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Use of an Electronic Nose for Indoor Air Quality Monitoring

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Indoor air quality is important to occupant health because it affects the health and comfort of occupants. Ventilation is the technique used for regulating indoor air quality. Currently, CO_2 is the pollutant that is taken as the reference to calculate the makeup air rate and recirculation air rate of indoor spaces. Indeed, the quality of indoor air is affected by all microclimate components of the environment, concentration of odours and toxic materials, number of aerosols and microbes in the air, contamination by radioactive gases, static electricity etc. Regarding air quality, pleasant or unpleasant odours dominate the perception of the environment by the occupant and, among other pollutants that may be present in indoor environments, odour has been considered as one of the causes of different symptoms of the Sick Building Syndrome. This paper discusses the laboratory and indoor field tests conducted measuring both CO_2 and odour in order to compare the concentration trends of these two parameters. The indoor air monitoring trial was conducted for a three month period in a university room used by students as a break room. Moreover, the performance of an innovative electronic nose, designed specifically for indoor applications (EOS 101), was evaluated. The tests prove the simplified electronic nose EOS 101 to be effective in the detection of odours in an indoor environment.

1. Introduction

Nowadays people spend more than 80% (90% in industrial countries) of their time indoors (Arnold et al., 2002; Herberger et al., 2010). As a consequence, there is a growing incidence of a new kind of disease related to bad indoor air quality, identified as building-related illnesses (BRI) and sick building syndromes (SBS) (Zampolli et al., 2004). High occupancy, human activities, accidental events or pollutant coming in from outside can affect indoor environment by changing air composition and thus worsening the living conditions. Chemical contaminants and gaseous compounds are held responsible for both the BRI and SBS disease, since in buildings with limited natural ventilation (Batog and Badura, 2013) and without a demand-controlled ventilation they can accumulate with time (Zampolli et al., 2004). For this reason, there is an increasing interest in indoor air quality (IAQ) monitoring in order to improve our lives, reducing the causes of these illnesses, and to devise energy-efficient ventilation strategies. More than 40% of primary energy in Europe is consumed in buildings to ensure better indoor conditions for all the occupants, especially for heating, cooling and ventilation (Herberger et al., 2010).
Current systems used for indoor environmental monitoring are based on temperature, humidity and carbon dioxide (CO_2) concentration measurements. CO_2 concentration can be easily considered as an indicator for bad air quality caused by humans (Herberger et al., 2010; Batog and Badura, 2013), since both CO_2 and bio effluents emissions depend on human metabolism and activities. ANSI/ASHRAE Standard 62-2001 states that comfort criteria with respect to human bio effluents like odours are fulfilled if the ventilation ensures a CO_2 concentration less than 700 ppm above the outdoor concentration (Batog and Badura,

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2013). CO_2 concentration is also taken as the reference parameter in other standards and guidelines about ventilation and indoor air quality, such as the European Standard EN 13779, EN 15251 and German norm DIN 1946-2, which recommends keeping indoor CO_2 concentration below 1000 ppm (Herberger et al., 2010; Batog and Badura, 2013).
However the common experience shows that our indoor air quality judgment is closely related to olfactory perceptions. In general, people may be negatively affected by the presence of annoying or pungent odours, such as sweat, cosmetics or smoke in offices, meeting rooms, dwellings or in any other indoor environment. The most widely used technique to evaluate odours are sensorial techniques relying on the use of a human sensory panel. However, these methods are generally time consuming and cost-intensive so they are not suitable for continuous measurements (Herberger et al., 2010; Bitter et al., 2010). The drawbacks of sensorial analyses could possibly be overcome by the use of an "electronic nose". For this reason, this study investigates the possibility to use electronic noses for indoor air quality monitoring.

