

Indoor Environment Quality Cluster

Contribution of research topics from the Indoor Environment Quality sector to “Renaturing Cities: Addressing Environmental Challenges and the Effects of the Economic Crisis through Nature-based Solutions” and “Materials & technologies for improved Indoor Environment Quality” within EU Horizon 2020

An initiative resulting from the Session on Indoor Environment Quality at the ECTP-E2BA conference at 19th June 2014.

Stuttgart, 03rd July 2014

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Research topics of the Indoor Environment Quality sector for meeting the challenges of “Renaturing Cities: Addressing Environmental Challenges and the Effects of the Economic Crisis through Nature-based Solutions” and “Materials & technologies for improved Indoor Environment Quality” within EU Horizon 2020

Emissions from materials:

- The use of special building materials (e.g. insulation) for the construction of nearly zero energy buildings may lead to IEQ problems due to the materials’ emissions. Emphasis should be given to new materials, used for this cause, and to the relationship between their emissions and Indoor Air Quality (IAQ). There should be a balance between energy efficiency and IAQ.
- The use of nature based or recycled materials (renewable sources, waste, etc.) is recommended due to lower embodied energy and resource efficiency. Nevertheless to reach building standards (fire resistance, mould prevention, stability, etc.) the use of additional compounds (flame retardants, biocides, etc.) is often needed. Some of them increase the emission of Volatile Organic Compounds (VOC). This could influence the Indoor environment Quality (IEQ) by emissions. Research is needed to improve products to meet the building regulations without further emissions.
- Hybrid materials: Combining the properties of natural material and artificial ones takes advantages of both worlds. An example is concrete/hemp. In addition aging and treatment (compounds for flame retardants, biocides) can be optimised limiting both VOC emission and costs. Composite mixture or layer superposition (example phase-change materials (PCM)) can improve or tune the water vapour permeability, energy transfer, energy storage (reinventing Trombe wall or passive cooling and PCM together, etc.) and filtering of indoor/outdoor pollutants at large scale.
- Use of chemicals for conservation, cleaning and other products are main sources of pollution, VOC’s in particular. Research is needed to develop conservation, biocides and other treatment products for wood and stone on the basis of green chemistry and nature based materials. Nanostructured surfaces are good candidates for biocidal surfaces.
- Realistic test scenarios: The climate change is anticipated to increase the ground ozone level and the relative humidity. Based upon this, two aspects are relevant for IEQ. Emission testing of materials and consumer products should be carried out in conditions that mimic realistic atmospheric conditions for proper risk assessment, rather than artificially clean air conditions. The reason is that new pollutants with possible adverse health effects are produced by the induction of ozone, nitrogen dioxide, and/or humidity.
- There is a strong need for harmonization of emission test conditions of construction and consumer products, and risk assessment procedures. These developments need to be accompanied by development of appropriate measurement techniques and especially calibration standards for assessment of specific VOC emissions.

Influence of outdoor pollution on indoor environment:

- Outdoor pollution influences the IEQ. A renaturing of cities could reduce the outdoor pollution. Research is needed for nature based measures to reduce pollution, modelling of districts and cities and the possible influence on IEQ, impact control by advanced online monitoring and measures which influences the transport of pollution form outdoor to indoor

(e.g. advanced filter technologies combined with thermal recovery for HVAC systems, etc.). There is a need to research and monitor which kind and forms of pollution transport happen from outdoors to indoor and which kinds of pollutants are present, in addition to the most cited ones, as the varying climate and outdoor environment change the types of pollutants. Also bio-pollutants should be accounted for.

