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SUMMARY
At present, indoor air quality is assessed exclusively by human panels. Because this method is time consuming and cost intensive, little attention is paid to indoor air quality in the planning and operation of buildings. In recent years multi-gas sensor systems have been developed in order to imitate the human sense of smell. These systems comprise an array of gas sensors, with sensors of different sensitivity and selectivity, and a data processing unit. Up to now the sensors have not been sensitive enough to mimic the perception of a human being. Therefore the European research project SysPAQ (Innovative Sensor System for Measuring Perceived Air Quality and Brand Specific Odours) was started in September 2006.

The main goal of this project is to develop an innovative sensor system to measure indoor air quality as it is perceived by humans to be used as a control device for indoor air quality.

KEYWORDS
Perceived air quality, Perceived odour intensity, Profiling, Sensor system

INTRODUCTION
An innovative sensor system to measure perceived indoor air quality and odour intensity is in high demand for European society, as humans spend about 90% of their time indoors, either at work, at home or when commuting between work and home. Recent data show that improved indoor air quality results in fewer complaints, increased comfort, fewer health problems and higher productivity. Consequently, the quality of life is improved.

Up to now, indoor air quality has been quantified by applying three different measurement methods separately. The three methods are based on the human perception of indoor air quality, chemical measurements and sensors for specific odours. Regarding the measurement of perceived air quality, human assessments are still superior to chemical measurements because of the unmatched sensitivity to many odorous indoor air pollutants. One of the reasons is that in most cases the chemical measurements or signals from chemical sensors designed to detect special odours could not be correlated with the assessments made by humans. Obviously they do not measure the relevant indoor air pollutants that trigger human sensory response. The SysPAQ project builds upon current knowledge of the perceptual effects of indoor air pollutants and on the experience gained in using chemical measurements and sensors for specific odours. The approach of the project is to enhance the present state of the art of sensor systems, perceptual methods and software tools for modelling human response, in order to integrate them into a single innovative sensor system for measuring indoor air quality as it is perceived by humans. This would consequently create a bridge between the previous work in this area, and progress is achieved by integrating measurements, sensors and modelling using a holistic approach.

PROJECT OBJECTIVES

The main goal of this project is to develop an innovative sensor system to measure indoor air quality as it is perceived by humans based on perception modelling combining measurements of sensors and assessments of perceived air quality by sensory panels. The innovative sensor system can be used as an indicator, monitor and control device for the indoor air quality in buildings and vehicles. Furthermore, the system will be able to detect brand-specific odours, and it will serve as a novel interior odour design tool for the vehicle industry. The main objectives of the project are:

1. To define a method for measuring the perceived air quality and perceived odour intensity in buildings and vehicles. This method will be used by all different labs using sensory panels.
2. To find an advanced perception model for indoor air assessment. The model will be the major input to the software design for the innovative sensor system, and it will provide new insight into the human reaction towards odours.
3. To develop an innovative sensor system for measuring perceived air quality and brand-specific odours.
4. To calibrate and test the innovative sensor system for measuring perceived air quality and brand-specific odours. The final version of the system is intended for the following applications :
   - Monitoring the ambient air within buildings and vehicles.
   - Monitoring the quality of the inlet air into buildings to ensure the health and comfort of occupants.
   - Labelling emissions from building and vehicles materials.
   - Controlling the production process of building and vehicles materials.

Along with human activities, emissions from building materials, furnishings and equipment are the main contributors to air pollution indoors. Two suggested methods for reducing indoor air pollution are to use low-polluting materials and to increase outdoor air supply rates. The new EU Energy Directive requires substantial reduction of energy use, which may lead to reduction of ventilation rates and increased indoor air pollution, enhancing the need for low-emission materials. In addition to measurements of indoor air quality as perceived by humans, the system developed in the project can be used to control the emission rates from building materials as early as the production stage. At present, manufacturers generally reduce the emissions from building materials by monitoring the emission rates of a few compounds, but these are not necessarily the most relevant odour active compounds for perceived air quality. The pollution mixture affects the perceived air quality indoors. This has not been taken into account so far. The proposed system can be used by the producers of building materials, furnishings and equipment to ensure that the emissions from their products will not negatively affect the perceived air quality indoors. In many countries, labelling systems for building materials exist, so the end-users can select materials that fulfil certain criteria for emissions. The suggested system for measuring the perceived air quality can also be used to assess whether a material can get a label.