2. State-of-the-art

There are different studies regarding the possibility to replicate the human sense of smell by means of a compact and cheap device for indoor pollutants detection and quantification. Among those, electronic noses, composed by an array of gas sensors and pattern recognition techniques to detect and recognize odours, which were first be fabricated in the 1980s (Loufti and Coradeschi, 2008). Over these three decades, various studies have identified some important applications of electronic noses for the monitoring of different kind of indoor pollutants and odour sources.
VOCs produced by human metabolic processes and activities, which are detected in different indoor environments thus representing the main class of substances responsible for odours perceived from the occupants, could be monitored using electronic noses. Several researches used MOS (Metal Oxide Semiconductor) gas sensors for the identification and quantification of some of these compounds, such as acetone, ethanol, isoprene, nonanal, decanal and α-pinene connected to respiration and transpiration of skin and exhaled air, as well as limonene and eucalyptol attributed to cosmetics. Different real-life tests were carried out to show how during everyday situations like in a kitchen, a meeting room and a gym, these compounds may affect the indoor environment and worsen indoor air quality, even if the CO_2 concentration does not exceed the threshold limit (Herberger et al., 2010).
Some researchers proved the possibility to use an electronic nose for VOC detection and measurement at concentration levels that are typical of indoor environments with a 95% confidence interval. The tested devices are capable of differentiating and quantifying only those VOCs for which they had been calibrated. The necessity to calibrate each array of the device for a significant number of compounds means high costs and long time required, thus the impossibility of developing a low-cost instrument (Wolfrum et al., 2006).
As far as human activities are concerned, recent studies show the integration of electronic noses with other sensors on intelligent platforms in order to create a robot capable to identify odour sources. This device could be used as a home-care robot for elderly capable of recognizing for instance damaged foods as well as hazardous environmental conditions (Loufti and Coradeschi, 2008).
A second variety of indoor contaminants analysed by means of electronic noses are pollutants from building materials.
New home furnishings have a characteristic smell, likeable for some, for others extremely pungent. For indoor air quality monitoring purposes emissions from building materials are often considered as a constant background level (Herberger et al., 2010) but they should be considered with more accuracy because some of these compounds, like formaldehyde, are known to be toxic, allergenic or even carcinogenic. Some experimentations showed the ability of electronic noses to perceive odour emissions from several building products, like acrylic and silicon sealant, wood glaze, floor adhesive, wall paint and OBS (oriented strand board) with good accuracy that may also be increased by collecting more data (Bitter et al., 2010).
Another odour source and even possible cause of sickness connected with bad indoor environment is fungal contamination. In addition to air contaminants also moisture damage and subsequent fungal contamination, potentially causing allergies, irritations and odour nuisance, must be controlled to ensure healthy indoor conditions. An electronic nose was used in numerous researches for detection and classification of different fungal species especially in food industries, however the most important indoor application is the ability of this device to realize a rapid and non-costly detection of the presence of fungi in buildings and the resulting worsening of the indoor environment (Kuske et al., 2005).

A further interesting application of electronic noses in indoor monitoring concerns environmental safety. Several studies in this field are focused on the capacity of the instrument to quantify several extremely toxic by-products of combustion, such as carbon monoxide and nitrogen dioxide, considered as possibly indoor chemical contaminants, despite the presence of other substances considered as interfering species like VOCs and humidity (Zampolli et al., 2004).
Another study focuses on a commercial sensor used for CO detection in indoor environment with the additional purpose of developing a low size and power consumption (around 250mW) device that could be used in portable detectors (Burresi et al., 2005).
Within the indoor safety, also the possibility of using electronic noses as early fire detectors has been demonstrated. A study by Arnold et al. (2002) shows how this device was not only proved capable of identifying and quantifying toxic substances connected with combustion, analysed previously in this paper, but also detecting the presence of overheated wires by their typical gas release long before smoke emission could be observed and then prevent the risk of fire.
Additionally, in-car air quality monitoring and security are other useful applications of electronic noses. Such restricted indoor environment should be continuously monitored because bad air conditions or the presence of pollutants could affects the health of passengers and may cause driver distraction and accidents. For this purpose, in a study by Tian et al. (2012), a self-made, cost-effective and portable electronic nose able to quantify different indoor/in-car harmful gases like formaldehyde, benzene, CO, NO_2 and toluene was studied, whereby the novelty of this device is that the pattern recognition, which usually require a PC, was embedded into the electronic nose system creating a smaller, cheaper and less power-consuming system.

3. Materials and Methods

3.1 Aims of the work

The tests have been conducted in order to monitor the indoor air quality of an university room (cafeteria), used both as a lunchroom/cafe and a place for studying. An electronic nose EOS 101 (Figure 1) and a CO_2 analyser were used in parallel for this purpose.

3.2 The EOS 101 electronic nose

An electronic nose for indoor odour monitoring should ideally be a small and cheap object, in order to make it suitable for the integration in aeration systems such as air conditioning units.
For this reason, recent researches in this field have led to the development of a simplified electronic nose (EOS 101, Figure 1), not very expensive and small sized, to be used in indoor environments to determine the presence/absence of odours. The EOS 101 is equipped with a reduced sensors array, composed by three MOS sensors. The sensors are calibrated with a reference substance before their installation inside the instrument. Only one feature is calculated for each sensor: the EOS Unit (E.U.)

