalate esters (PEs)]

Published : Atmospheric Environment 79 (2013) 780-786

Lab Chemical Measurements studies- Identification of reactive species (NRCWE)

- Highly specialised techniques were developed for the further identification of reactive species resulting from secondary reactions **of terpene ozone mixtures**.
- The use of LTP for in situ ozonolysis and ionization represents **a new and versatile approach** for the assessment of ozone-initiated terpene chemistry.
- The method may be useful for the analysis of more complex ozone-initiated terpene reaction products.

Published:

1. **Journal of American Society of Mass Spectrometry 24 (2013) 1090-1096.**
2. **Analytical Chemistry, 85 (2013) 28-32**

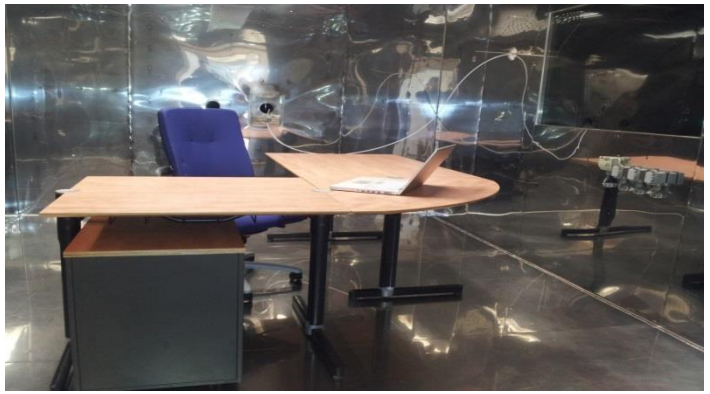
Lab Chemical Measurements studies- Formation of SRP (VITO, NRCWE, JRC)

- The **formation of secondary reaction products resulting from terpene ozone reactions**, was studied in targeted chamber experiments under controlled conditions, **simulating realistic indoor use.** The study was focused on the effect of **concentration levels**, **NO_2 and light on reaction products.**
- Synthetic mixtures were prepared feeding limonene, pinene and ozone into a test chamber, followed by sampling the source and reaction products.
- Considering the most important secondary reaction products, the results show that the factors **darkness and NO_2 cause a decreased concentration for 4-OPA, while formaldehyde and UFP formation was not influenced.**
- **Increasing the initial limonene level gives more reaction products, faster reactions and higher final concentration levels (except for 4-OPA).**
- **The presence of pinene in the mixture has a negative influence on the final concentration of 4-OPA, other reaction products are unaffected.**
- **UFP particle formation is a good indicator for the reactions and can amount under realistic concentration levels up to peak concentrations of 40000 particles/cc.**

Lab Chemical Measurements studies- Model room experiments (JRC, VITO, NRCWE)

- The applicability in real life office environments of the advanced newly developed analytical methods was successfully demonstrated in two different settings.

Indoortron 30m³ chamber



Unoccupied office

- The following set of health relevant air constituents was **measured**: pyrogens in air, PM and UFP, free acids in particulate matter, carbonyls, ozone, volatile organic compounds and **key terpene-ozonolysis secondary reaction products such as e.g. 4-OPA, IPOH, 4-AMCH.**
- **The secondary reaction products were for the first time quantified in real office circumstances and amounted up to 2-3 µg/m³.The cleaning activity caused only a minor increase of SRP's, clearly increased were dihydromyrcenol and selected glycolethers.**

Toxicological Studies - *In vivo studies (NRCWE)*

- The **respiratory effects of 60 min exposures to five common oxidation products** from abundant terpenoids (e.g. limonene), used as solvent and fragrance in common household products or present in skin lipids (e.g. squalene), were studied in a mouse bioassay;
- **Pulmonary irritation was unobserved as a critical effect.**
- The reference values indicate that the oxidation products would not contribute substantially to **sensory irritation in eyes and upper airways** in office environments. **Both IPOH and 4-OPA** may be of concern regarding **possible respiratory effects in the case of acute and constant emission sources of terpenes.**
- **Published : Toxicology Letters 216 (2013) 54-64**.

Proposed human reference values (ppm)		
Compound	**sensory irritation**	**airway limitation**
4-acetyl-1-methylcyclohexene (4-AMCH)	1.3	0.2
3-isopropenyl-6-oxo-heptanal (IPOH)	0.16	-
6-methyl-5-heptene-2-one (6-MHO)	0.3	0.5
dihydrocarvone	-	0.8
4-oxo-pentanal (4-OPA)	-	0.03

Toxicological Studies - *In vivo studies (NRCWE)*

- A well-established **mouse bioassay** was used as a model to study **upper airway (sensory) irritation**, **bronchoconstrictive (airway limitation) and alveolar level effects after exposure to ozone-initiated limonene reaction products** at controlled conditions.
- The effect of repeated exposures to ozone-initiated limonene reaction mixtures over ten days was studied.
- It was concluded that:
  - ➢ sensory irritation in the airways is not accumulated upon repeated exposures;
  - ➢ no sign of inflammation was observed in the exposed airways by analysis of inflammatory markers from bronchoalveolar lavage;
  - ➢ a no-observed-effect-level **(NOEL) of ≥ 0.1 ppm** ozone at elevated limonene concentrations is proposed by extrapolation of the animal data to human data.