The selection of interior materials is a very important factor for the vehicle and transportation industry (trains, cars, boats, airplanes, etc.). The goal of the selection process is to create a high standard of perceived air quality in vehicles combined with a brand-specific odour impression. To meet this goal, a system for measuring perceived air quality seems indispensable.

The interdisciplinary structure of the project consortium will make innovative research possible, and it will provide new insights into the human perception of air quality and brand-specific odours. The project management will ensure a strong interaction between new perception models, hardware development and software design for the innovative sensor system.

APPROACH AND METHODOLOGY

The overall approach of the project and the priorities of the different work packages are shown in Figure 1. The figure illustrates the parallelism of the human perception of air quality and brand-specific odours on the left hand side and the development of the sensor system on the right hand side.

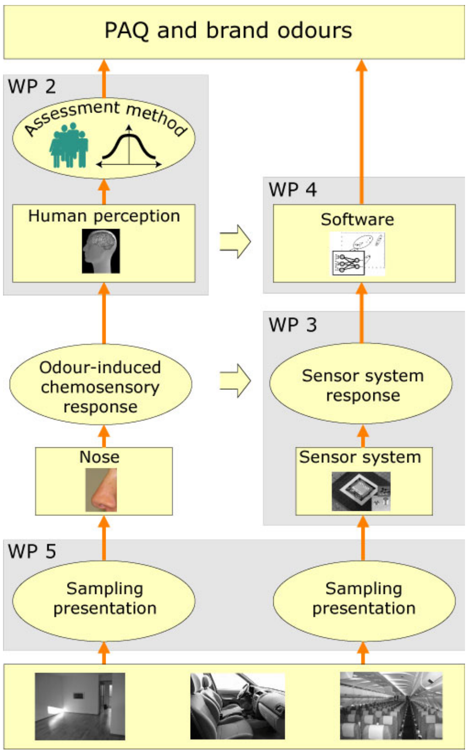

Figure 1. Parallelism of the human perception of air quality and brand specific odours on the left and the sensor system development on the right.

The two arrows in the centre of Figure 1 indicate the coupling of sensory panel experiments and the development of the sensor system hardware and software. The innovative sensor system has to detect all relevant odour active substances. Based on the knowledge of the project partners and experiments of the project, a list of relevant substances is submitted to the two sensor specialists. The second arrow indicates the input of the new perception model of the perception specialist into the software development. The mathematical model of the new software for the sensor system will apply a reference odour system to reproduce an odour space that covers perceived air quality and brand-specific odours in buildings and vehicles.

Work planning

The **human perception** task of the project is mainly handled in WP2. The starting point of WP2 is the definition of a method for all sensory panel assessments of perceived air quality and odour intensity. The method is based on the knowledge of the project partners, who have a great amount of experience with experiments in the field, and the input of new multidimensional psychophysical perception models. This common standard for the assessment method guarantees comparable measurements at all labs for the innovative sensor system calibration data. The second and the most important part of WP2 is the definition of a new odour space based on reference odours. The new odour space has to cover all relevant odours of indoor air environments focusing on materials. All project partners of WP2 have experience with working on the characterisation of odours. The work package leader Karolinska Institute (KI) will provide a human perception model as a theoretical base for the new odour space. Initial experiments by KI will examine the useability of the new odour space based on reference odours to reproduce indoor air odours from building and vehicle environments. The quality of the odour space is the critical factor for the innovative sensor system, and it will influence the software design process. A continuous knowledge transfer between WP2 and WP4 will ensure a fast translation of new findings into the software system.