Figure 1 The EOS 101 Electronic Nose

The EOS 101 electronic nose has two inlets: one for the “reference” air, which is used to restore the baseline, and one for the sample inlet. The EOS 101 is not equipped with a system for neutral air generation; as a consequence, the reference air has to be provided connecting the inlet to a source of neutral air, as for instance an air bottle, or a filtration system. Moreover, the instrument isn't equipped with a specific humidity regulator that directly modifies the sample air humidity. For this reason, a software compensation of the sensor responses has been introduced, which is considered to be sufficient for indoor applications, where humidity variations are expected to have a lower extent than those that typically occur outdoor.

The EOS 101 has been developed in order to just determine the presence/absence of odours, without classifying the detected odours. For this reason, the instrument is not designed for the classification of the analysed air. The instrument analyses the indoor air continuously, recording the E.U. and the variations of resistance (R_i) relevant to each sensor every second.

If the E.U. of at least one sensor is major than a so-called "threshold", set by the operator, the instrument displays the presence of odour. As the output of the instrument is the exceeding of the set "threshold" value, the definition of this threshold is a critical aspect for the instrument functioning, in order to optimize the correspondence between the instrument responses and the real conditions of odour perception.

A value of 6 E.U. was set as "threshold" based on the results of previous studies, which proved that this is the value for which the instrument is able to detect the presence of odour at the same concentration perceived by human smell.

The EOS 101, like other commercial electronic noses, needs to periodically reset the E.U. to zero during the monitoring in order to realize its reference condition.

For this purpose, after each week of the monitoring trial, the instrument has been re-calibrated with n-butanol, and the E.U. set back to zero. The reference air to be connected to the EOS 101 has been obtained by taking neutral air from a compressor and stored in a bag of Nalophan^{TM} for a sufficient time to re-equilibrate the humidity to the level of the external environment.

3.3 Indoor Tests

The indoor environment monitored is a "cafeteria" used both as a lunchroom/coffee room and a study room for students. The instrument was placed in an adjacent room and connected to the cafeteria using a Teflon pipe through a hole in the wall. The air of the cafeteria was then aspirated and analysed continuously. The aspired air was monitored both by EOS 101 and a CO_2 analyser. Moreover, the number of occupants of the monitored room was counted and registered every hour, and the main activity that was taking place (study or lunch) was registered, as well.

The monitoring data were processed based on the resistances of the sensors. The resistances registers by each sensor (R_i) are normalized with respect to the base line resistance (R_0). The R_i/R_0 trends over time are reported in the Results section (Figure 2). The ratio R_i/R_0 was preferred as a feature to the E.U. because it allows a more immediate identification of anomalous trends.

4. Results and discussion

Table 1 reports the average number of occupants in function of the time of the day, obtained by averaging the number of occupants counted throughout the monitoring period from December 2013 to February 2014. Moreover, Table 1 also shows the main activity that was taking place in the cafeteria during the observation period.

Table 1 Average people present in the cafeteria and their activity

Time	Average People	Activity
8:30		-
9:30	3	Study
10:30	9	Study
11:30	13	Study
12:30	25	Lunch-Study
13:30	28	Lunch-Study
14:30	10	Lunch-Study
15:30	8	Study
16:30	8	Study
17:30	7	Study
18:30	4	Study

Figure 2 shows some extracts of the monitoring results, by reporting the trends of the sensor responses (R_i/R_0) of the electronic nose EOS 101. The lower line reported in the graph indicates the trends of the CO_2 concentration. It is possible to observe that both odour and CO_2 concentration peaks occur concomitantly with lunch times. During these hours the cafeteria is more populated (see Table 1), thus the CO_2 concentration is higher. In addition, the main activity during this time is related to the lunch: students who gather in the room usually use the microwave to heat their food, therefore releasing odours that are detected by the electronic nose.

