

A Versatile System for Indoor Monitoring of Some Volatile Organic Compounds

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The paper presents a versatile system for assessing the conditions that may lead to acute intoxications or chronic illnesses caused by indoor acute or chronic exposures to volatile organic compounds. The method may provide valuable information related to the individual or overall concentration for a certain or more than one compounds, as well as a track record of this concentration versus time for further references.

Keywords: volatile organic compounds, indoor pollution, monitoring system

The rapid development of substances based on volatile organic compounds, along with the long-time period people tend to spend in the indoor environment, led to an increase of negative health effects, including respiratory and cardiovascular medical issues, changes in lung function, asthma attacks, immunological and endocrine issues, cancer and early mortality [1]. Cancer and non-cancer health impacts associated with environmental exposures to volatile organic compounds (VOC) require the development of reliable risk assessment methodologies in order to estimate the environmental health risks [2, 3].

Volatile organic compounds are considered among the most dangerous indoor pollutants because of their diffusion properties and their continuous emission from many sources, predominantly from organic compounds and chlorinated and non-chlorinated solvents [4, 5]. The absence of an efficient ventilation system, along with the increased use of synthetic materials in buildings, resulted in increasing medical issues caused by allergens, carcinogens, neurotoxins, immunotoxins or highly irritants originating from VOC [6].

Some of the main sources of VOC associated to the indoor pollutions are as follows: human activities inside buildings using VOC based compounds, emissions from building materials containing VOC compounds and the contaminated air from outside introduced inside the buildings through ventilation processes, the pollutant concentration depending largely on the location, construction materials, and the activities that occur inside [7-10].

While some specific outdoor sources may also lead to high concentrations of VOC into the indoor air environment: landfill generated gases from oil and petroleum based products contamination, automotive and aircraft emissions [11], one may also trace other sources of VOC indoor pollution generated by the use of household cleaning products, cosmetics, deodorants, perfumes and even smoking by-products [12] so that by determining the overall concentration of VOC is particularly important in assessing the indoor air quality, in order to use it as an adequate descriptor in characterizing the anthropogenic pollution [13], the health condition being directly dependent on both the exposure to pollutant concentrations and the length of exposure, the long-term exposures having a larger, more

persistent cumulative effect than the short-term exposures [4].

In a normal monitoring process, a lot of difficulties may occur in data collection and evaluation when the volatile pollutant concentration value is recorded at a high level but below the critical admissible limit or in cases of a simultaneous occurrence of contaminants at sub-toxic concentrations [13]. A weakness in indoor air quality research is represented by insufficient data available on the sensory effects of VOC mixtures and, for some individual compounds, where little toxicological knowledge is available. Safety standards rarely take into account the occurrence of chronic or carcinogenic diseases at their face value, based on long-term action of certain volatile pollutants on human health; this is why the environmental sampling and analysis is a key factor in identifying dangerous agents in order to predict their concentrations and distributions and minimize workers exposure [14].

Chronical illnesses could be prevented by monitoring the air quality conditions using distributed smart sensing systems, characterized by accuracy, short time response, and robustness, as well as by data processing, data logging and data communication capabilities [15].

Studies concerning the detection of valid biological evidence for toxic and/or carcinogen potential of the substances, according to International Agency for Research on Cancer test guidelines and standard protocols are aimed on investigating of several standard criteria such as: acute toxicity, sub-chronic toxicity, chronic toxicity, reproductive toxicity studies, developmental toxicity and genotoxicity studies. There are several databases, such as IRIS, (Integrated Risk Information System), a true human health assessment program that evaluates information on health effects which may result from exposure to environmental contaminants, considering a whole range of substance reference doses and inhalation reference concentrations for highlighting the potential cancerous effects known or presumed to be produced.