WP3 covers all activities related to hardware improvements for the **innovative sensor system**. This work package includes the improvement and adaptation of individual multi-gas sensors as well as the combination of different multi-gas sensor technology. The adaptation process and the selection of sensors are based on a literature review and some analysis of the indoor air environment of buildings and vehicles in terms of odour active compounds. The sensor development and sensor combination are handled by two experienced sensor specialists: Alpha MOS and Forschungszentrum Karlsruhe (AM, FZK). The two partners can provide gas chromatography/mass spectrometry combined with sniffer experiments to check the response of the multi gas sensor system to odour relevant substances. Controlling and the minimisation of cross sensitivity (to other chemical compounds, relative humidity and temperature of sample air) of the sensors provides reproducible measurements. The sensor specialists (AM, FZK) manufacture three similar measurement devices for the calibration and validation measurements. The three systems will be jointly used by all partners. Additionally, partners AM und FZK will provide all necessary hardware information and prototypes to partners Centre Scientifique et Technique du Bâtiment (CSTB) and Technical University of Berlin (TUB) to ensure parallel development of the data processing and pattern recognition software (WP4).

The set-up of the general software layout for the **data processing** will be handled in WP4. The work package leader Technical University of Berlin (TUB) contributes many years of experience in pattern recognition methods and software development to calculate the perceived odour intensity based on multi-gas sensor systems. The separation of software and hardware (WP3 and WP4) enables a company to produce independent and extendable mathematical modelling of low-concentration odour mixtures regarding sets of critical odours for building and vehicle materials and products and as well as combinations of the products. The task of the computational data processing is to model the human odour perception of the air samples. The method will consider existing theories of perception and link the measurements with psychophysical aspects of odour sensing. The response values of the sensor device will act as the stimuli, and the software will imitate the human perception and evaluation process. The core of the data processing method will be the “memory”, the calibration database. This database will have a major influence on the performance of the method, especially on the classification of the investigated odour samples. Therefore the data shall span the whole odour space which is developed in WP2. The principle components of this odour space will be the basic odours. The data of the database consist of a combination of sensor response values and air quality assessments according to the methods of WP2 for a specific odour sample and concentration. The database will contain data for different stimuli concentrations for each odour class. The system will be adaptive, which requires the database to be expandable and open for new data from odour investigations. The calculation models will always refer to the current data, and, therefore, the algorithms will be adjusted to the extended data set.

The unknown odour will be positioned inside the odour space, which is a classification process for “odour recognition”. Unknown odours will be expressed as a combination of the basic odours. Once the sample is classified the quantitative and qualitative parameters of the perceived air quality will be estimated. This step of the data processing uses the calibration data of the basic odours, as well as the regression and calculation algorithms for these odours and weighing algorithms which consider the position of the unknown odour sample in the odour space. Data of odour samples other than the basic odours is needed to develop, test and optimise the weighing algorithms and to estimate the perceived air quality of different odours. Most of the odour space and combinations of basic odours will be covered. During the validation process of the software the new collected data will be included into the database which may furthermore improve the performance of the data processing method.

The innovative sensor system has to identify all reference odours and their combinations in indoor environments. Additionally, the system will link the pattern recognition method for the identification process to the sensory panel results. Due to the multidimensional character of the problem, a large amount of effort is necessary to calibrate the innovative sensor system. WP5 handles the **collection of the calibration data**. It consists of simultaneous measurements of perceived air quality and the perceived odour intensity by a sensory panel as well as measurements from the sensor system using the most relevant sensory methods selected in WP2 and the most promising innovative system/technical device selected in WP3. All data from WP5 is employed in the enhancement of the software in WP4. The odours for calibration measurements for WP5 are produced in ventilated emission chambers. The air flow through the chambers is polluted by a series of building and cabin materials. The concentration of air pollutants will be varied within a realistic indoor range to test if the system works properly. The variation in concentration will be achieved by varying the material loading and the ventilation rate and by selecting materials with high and low emisson levels. Measurements will be performed for individual materials in a laboratory setting, for combinations of materials in a full-scale setting, and in real buildings and vehicles. All data from WP5 are stored in a database. A final test run of the innovative sensor system after calibration will show the ability to predict perceived air quality and to characterise brand-specific odours. During the sensor development WP5 will provide preliminary test set-ups of building materials in order to secure reasonable sensitivity and discrimination power of the novel sensor system.