- The outdoor/indoor interface with particular focus on ozone and nitrogen dioxide initiated reactions on materials and interior surfaces in general should be investigated for the impact upon material sustainability and production of potentially new reaction products.
- There is a need for advanced, pervasive and flexible new monitoring approaches, developed according to different perspectives. E.g. one of the most dangerous outgassing is related to formaldehyde; a sensor solution for online monitoring of formaldehyde is a priority. In order to implement it widely, the sensor solutions should be low cost.
- Filters catching mechanical particles are state of the art in HVAC systems. There is a need to develop more advanced filter materials which can filter gaseous chemical pollution without disturbing the system performance. The focus should lie on cost-efficient solutions to guarantee a wide distribution.
- Further development of innovative insulation materials to improve the indoor conditions and isolate from the outdoor changing climatic conditions is necessary. The solutions have to ensure higher insulation with sufficient water vapour permeability, end users' adaptability, lightweight and low environmental impact. Advanced monitoring is needed with an additional focus on the long term performance of the new materials and natural materials. The developed solutions will need a LCA.
- Nature based waste materials to filter and reduce indoor pollution and smell due to cooking, furniture emissions, and pollution from outdoor need to be developed for a higher, effective and low cost indoor air cleaning.
- Active air treatment technologies (e.g. filtering, chemical oxidation with ozone, photocatalysis) need to be studied to allow optimal ventilation schemes both from outdoor to indoor as well as indoor recirculation with cleaning/filtering. These measures also require appropriate monitoring technologies for optimal efficiency in terms of IAQ as well as energy consumption.

Controlling the indoor environment quality:

- The indoor environment quality is strictly connected with the ventilation systems, which also are strictly connected with the thermal conditioning. Furthermore, the thermal conditioning is connected with the human behaviour area. In this field, the research should aim to the development of methodologies and tools for efficient personal comfort systems to complement the central conditioning in indoor environments.
- Self-cleaning capacity: Extensive research and development has been done on TiO₂ based photo catalytic self-cleaning but with varying and usually low success rates in terms of efficiency and cost. Further research is needed on solutions which do effectively work, improve the efficiency, improve the safety and reduce the costs. Further researches should consider not only the improvement of the efficiency, but also the elimination of dangerous intermediates in photocatalytic reactions. In conjunction with Photo-catalysis cleaning strategies, appropriate measurement technologies - id est. sensors/sensor arrays – are

required; besides the individual development of both systems, there is a need for the development of a holistic approach combining them.

- Illumination systems to date are not providing the full daylight spectrum. The increased use of LED's will further worsen this situation. Natural daylighting systems are improving the indoor illumination quality next to saving energy but are to date limited in their application (light pipes, reflectors, etc.) due to the need to have windows nearby or due to the high cost of existing solutions (fibre optic transmission from concentrators). Research is needed on such natural daylighting systems to increase their efficiency and their application potential but also to limit possible harmful parts of the spectrum or discomfort aspects.
- Relative humidity content in the Indoor Environment is a crucial key-factor for comfort and health (e.g. mould). There is a need to develop innovative ambient conditioning systems based on new technologies and materials able to stabilize the desired relative humidity. Innovative solutions will have the potential to penetrate competitive markets such as Europe, Asia and the US.
- Controllable properties in structural materials: While some manufacturers have introduced dynamically changing properties of material (for example glass changing their light transfer spectrum) the domain of controllable properties is quite unexplored, or quite hidden in the research labs of big material or panel manufacturers. The question of measuring flux of any kind (thermal, humidity, air, chemicals), controlling the transfer properties, adsorption properties of smart materials is an open question which may be driven in the near future by M2M revolution. Also active noise camouflage has been explored but combination with tuned noise adsorption can be envisioned (tuned damping material).
- With attention to Cultural Heritage environments, in addition to end users comfort, also "well-being" of objects, collections and surfaces are of interest, including reconciliation of "comfort" between human beings and such objects.

