

Evaluation of Indoor Air Quality on the Basis of Measurements of VOC Concentrations

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Measurement of concentrations levels of volatile organic compounds (VOC) such as benzene, toluene, butyl acetate, ethylbenzene, *m*-xylene, styrene and *m*-dichlorobenzene was carried out in three newly erected and remodelled dwellings in Tricity area. To collect the series of air samples the active and passive methods were used. In both cases activated charcoal was applied as a sorption medium. The samples were liberated by solvent extraction, and analyzed by capillary column gas chromatography, employing a flame ionisation detector. The study also attempted to examine the time dependence of concentrations of selected VOC in each investigated dwelling. This was accomplished by at least triplicate measurements of the IAQ. The experimental results showed that values for analyzed VOC were exceeded (even a few orders of magnitude) for the measurements made before inhabiting of the occupants, in every investigated dwelling. The concentrations of the investigated VOC decreased significantly with time, which should be expected, although in some cases the levels of selected VOC remained still high. Our experience indicates that application of two different indoor air sampling techniques to determine analytes of interest, though more laborious and time consuming, can lead to significant conclusions concerning indoor air quality.

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Jakość powietrza wewnętrznego badano w trzech nowowytbudowanych i wyremontowanych pomieszczeniach mieszkalnych położonych na terenie Trójmiasta. Oceny jakości powietrza dokonano na podstawie pomiarów poziomów stężeń wybranych lotnych związków organicznych, takich jak: benzen, toluen, octan butylu, etylobenzen, *m*-ksylen, styren i *m*-dichlorobenzen. Próbkę powietrza pobierano wykorzystując dwie różne techniki izolacji i wzbogacania analitów z medium gazowego – technikę pasywną i technikę dynamiczną. Jako medium sorpcyjne, w obydwu przypadkach, stosowano węgiel aktywny. Analizy wykonywano za pomocą kapilarniej chromatografii gazowej. Celem przeprowadzonych badań było również określenie wpływu czasu eksploatacji mieszkań na poziom stężeń monitorowanych lotnych związków organicznych. Dokonano tego na podstawie trzykrotnych pomiarów jakości powietrza wewnętrznego. Na podstawie otrzymanych wyników stwierdzono, że wyznaczone, w pomieszczeniach przed zasiedleniem, wartości stężeń badanych związków przekraczały (znacznie) wartości stężeń dopuszczalnych. Wyniki badań wykazują, że stosowanie dwóch technik pobierania próbek z powietrza wewnętrznego w celu oznaczenia analitów może stanowić podstawę do wysuwania pogłębionych wniosków co do jakości powietrza.

Researches indicates that people spend 60–80 % of their time indoors, which is why the quality of indoor air should be one of most important factors that has to be taken into consideration when assessing human exposure to hazardous air pollution.

Evaluation of the indoor air pollution problem requires an understanding of several factors, including [1,2]: the source of the indoor pollutants; emission characteristics of the source; air exchange between the building and the outside; air movement within the building; interaction of the pollutant with surface within the building (*i.e.* sink effects) and; chemical and physical interactions affecting the pollutant concentration.

Volatile organic compounds (VOC) are emitted to indoor environment by outdoor air pollution sources as well as by humans, by many natural materials and, most importantly, by a large number of man-made building materials, furnishing and equipment used in buildings [3]. The VOC detectable in a given building may consist of hundreds of different organic compounds, which makes analysis, risk assessment (including combined effect) and guideline setting for these compounds an exceptionally difficult task [1,2].

The compounds found in indoor environment are ranked according to their concentrations and divided into the following classes [4–6]: alkanes ($100 \mu\text{g}/\text{m}^3$); aromatics ($50 \mu\text{g}/\text{m}^3$); terpenes ($30 \mu\text{g}/\text{m}^3$); halocarbons ($30 \mu\text{g}/\text{m}^3$) and other ($50 \mu\text{g}/\text{m}^3$).

The sum of individual classes gives the total VOC (TVOC) value. The proposed target guideline value for the TVOC is $300 \mu\text{g}/\text{m}^3$, and no individual compound should exceed 50% of its class target or 10% of the TVOC target guideline value [4]. An understanding of the dynamics of the indoor environment is important for designing a proper sampling strategy as well as for evaluation of the results.

Usually, indoor air pollution cannot be controlled on a continuous basis in view of the huge number of individual indoor spaces with different sources and pollution patterns. The objective of measurement, *e.g.*, the identification of sources of complaints

on poor indoor air quality, the determination of population exposure levels or the check of compliance with air quality criteria, decides on which pollutants are of interest, and on whether maximum or mean concentrations or the variation of concentration with time have to be determined. Besides the selection of sampling site and sampling objectives, also time of sampling, frequency and duration of sampling will have an important influence on the final results according to European Concerted Action [7].

On this basis it can be stated that analytical results depend mainly on three factors [8]: the sampling strategy, the sampling procedure and the analytical procedure.