Published: Toxicology Letters 209 (2012) 166– 172

Toxicological Studies - In vivo studies (NRCWE)

- Examine if inhalation of the reaction products of ozone and limonene as well as low-level ozone and limonene themselves, would induce allergic sensitization (formation of specific IgE) and airway inflammation in a subchronic mouse inhalation model in combination with a model allergen “ovalbumin” (OVA). (Chicken egg ovalbumin).
- **Limonene itself showed anti-inflammatory properties.**
- **Normal mice (saline-sensitized) housed in a dry environment responded more vigorously in the lower airways to formaldehyde concentrations at 1.8 and 7 ppm than ovalbumin (OVA)-sensitized mice.**
- **It is speculated that increased mucus production in the OVA-sensitized mice has increased the “scrubber effect” in the nose, consequently protecting the lower airways.**
- **At high relative humidity no difference in the lower airways was seen between OVA- or saline-sensitized mice up to 1.8 ppm formaldehyde; however, effects occurred in the OVA-sensitized mice compared to the saline-sensitized control mice at 7 ppm formaldehyde.**
- **Sensory irritation of the upper airways was unaffected by sensitization and humidity up to 1.8 ppm formaldehyde.**
- **Published: Toxicology and Applied Pharmacology 268 (2013) 294–299**

Toxicological studies - In vitro studies (JRC)

- **A549 (carcinomic human alveolar basal epithelial cell line)** was exposed to controlled atmospheres in CULTEX chambers containing individual compounds of limonene, ozone, formaldehyde and mixtures (limonene/ozone). Cells were exposed for 1 and 2 hours.
- Various endpoints such as cell viability, membrane damage, inflammation and stress oxidation were selected to assess potential lower airway effects.
- Target limonene concentrations were high and low (2.5 ppm, 0.5 ppm and 0.02 ppm), ozone (70 ppb), target formaldehyde levels were 100 µg/m^3 (WHO indoor air guideline value) and 10 µg/m^3 (a realistic indoor level).
- Based on the endpoints, the exposure experiments with pure limonene, ozone, or formaldehyde, respectively, or the ozone-initiated limonene reaction mixture **did not produce cytotoxic effects, nor did they induce inflammation and oxidative stress of the cells.**

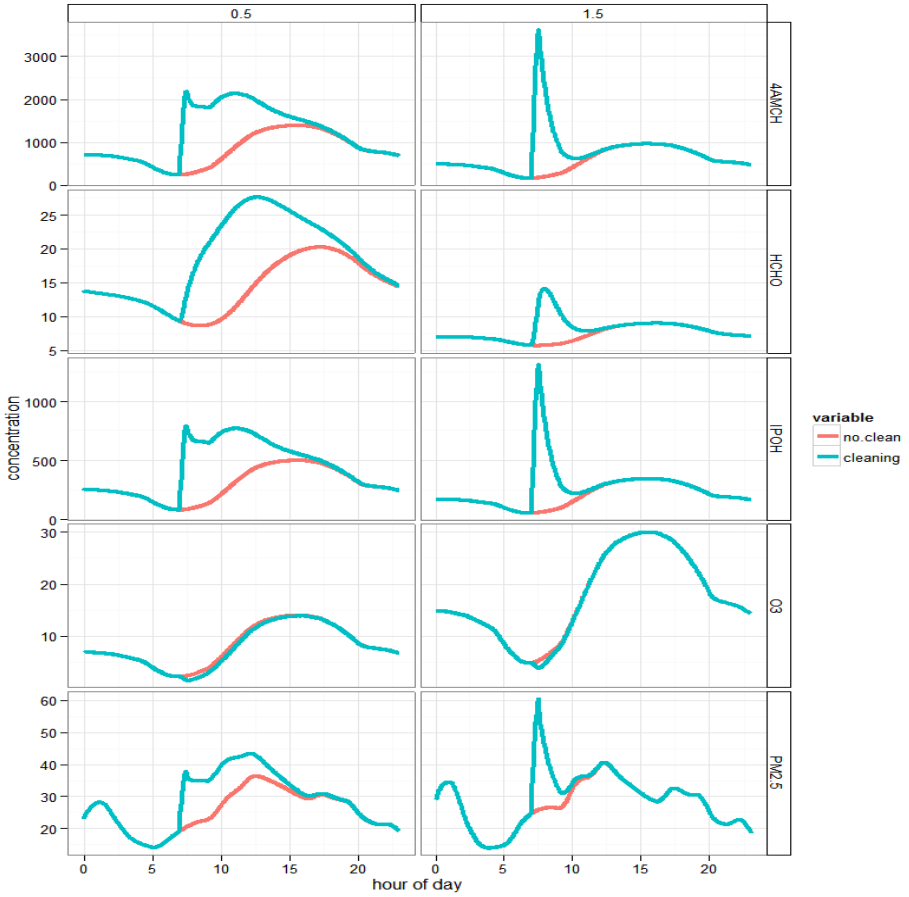
Toxicological studies - In vitro studies (VITO)