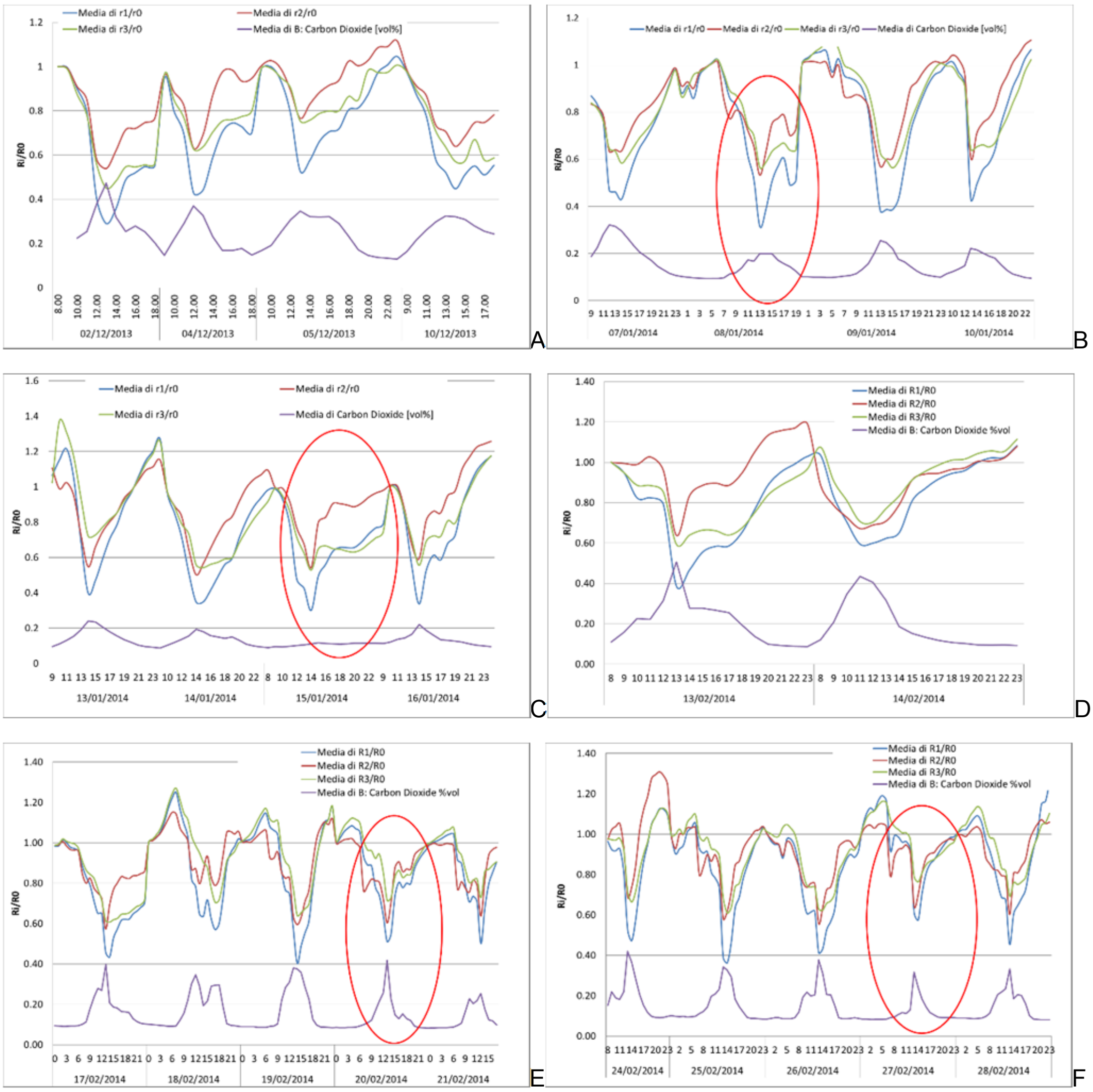

Figure 2. Trends of the electronic nose responses and CO_2 concentration

From the above reported values it is interesting to observe the trends of the days 8 January (Figure 2B), 15 January (Figure 2C), 20 February (Figure 2E) and 27 February (Figure 2F). During the afternoon of January 8 (Figure 2B) an odour peak is observed. It was due to a party that took place in the cafeteria. However, the CO_2 concentration measured was rather low, as there weren't many people inside the room.

On January 15 (Figure 2C), the CO_2 concentration measured was low because the door of the monitored room was kept open, in order to facilitate the circulation of the air. The electronic nose has, however, revealed the presence of odours, especially during the lunchtime (12-14).

Lastly, on February 20 (Figure 2E) and February 27 (Figure 2F) at 7:00, the electronic nose detected an odour peak, which was related to the extraordinary cleaning of the cafeteria.
These observations point out that a monitoring system that is solely based on CO_2 and temperature detectors might not be sufficient for indoor air monitoring purposes, proving that there might be situations where odours can be perceived intensely while the CO_2 concentration remains low. An electronic nose integrated with the indoor air quality monitoring system could allow to activate air recycling in such cases.

5. Conclusions

The above reported results prove that the electronic nose is able to monitor the air quality and detect the odours related to the activity performed in the monitored room.
In the future, a simplified nose like the EOS 101 could be integrated in air monitoring and air recycling systems, allowing a more efficient control of indoor air quality, not solely based on CO_2 concentration and temperature control, which this study proved not to be sufficient in order to account also for the presence of odours in indoor environments.

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