For VOC which are most often present in indoor air and likely to cause chronic or other long-term effects, generally long-term measurements, *e.g.*, over two or three weeks – applying passive method – are suited. In contrast, to determine more rapid changes in concentrations, which is important for those VOC which cause acute effects, short-term or continuous measurements applying dynamic method using a classical charcoal sorption tubes (CT) is recommended [9,10].

It is very important to select a proper method for the collection of air samples which would ensure the representativeness of samples which, in turn, relates to the representativeness and reliability of the results of analytical measurements.

The present paper describes the results of investigations of indoor air quality and fluctuations of concentration expressed by measurements of levels of concentration of selected VOC in various, newly erected and remodeled buildings in the Gdańsk region. The measurements were carried out using techniques of air sampling mentioned above.

EXPERIMENTAL

Methods and materials

Indoor air quality was monitored by identifying and determining organic compounds, such as benzene, toluene, butyl acetate, ethylbenzene, *m*-xylene, styrene and *m*-dichlorobenzene.

The time that is required to collect an air sample depends on: the lower detection limit of the analytical method, the potential health effects of the pollutant(s) in question (acute or chronic), the emission characteristics of the source(s) and other factors influencing the concentration levels and on any specific objectives of the measurements.

In practice, the minimum mass of pollutant in a sample required to exceed the detection limit of an analytical method is determined.

Taking into consideration the above requirements, two techniques of isolation and enrichment of the analytes from indoor air were used:

- passive dosimetry, which is the technique recommended for long-term monitoring of indoor air and which allows the determination of time weighted average (TWA) concentrations during the exposure of dosimeters, which lasts about three to five weeks [2,11] and
- dynamic, which enables the determination of one- and 12-hour TWA concentrations of the analytes and thus the observation of fluctuations in concentrations of the analytes in a given dwelling during the exposure of dosimeters.

Home-made badge-type permeation passive samplers were used for sampling indoor air [12,13]. The samplers were calibrated experimentally by exposing them to known concentrations of the analytes in exposure chambers filled with standard gaseous mixtures [13,14].

In each investigated dwelling, passive samplers were placed centrally at a height of the breathing zone of occupants (*ca* 1.5 m above the floor level) and about 20 cm apart in order to ensure homogeneity of air samples collected. The time of exposure of the samplers ranged from 3 to 5 weeks depending upon the type of the investigated dwelling. TWA concentrations of the analytes were calculated using the following equation:

$$C = \frac{M \times k}{t} \quad (1)$$

where: C – time-weighted average concentration of the analyte (mg/m^3);

k – calibration constant of passive sampler, determined experimentally using model mixtures, (min/m^3) [12–14];

M – mass of the analyte trapped on the sorbent bed in the sampler during the exposure, determined by GC (mg);

t – exposure time of the sampler (min).

In the dynamic method, a six-channel automatic sampler APG-1 (Institute of Heavy Organic Synthesis, Chemical Production, Inc., Poland) was used to collect analytes from indoor air samples. The following parameters of the sampler could be programmed: start and end of sample collection, time of sample collection, and the flow rate of air through a sorption tube. The flow rates of air samples were 20 l h^{-1} and 80 l h^{-1} for 12 h and 1 h sampling times, respectively. Concentrations of the analytes in collected air samples were determined from known volumes of air samples and the masses of analytes trapped on a sorbent bed were determined chromatographically.

In both sampling techniques, granulated activated charcoal (40–50 mesh) was used as a sorbent. The amounts of charcoal used were *ca* 300 mg and 150 mg for a passive sampler and a sorption tube, respectively. The advantages of activated charcoal, including high breakthrough volume (BTV), high specific surface area and low susceptibility to fluctuations in parameters such as temperature or atmospheric pressure make it suitable for both long-term sample collection and enrichment and the collection of samples of a large volume.

Analytical procedure

The analytical procedure, *i.e.* liberation of the trapped analytes from the sorbent bed by solvent extraction, separation of the mixture in a capillary column, identification and quantitation were identical for both methods, passive and dynamic. As sorption tubes had two layers: main and backup, each of the two layers was extracted and analyzed separately. Details of extraction and analysis conditions are shown in Table 1.

Table 1. Procedure for desorption of analytes from a sorbent bed and GC conditions of extract analysis

| | Analytical procedure |
|----------------------|---|
| Desorption medium | 0.5 cm^3 of CS_2 (after transferring charcoal to a glass vial) |
| Desorption time | 30 min (static system) |
| Gas chromatograph | Hewlett–Packard, GC System 6890 |
| Detector | FID, |
| Detector temperature | 250°C |
| Make up gas | Helium 25 ml min^{-1} |

| Table 1 (continued) | |
|--|---|
| Injection made | Split/Splitless |
| Injector temperature | 200°C |
| Splitless time | 50 s |
| Sample volume | 1 µl |
| Carrier gas | Helium at 2.2 ml min ⁻¹ |
| temperature program | 37°C for 4 min 10°C min ⁻¹ to 120°C 120°C for 10 min |
| Integration system | Chem Station |
| Capillary column: | 32 m DB-1 |
| – diameter | 0.32 mm |
| – thickness of stationary phase film | 5 µm |
| Calibration | External standard |
| Detection limit: | |
| – passive samplers | 0.1 µg m ⁻³ |
| – active sampling – 240 l | 0.5 µg m ⁻³ |
| – active sampling – 70 l | 1.7 µg m ⁻³ |
| Recovery of the analytes trapped on charcoal (determined experimentally) | 95% |