- **BEAS-2B (Human bronchial epithelial cells)** cultured at the air-liquid interface were exposed for one hour in a VITROCELL system to ozone and limonene, separately, or as a reaction mixture generated in a climate chamber, and tested with a number of biological assays (cytotoxicity, apoptosis, oxidative stress, and inflammation).
- Exposure of the cells up to 5000µg/m^3 (0.9 ppm) limonene did not show signs of cytotoxicity or apoptosis.
- Limonene showed no effect on either bronchial or alveolar epithelial cells at the concentrations tested.
- Exposures to climate chamber generated reaction mixtures of limonene and ozone of about 400µg/m^3 and 400 µg/m^3 (initial concentrations), respectively, were not significantly cytotoxic; furthermore, no apoptosis, oxidative stress, and inflammatory responses were observed.
- It was shown that additional contribution of the exhaust (i.e. particles) from a running inkjet printer combined with the limonene/ozone reaction products did not alter the cells bioresponses.

Field Intervention Studies (substitution of floor cleaning product with another product with low terpene and aldehyde content)

- **Indoor air measurements were carried out before and after four weeks of intervention procedure (change of cleaning product), at two locations: the intervention room and the control (reference) room.**
- **Five(5)countries: FR, GR, HU, IT, and PT; 8 buildings**
- **For the first time, indoor concentrations of terpene oxidation products, such as 4-OPA and 6-MHO, were measured in real workspaces (mean indoor concentrations around 3 and 1 μg m^{-3} respectively).**
- **After the intervention, a decrease of the ozone-initiated reaction products was generally achieved in all offices, except in the control room.**
- The overall lower concentrations are considered to be caused by the replacement of the cleaning agent, because the AER in the offices was maintained during the two field campaigns and the daily activities were practically the same.
- **Published: *Environ. Sci. Technol.*, 2014, *48* (22), pp 13331–13339**

Modeling Intervention studies (ventilation and cleaning schedule)



Cleaning intervention study for Paris August 2003 and the simulated indoor concentrations of 4-AMCH (ppt), HCHO (ppb), IPOH (ppt), O_3 (ppb) and $PM_{2.5}$ (µg m^{-3}) for AERs of 1.5 and 0.5 ach^{-1}. The red line shows the baseline run with no cleaning and the blue line shows the concentrations with the cleaning interventions.

Simulation of the before office hours cleaning period showed:

a) The $PM_{2.5}$, HCHO, IPOH and 4-AMCH mean exposures increase after cleaning, particularly at the lower ventilation $rate^{-1}$,

b) With lower ventilation rate (0.5 ach^{-1}) the products of limonene degradation persist for much longer with reduced leakage to outdoors.

A cleaning event after office hours has negligible effect on office worker mean exposure on the following work day (the limonene degradation products are depleted overnight)

Best Practice:

1. Organize cleaning in each location in the office building at the end of each working day, rather than just before the start of the day

2. Ensure good ventilation (natural or mechanical) of the room.

Published: Atmospheric Environment, 82, (2014), 9–16

Health Risk Assessment (UMIL)