A risk assessment procedure is a process of estimating the potential impact of a chemical, physical, microbiological or psychosocial hazard on a specified human population, under a specific set of conditions and for a certain timeframe, and the level of risk can be described either qualitatively or quantitatively [2]. Cumulative risk

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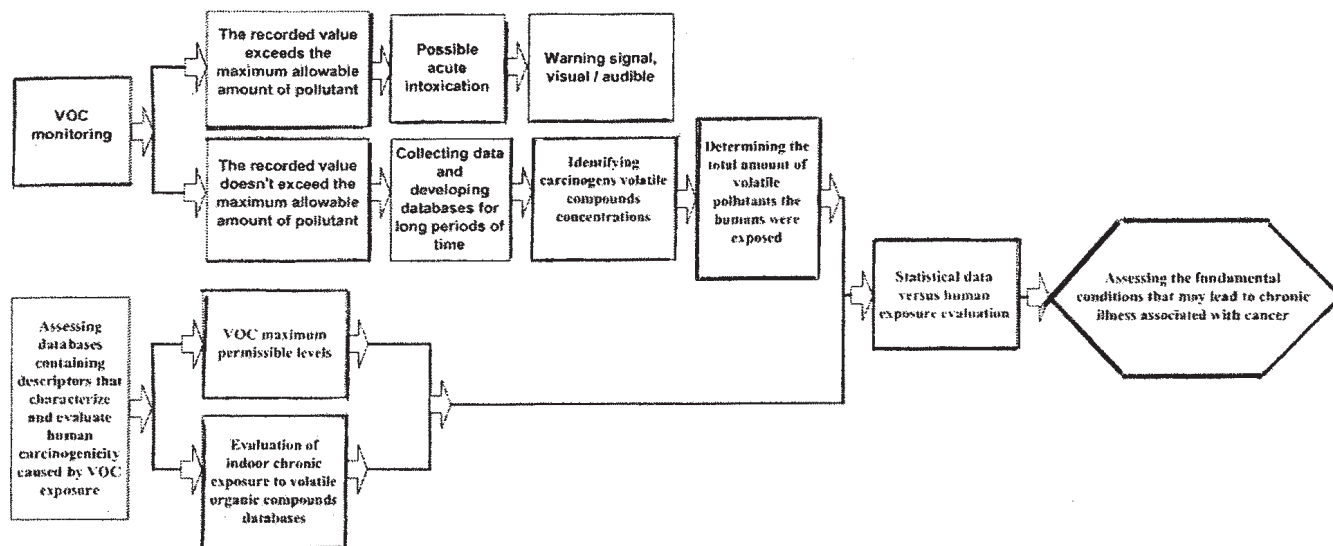


Fig. 1. Method for assessing the fundamental conditions that may lead to chronic illness associated with cancer, caused by indoor chronic exposure to volatile organic compounds

assessments are more difficult to achieve being highly dependent on toxicology information about each of the various toxic substances and exposure pathways. If toxicology information is not present, then the evaluation cannot be credibly completed. A major weakness of present risk assessment methods consist in inaccurate quantitative estimations regarding the low levels of exposure [16], therefore the use of additional mathematical models for the environmental health risk assessment can significantly improve the estimations regarding potential carcinogenic health effects due to prolonged exposure to hazardous volatile compounds.

According to US EPA (United States Environmental Protection Agency), a proper evaluation of the risk assessments include a hazard identification to determine the potential adverse health effects based on an epidemiological, clinical, toxicological, and environmental evaluation, a dose response assessment, an exposure assessment and the risk characterization.

One important issue considered when modelling the results is the interactions between the physical, chemical, biological and social hazards which need to be identified as part of the risk assessment is the potential types of interactions between agents that might be additive, synergistic, potentiation and antagonistic [17-19].

Experimental part

The scope of this paper was to manufacture a versatile system for measuring and monitoring the indoor concentration of some VOC and to find a series of correlations between the sensor response signal and the monitored VOC concentrations.

Once the system is constructed and calibrated, it may also be associated with various predictive models, based on certain descriptors, to characterize and evaluate the carcinogenicity caused by VOC, in order to generate automatically a set of scenarios related to the level of exposure consequences and allowing later on estimations of the potential adverse health effects (a representative example is depicted in fig. 1).

The system used for evaluating VOC concentrations (fig. 2) consisted of a Kemo B051 / V003 gas sensor (Germany) fitted on a pcb (printed circuit board) electronic interface containing also a relay for triggering an alarm, the system

being connected to a data acquisition system, namely USB DataLogger EI-USB-3 (Great Britain), as seen in figure 3. After the recording, the data package is transmitted to a computer via the EasyLog USB software and processed as excel or ASCII database.