The **dissemination** task of WP6 provides the publication of all project results. The main communication medium of the project is an advanced internet portal that offers a public and a non public information area (www. syspaq.eu). The public area publishes all non confidential findings of the project partners during the lifetime of the project. The non public area handles the data exchange of all project partners. All project-related findings will be open for the public after the completion of the project. The project will provide a final workshop in order to discuss and disseminate all findings of the project. The consortium will prepare a brief project presentation in English which will be written in a style which is accessible to non-specialists, avoiding technical language, mathematical formulae and acronyms as much as possible. Publication will be done via the NEST www page.

RESULTS

First results in WP 2 Sensory assessments

In the SysPAQ project, the perceived odour intensity has to be measured with high accuracy and in a way that allows for comparison. This can only be accomplished by using a set of well-controlled reference odour concentrations. The TUB's method of equal-intensity matching to a number scale of reference odour intensities Müller (2004), involves a constraint in that the participants are taught and trained to use a series of reference concentrations in the assessment of perceived odour intensity. The SysPAQ group have decided to use the intensity method with a comparison scale of an acetone-air mixture.

For the Perceived Air Quality measurements, it has been decided to use an acceptance scale and a profiling list. Context shall be specified as "Imagine that you, during your daily work, would be exposed to the air in this diffuser/room. How acceptable is the air quality?"

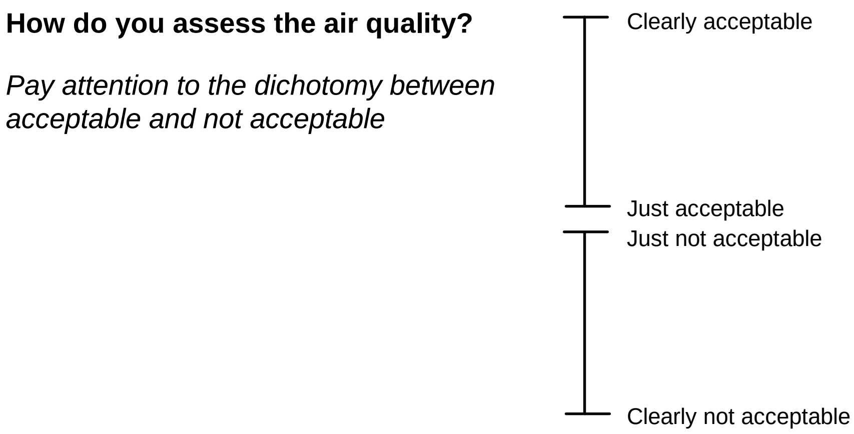

Figure 2. Pair of Visual Analogue Scale (VAS) for evaluating indoor air quality as regards degree of acceptability and non acceptability. (Berglund et al 2007, Dlev. 5).

Ideally, descriptor profiles should be built from 8-10 perceptual-emotional attributes. A sheet with visual analogue scales for each attribute will be prepared. Appropriate context questions have to be developed. The descriptors have to be carefully selected with regard to partner languages, especially Danish and German. The endpoints are marked 0% match and 100% match. The task is formulated as follows:

Instructions: Please consider the attributes one at a time and mark the line that indicates how well the attribute matches the perceived air quality of the exposure (materials emission, indoor air).

Table 1. Possible descriptor list (Berglund et al., 2007).