Management, maintenance and monitoring the IEQ:

- During the retrofit of a building it needs to reach the indoor comfort and IAQ levels expected by end-users. It is necessary to establish the most suitable management and maintenance strategies, tools and monitoring the environmental conditions. This includes systems (RFID, BIM, etc.) allowing traceability of products and substances imputed in buildings during entire lifetime.
- Improved energy efficiency – often connected to reduced air exchange rates and increased humidity – could drastically increase the formation of moulds, especially in renovated, retrofitted buildings. Appropriate on-spot measurement or continuous monitoring solutions are required to detect mould formation at an early stage.
- There is a need for controlling the efficiency/impact of ventilation strategies by using distributed air quality sensors based on both VOCs and CO₂ detection principles. The target VOCs should be chosen according to the building use, i.e., schools, offices, etc.
- Forms and origin of dust and particles (e.g. PM10) and their consequences on indoor health should be monitored and investigated. Studies could also address specific living/work environments and public spaces.
- With reference to historic Indoor Environments, but not only, there is a need to analyse the building in a holistic perspective, defining a "model of life" in which are actively combined

technological components and elements of bio-architecture (for minimum intervention and compatibility of materials and measures taken).

- There is a strong need to assess the health implication of indoor generated particles (e.g. secondary organic aerosols) in comparison with ambient particles.
- Measures taken to improve IEQ need to be implemented following a holistic approach and taking into account different aspects such as light, noise, comfort and air quality, among others. The problems related to each aspect have to be measured (advanced sensing systems), the remedial actions implemented (i.e. improved HVAC control), and also the long-term effect of the approaches on citizen's health needs to be addressed. Although many studies about the mentioned problems on people's health have been carried out, the involvement of health experts is important to verify the efficiency of the measures.
- There is a strong need for an integrated understanding of the overall toxicological impact of single as well as mixtures of pollutants (in a cost effective way) in defined scenarios, which also includes comfort and productivity from adverse IEQ and concerted with other risk factors (occupational, environmental, and personal).

Influence of human behaviour and perception on IEQ

- Human behaviour has an important influence on the indoor environment quality together with pollutant's source properties and other attributes such as building characteristics. Behavioural effects are relevant not only during the operational phase but also on the overall life cycle of the building (from the design to the demolition). The research topic in this area should detect which are the main human IEQ impacts in relation to the behaviour and study the occupant and operator behaviours and their impact on IEQ and energy use in different classes of buildings.
- Each indoor microenvironment is unique and is characterized by the outdoor air, the indoor building characteristics and the indoor activities. The human perception of IEQ is subjective and depends on various sensory processes, that is why each person may perceive differently the IEQ of the same environment. Research is needed on the relationship between measured IEQ vs perceived IEQ in respect of comfort, spaces, behaviour, etc.
- There is a strong need for methods to identify adverse odour (IEQ) perception and its implication and impact on health perception and productivity as well as to assess "chemophobia" in view of alleged adverse health effects of selected SVOCs.

Benchmarking and assessment strategies

- Benchmarking and assessment is an important topic. As done for the energy, it is important to develop a procedure to measure progress and identify changes in the indoor environment. Benchmarking and monitoring changes in IEQ offers considerable challenges due to the complexity of the indoor environment and the amount of variables needed to assessing IEQ.
- There is a strong need to develop socio-economic approaches as tools to identify the better solutions to improve IEQ for the stakeholders, particularly the policy makers.

Please consider the following questions, citing any available evidence such as foresight and other assessments of research and innovation trends and market opportunities:

1) What is the biggest challenge in the field concerned which requires immediate action under the next Work Programme? Which related innovation aspects could reach market deployment within 5-7 years?