The actual VOC sensor (1) from figure 2 is powered either by the normal power supply or by a back-up sealed lead acid rechargeable battery (2), which ensures its autonomy in case of a power failure, the sensor being equipped with a light and sound warning system (3). The system was designed with the possibility of an offset calibration knob, using a dedicated precision adjusting potentiometer (4). The difficulties in positioning the sensor so that it will relate to the correct amount of pollutants is

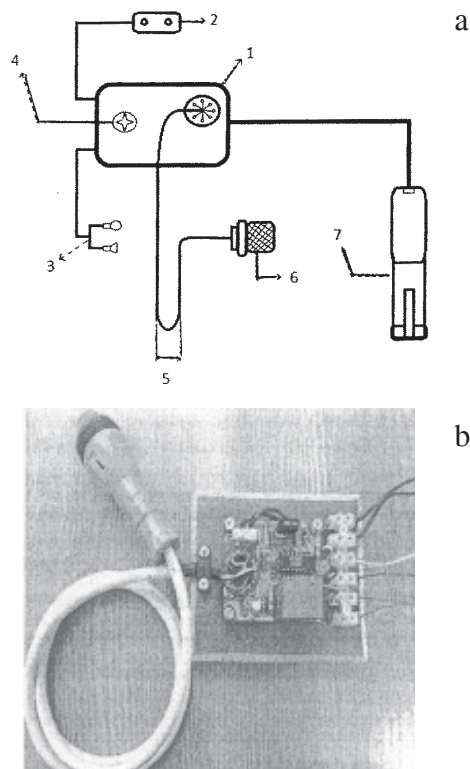


Fig. 2. Schematic diagram (a) and a photography (b) of the sensor pcb layout (not at real size) for monitoring the VOC

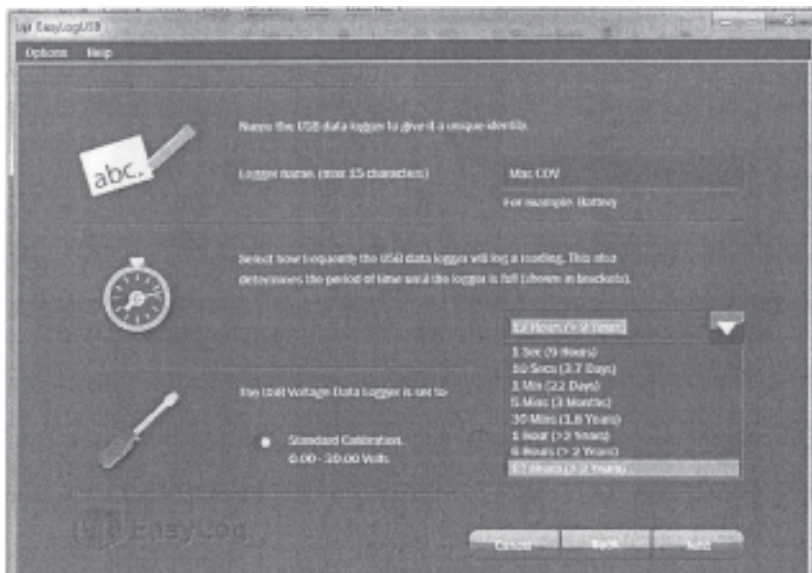


Fig. 3. EasyLog data acquisition software, setting the sampling rate

solved by extending the cable (5), so that the tip of the sensor (6) is brought closer to the point or area where the pollutant concentration is presumed to be at the highest level, allowing the operator to decide on a particular spot without the need to relocate the whole system. The data acquisition process is performed using an USB DataLogger (7), this device being able to operate continuously for over two years, depending on its initial configuration.

After determining the volatile compounds concentrations, the data package is automatically compared with the maximum permissible limits or thresholds and should the case arise when the measured values exceed these limits, the system automatically triggers the acoustic and the visual alarms signalling a possible acute intoxication. If the maximum permissible doses are not exceeded, the measured values are automatically recorded as chronographic reference measured values for further processing and considerations for chronic intoxications.

Figure 3 illustrates an example for data acquisition once every 12 h. For shorter time periods one may opt for an increased data sampling.