• Appealing	• Refreshing/Fresh
• Pleasant	• Exciting/Expressive
• Subtle	• Dryness
• Sweet	• Irritating
• Comfortable	• Cool/Cooling
• Interesting	• Flat
• Stale/Stuffy	• Sickly/Nauseous

The scale values of attribute matches (0-100%) provide a characteristic profile for attributes. A correlation matrix is formed from all pairs of profiles. Each profile represents one mixture of emissions (one characteristic indoor air), the correlation matrix can be viewed as a matrix of "similarities".

First results in WP 3 Sensor development

First tests with nano-particle (NP) and nano-wire (NW) sensors have been completed. As shown in Figure 3 the detection limits for an NP – sensor are less than 10 ppb. In contrast, the detection limits for sputtered metal oxide sensors are around 1000 ppb. The main, as yet unsolved, problem of the NP coatings is the instability of the sensor over longer time periods at the operating temperature of about 300°C. Up to now the sensor is only stable for a few weeks.

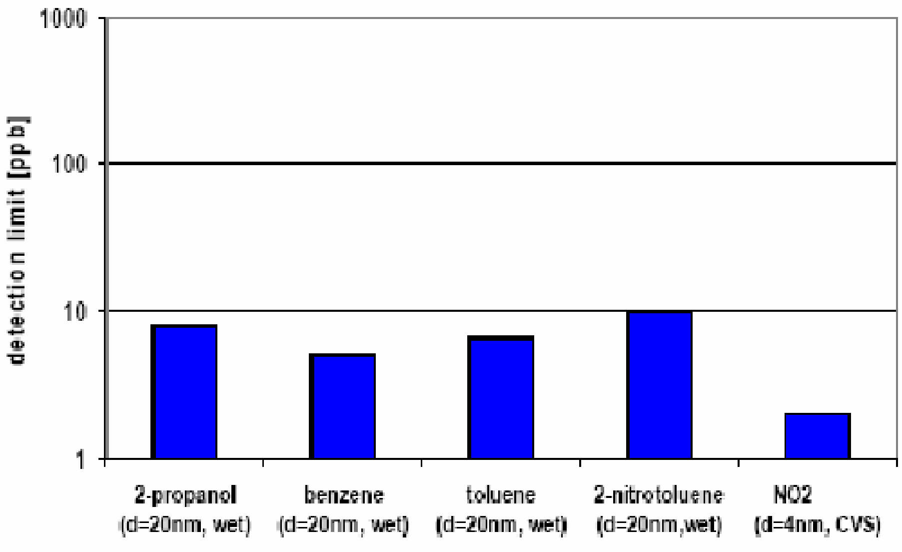

Figure 3. Detection limit for different substances of a nano-particle sensor after fabrication.

The diameter (d) of nano-particles produced by a wet chemical method (wet) was 20 nm, smaller sized nano-particles were achieved by chemical vapour synthesis (CVS).

In Figure 4 the SysPAQ-Box is shown. It is the first prototype of the innovative sensor system which includes two different sensor systems composed of different metal oxide sensors. With this SysPAQ-Box and the new software the first investigations began in April 2008.

Figure 4. The SysPAQ-Box.

DISCUSSION AND CONCLUSIONS

The project SysPAQ has reached the mid-term period. First results from the sensor development are available. The first results with nano-particle sensors and nano-wire sensors are good, but the instability over time has not yet been solved. Different types of sensors have been tested, but the most promising sensors for the project seem to be metal oxide sensors. The KAMINA chip with 38 sensor segments, which is currently in use, was equipped with a sputtered layer of platinum-doped SnO_2 coated with a gas permeable SiO_2 gradient membrane, the thickness of which varied from about 2 nm to 12 nm over the micro array. Results from the SysPAQ-Box are not yet available but the pre-test of the sensors and the software looks good. We are looking forward to the next milestones of the project; the goals of the project are still approachable.

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