Biggest challenges:

1. **Impact of material emissions on the Indoor Environment Quality (IEQ).** New Materials for construction, conservation, cleaning, etc. could emit VOCs, especially if they are treated with compounds to meet building requirements (flame retardants, biocides, etc.). This could be a major hindrance for the use of new nature based or recycled materials. There is a need to develop realistic test scenarios and harmonised tests.
2. **Outdoor pollution influences IEQ.** Renaturing cities could lower this impact. There is a need to simulate, model and assess this effect on district level. Advanced approaches and tools for monitoring, air treatment and filtering should be developed.
3. **New control strategies to improve IEQ.** This includes methodologies and tools for efficient personal comfort systems (thermal, moisture, illumination, and noise), reduction of pollutants by advanced self-cleaning capacity and smart materials with controllable properties (adsorption, transport).
4. **Management, maintenance and monitor the IEQ.** There is a need of reliable and diffuse sensing systems for specific pollutants (VOCs, dust, particulates, biological and chemical). This includes new monitoring approaches, according to different perspectives and standardisation of sensor technologies. Assessment of health and toxicological impacts of pollutants (single, mixtures and secondary generated).
5. **Human behaviour and perception** has an important influence on the IEQ together with pollutant's source properties and other attributes such as building characteristics. A special regard should be dedicated to the subjective human IEQ perception comparing with the real IEQ measured.
6. **Benchmarking and assessment strategies** to develop procedures to measure progress and identify changes in IEQ. This includes socio-economic approaches as tools to identify the better solutions to improve IEQ for the stakeholders, particularly the policy makers.

2) What are the key assumptions underpinning the development of these areas (research & innovation, demand side and consumer behaviour, citizens' and civil society's concerns and expectations)?

In developed societies, people spend on average over 90% of their time indoors¹. Therefore indoor environment quality is a major impact factor of the health and comfort situation of people, which influences productivity and wellbeing. The indoor environment quality cluster will develop a roadmap and strategic research agenda to define the needs for research and innovation. The identified research topics mentioned in the first part are the starting point of this development.

¹ De Bruin et al. *Environ SciPoll Res*15 (5), pp. 417-430.

3) What is the output that could be foreseen, what could the impact be, what would success look like, and what are the opportunities for international linkages?

The transfer and implementation of research results into daily practice will boost the related industrial sectors, with a high percentage of innovative SMEs. Improving IEQ is a global challenge; therefore innovative products will be competitive on international markets (e.g. Asia and US).

4) Which are the bottlenecks in addressing these areas, and what are the inherent risks and uncertainties, and how could these be addressed?

The IEQ sector is highly trans-disciplinary from advanced sensing, materials and systems to health assessment as well as behavioural and socio-economic issues. The newly formed IEQ cluster will help to generate a common approach by involving the stakeholders in this sector.

5) Which gaps (science and technology, markets, policy) and potential game changers, including the role of the public sector in accelerating changes, need to be taken into account?

A common EU legislation on IEQ would boost first the research and then implementation of all the proposed technologies.

6) In which areas is the strongest potential to leverage the EU knowledge base for innovation and, in particular, ensure the participation of industry and SMEs?

- 1 To design adequate calls for proposals with the relevant stakeholders and make it attractive for industry and SMEs. Research institutions have proven in the past to be the partners looking strongly for industrial participation and this should be further enhanced.
- 2 Development of sustainable solutions for improving IEQ on the basis of new technologies
- 3 Development of new materials/ technologies/methods for IEQ.

What is the best balance between bottom-up activities and support to key industrial roadmaps?

The IEQ sector is dominated by small and medium enterprises. The use of the HORIZON 2020 SME instrument allows a bottom-up approach for research affine companies in this sector. There is a need to address the IEQ theme in HORIZON 2020 SME calls. Collaborative research of trans-disciplinary partners should support the key industrial roadmaps.

7) Which areas have the most potential to support integrated activities, in particular across the societal challenges and applying key enabling technologies in the societal challenges and vice versa; and cross-cutting activities such as social sciences and humanities, responsible research and innovation including gender aspects, and climate and sustainable development? Which types of interdisciplinary activities will be supported?

The area of IEQ has been funded through various framework programmes. This development should be further enhanced through continuous funding as well as to invest into the younger professionals and experts who are needed for the future. Therefore it is necessary to have also funding schemes for conferences, workshops and advanced training activities.