- A detailed Health Risk Assessment (HRA) was performed in relation to selected indoor air pollutants reported in the office environment and associated to potential adverse health effects **(irritative, respiratory and cardiovascular).**
- Focus on their acute and/or longer-term inhalation exposure to the following selected indoor air pollutants: **formaldehyde, acrolein, d-limonene, α-pinene**, **3-isopropenyl-6-oxo-heptanal (IPOH), 4-oxopentanal (4-OPA), 4-acetyl-1-methyl-1-cyclohexene (4-AMCH), 6-methyl-5-heptene-2-one (6-MHO), ozone and $PM_{2.5}$.**
- Regarding the **outcome based on the exposure modeling**, the estimated worst-case indoor air concentrations of the pollutants studied did not exceed the corresponding limits of exposure. The modeled exposure to **formaldehyde, IPOH and 4-AMCH** was well below the exposure limits for the relative time periods, even assuming afternoon cleaning conditions during a 'heat-wave' period. **Concerning $PM_{2.5}$, however, elevated concentration levels were predicted, probably attributed to outdoor rather than indoor sources.**
- Regarding the **outcome based on the field campaign**, average and maximum measured concentration levels of formaldehyde, acrolein, d-limonene, α-pinene, 6-MHO, 4-OPA and ozone were always lower than the corresponding limits of exposure when either acute or longer-term exposure was assessed. **Elevated maximum concentration levels were reported, however, in the case of longer-term exposure to acrolein (**'Detailed investigation'), but the well-known difficulty to analyse this compound has to be taken into consideration. **Concerning $PM_{2.5}$, average and maximum concentration levels ('Detailed investigation' and 'Intervention study') exceeded the corresponding longer-term limits of exposure (WHO 2005 Air Quality Guidelines, AQG) in most cases; nevertheless**, this comparison in terms of risk characterization has to be evaluated with caution, given the elevated outdoor $PM_{2.5}$ levels as well as the fact that these AQG are related to ambient air**.**

Concluding Remarks

- The outputs of the OFFICAIR project, in association with other past or on-going European initiatives regarding buildings and associated products and practices, are expected to have an important impact on:
  - The **assessment of the IAQ actual conditions** with a reliable, economically acceptable and meaningful way, in terms of health effects and correlated guarantees;
  - The setting of **good practices and target indicators** for the design, construction, maintenance and management of office buildings, bearing in mind the overall "sustainability" assessment, in other words, the IAQ conditions for comfort and health and the energy use conditions.
  - A **healthier life** at work for **building occupants** and a help to steer EU policies towards the better protection of office workers by clarifying the **mechanisms** surrounding **exposure conditions and effects**.
  - Developing a new ground on **IAQ research and its priorities** to ensure **healthy** working conditions in modern offices across Europe.

Some Recommendations for future work - 1

- A better understanding of the respective contributions of the outdoor and indoor sources to the indoor air pollution and their relative impact on health issues is still needed. Emphasis needs to be given to new materials and near zero energy buildings.
- It is highly recommended to keep studying the complexity of sources and pollutants with focus on cleaning agents and their impact on ozone-initiated chemistry, and synergies with microclimatic and psychosocial stress factors.
- Further research is needed on the relationship between real IAQ vs perceived IAQ.
- Office architecture (open vs cellular environment) and its impact on indoor air quality and health needs further investigation. More detailed spatial and temporal measurements in real environments are necessary for this purpose.

Some Recommendations for future work - 2

- Further studies on exposure of new critical respiratory pollutants from ozone terpene chemistry.
- Investigation of pre-exposures influence on health and well-being in offices.
- The role of noise and IAQ particulate matter on cardiovascular symptoms needs to be further evaluated.
- Humidity influence on well-being, health, and performance indoors

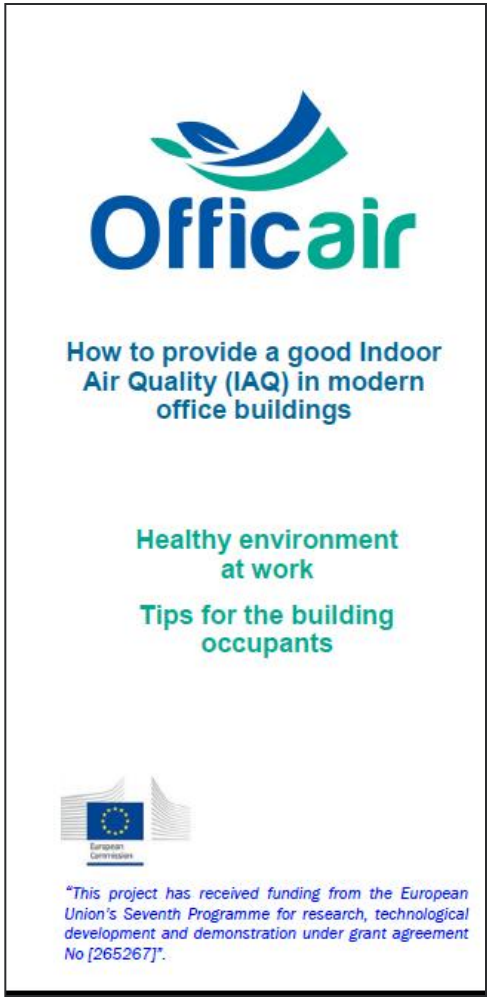
OFFICAIR Publications and brochures

• OFFICAIR Publications until now:
- 17 publications in peer-reviewed journals and
- 26 participations in conferences.

• **Two OFFICAIR brochures were produced, one containing tips for the office building owners and managers and one with tips for the building occupants.**

Both brochures are available at the project website:

http://www.officair-project.eu/



Ευχαριστώ

Thank you