When the monitoring period ends, the data acquisition system uses the USB computer link to upload the recorded data as excel, ASCII or text database and transmits it to a designated server for storage or for further processing. These databases may provide information related to the VOC exceeding the maximum permissible levels and the total amount of volatile pollutants the humans were exposed during the considered period. By using the statistical data and analysing the available risk assessment reports on the basis of the maximum acceptable intake values a human can absorb either in a single day or in his entire life without experiencing any chronic effects, one can make an assessment of the considered risk based on actual measurements rather than on estimated concentrations.

Results and discussions

A particular problem encountered in classic system is the fixed position of sensors (e.g. the smoke or methane sensors) such devices being mounted in the upper side of the room, where the pollutants dispersion determines a lower reading for the measured values, especially if the air conditioning or ventilation systems are located near the sensor. This issue was sorted out using an extension cable, with the tip of the sensor closer to the area where the

pollutant concentration was measured, allowing relocation at will with minimum efforts.

Another drawback of such sensors is their non-linear calibration relationship, being very difficult to achieve it by non-experts, and difficult to perform it, especially if they are mounted in the upper side of the room. The proposed sensor has the advantage that is mobile and once a calibration relationship has been established it may be calibrated easily by anyone, for any particular VOC of interest. In figure 4 is presented the variation of the sensor output response versus time for known incremental concentrations of benzene. The response signal from figure 4 is then fitted to a regression equation (fig. 5) that corresponds to a modified Morgan-Mercer-Flodin (MMF) model, and these calibration curves may be used later on for direct determinations of the considered VOC concentrations. Similar calibrations were carried out for acetone, benzene, commercial thinner, commercial gasoline fuel, dichloroethane, anhydrous ethyl ether, methylene chloride, toluene, hexane, and dichloro benzene and the results are presented in table 1. As one can see from table 1, the modified MMF model fits very well all the considered VOC, the correlation coefficients being above 0.99 in all cases.

Once the calibration is carried out, the system may be put to work and one may now corroborate the actual measured values with the ones presented in table 2 and may easily calculate the total intake of a certain person who was exposed for a given time in the contaminated atmosphere and one may now decide if that person should be replaced or withdrawn from that location.

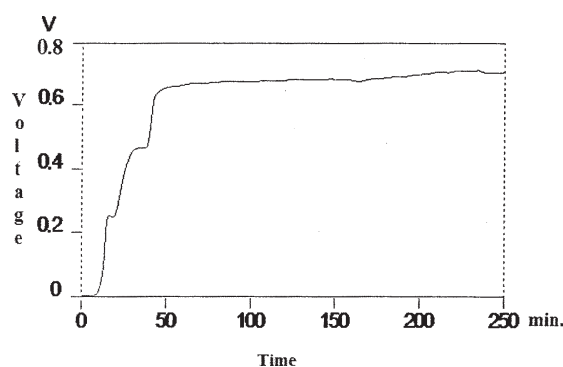


Fig. 4. The variation of the response signal versus time for benzene

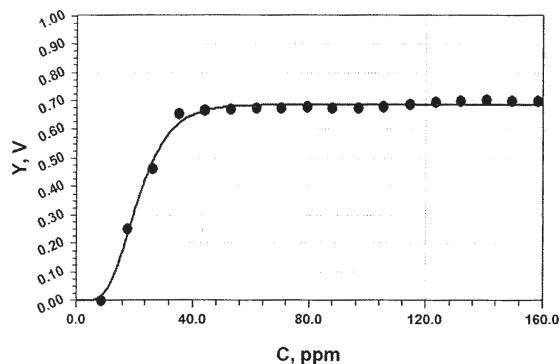


Fig. 5. The dependence of the response signal versus the VOC concentration (Y, sensor response, (V) versus C, concentration of VOC, ($\mu\text{L VOC} / \text{L air}$))

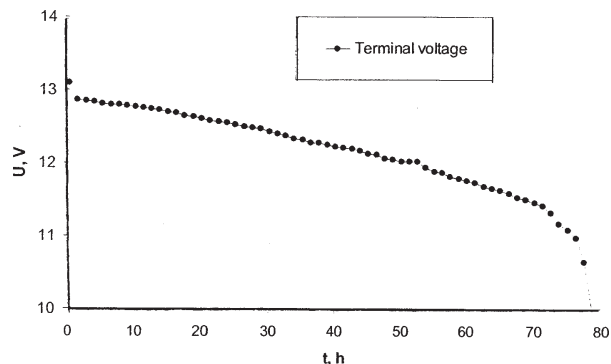


Fig. 6. The autonomy of the back-up battery calculated for a 0.4 A discharge current

Table 1

SENSOR CALIBRATION EQUATIONS (Y, SENSOR RESPONSE, (V) VERSUS C, CONCENTRATION OF VOC, ($\mu\text{L VOC} / \text{L AIR}$))

VOC	Calibration equation	Correlation Coefficient
Acetone	$Y = \frac{-87.06 + 0.73 \cdot C^{2.96}}{10673.77 + C^{2.96}}$	0.995
Benzene	$Y = \frac{-1087.97 + 0.69 \cdot C^{3.89}}{126486.69 + C^{3.89}}$	0.996
Thinner D506	$Y = \frac{-30.55 + 0.78 \cdot C^{1.69}}{29.94 + C^{1.69}}$	0.991
Gasoline	$Y = \frac{-120.87 + 0.69 \cdot C^{2.61}}{71.55 + C^{2.61}}$	0.997
Dichloro ethane	$Y = \frac{-5.51 + 0.75 \cdot C^{0.81}}{0.43 + C^{0.81}}$	0.997
Anhydrous ethyl ether	$Y = \frac{-3457.69 + 0.76 \cdot C^{4.37}}{64883.84 + C^{4.37}}$	0.996
Methylene chloride	$Y = \frac{-5.84 + 0.69 \cdot C^{0.83}}{5.23 + C^{0.83}}$	0.993
Toluene	$Y = \frac{-45.95 + 0.72 \cdot C^{1.94}}{28.99 + C^{1.94}}$	0.992
Hexane	$Y = \frac{-127.77 + 0.71 \cdot C^{2.99}}{4044.76 + C^{2.99}}$	0.992
Dichloro benzene	$Y = \frac{-33.95 + 0.37 \cdot C^{1.68}}{3.36 + C^{1.68}}$	0.999

Table 2

IDLH THRESHOLDS FOR MONITORED VOC [20, 21]

VOC	Immediately Dangerous to Life or Health concentration (IDLH) ppm ($\mu\text{L VOC/L air}$)
Acetone	2500
Benzene	500
Thinner D506	100
Gasoline	500
Dichloro ethane	50
Anhydrous ethyl ether	1900
Methylene chloride	2300
Toluene	500

The system autonomy is particularly important in cases of electrical grid failure, the system being provided with a back-up sealed lead acid rechargeable battery of 34Ah capacity. Depending on the operation mode, one has assessed the autonomous operation time versus the power drawn from the back-up system. If the main power supply is interrupted for any reasons, the monitoring system may be powered by this back-up rechargeable battery for more than 3 days (78 h – fig. 6, the theoretical value given from the battery capacity being of 85 h around 0.4 A). However, if one may consider this system for powering also the portable computer and the transmission module is also activated, (via a 12 V D.C. – 220 V A.C. inverter, drawing a cumulated current of 4.5 A) it is still able to continue the monitoring of the volatile pollutants for at least 6 h (the theoretical value being 7 h and 30 min), offering enough time for mending and restoring the main power.

Conclusions

The manufactured system has proven to be effective in monitoring some VOC, despite the low investment cost (around 400 Euros, excluding the portable computer) being

able to reveal not only the concentration of VOC at a given moment in time or when it goes above the maximum limit, but also its variation in time, recording and storing the data for further references. The proposed monitoring system may be a useful tool to design and build proper ventilation systems inside the workspace when working with hazardous volatile organic compounds.

The system has a high degree of versatility being able to monitor a large number of volatile compounds and by setting the alarm trigger value to a limit below the maximum limit, one may send a warning signal when the pollutant concentration becomes dangerous close to the threshold value. It may be easily placed in any room intended for storage of hazardous substances to monitor and to keep track of the VOC emissions versus time.

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