RESULTS AND DISCUSSION

Three dwellings were selected for investigations:

- 1) a flat in a newly erected tenement building. The owner had no control over the building materials used (flat No. 1);
- 2) a flat in a newly erected building occupied by four families. The owner himself selected building materials and technologies (flat No. 2);
- 3) a flat in an old apartment house which has undergone complete renovation – replacement of floors and wall and ceiling covering, and a complete replacement of furniture (flat No. 3).

The main building characteristics obtained from the inspection of the buildings are shown in Table 2. Based on the data shown in Table 2 it can be concluded that ambient air can have a significant effect on the quality of indoor air, since all the investigated dwellings are located near highways with the heavy traffic, and the traffic is known to be one of the more important sources of air pollution with organic compounds [3].

Since inhabitants spend most time in a dwelling in the living room, this room is considered to be most representative in terms of human exposure to VOC and, consequently, air samples were collected there. During the monitoring period, normal activities of the occupants were not limited in any way. Conditions of exposures carried out to determine the quality of indoor air in the monitored dwellings are listed in Table 3.

Table 2. Dwelling characteristics

| Dwelling Number | Situation | External pollution | Ventilation system | Occupants n | Age of building years | Total floor areas, m ² | Surface materials floor |
|-----------------|-----------|------------------------------------|-----------------------|-------------|-----------------------|-----------------------------------|-------------------------|
| 1 | Suburb | Road with moderately heavy traffic | Gravimetric (natural) | 1 | 1 | 50 | Ceramic, panels |
| 2 | Suburb | Road with moderately heavy traffic | Gravimetric (natural) | 4 | 1 | 72 | Ceramic, panels, carpet |
| 3 | Downtown | Road with heavy traffic | Gravimetric (natural) | 1 | 30 | 42 | Wooden floor |

Table 3. Description of exposure conditions

| Exposure | Dwelling No. | | | |
|----------------------|---|--|---------|--|
| | 1 | 2 | | 3 |
| Exposure I | A flat prior to inhabiting, partly furnished | A flat prior to inhabiting, extensive finishing works carried out inside | | A flat two months after remodeling |
| Duration of sampling | October, 1997 | August, 1997 | | March, 1997 |
| Sampling method | Passive | Passive | Dynamic | Passive Dynamic |
| Number of samples | 4 | 4 | 34 | 4 9 |
| Exposure II | A flat 6 months after inhabiting, fully furnished | A flat 1 month after inhabiting, partly furnished | | A normally exploited flat, 4 months since the end of remodeling |
| Duration of sampling | April, 1998 | October, 1997 | | May, 1997 |
| Sampling method | Passive | Passive | Dynamic | Passive Dynamic |
| Number of samples | 4 | 4 | 30 | 4 9 |
| Exposure III | – | A flat nine months after inhabiting | | A normally exploited flat, 6 months since the end of remodeling |
| Duration of sampling | – | May, 1998 | | June, 1997 |
| Sampling method | – | Passive | Dynamic | Passive Dynamic |
| Number of samples | – | 4 | 40 | 4 60 |
| Exposure IV | – | – | | A normally exploited flat, 14 months since the end of remodeling |
| Duration of sampling | – | – | | March, 1998 |
| Sampling method | – | – | | Passive Dynamic |
| Number of samples | – | – | | 4 30 |

Of the wide range of organic compounds occurring in indoor air, only seven (mainly aromatic hydrocarbons) were identified and determined in the monitored dwellings. The selected analytes, however, belong to the group of compounds which

are most often monitored in indoor air in Poland by the agencies responsible for monitoring the living conditions in dwellings.

The maximum allowable concentrations of pollutants emitted by building materials and furnishings in inhabited closed areas are regulated by the decree of the Minister of Health and Social Security of Poland from March 12, 1996 [15]. Current values of maximum allowable concentrations for the examined analytes are listed in Table 4.

Table 4. Current values of maximum allowable concentrations (MAC) for selected VOC in indoor air [15] (Regulation of the Minister of Health and Social Security, 1996)

| Substance | MAC for indoor air, $\mu\text{g m}^{-3}$ |
|---------------------------|--|
| Benzene | 10 |
| Toluene | 200 |
| Butyl acetate | 100 |
| Ethylbenzene | 100 |
| <i>m</i> -Xylene | 100 |
| Styrene | 20 |
| <i>m</i> -Dichlorobenzene | 30 |

In dwelling 1, air samples were collected using only the passive method and the results obtained are shown as a histogram in Figure 1. The results confirm the well-known opinion on the necessity of ventilation of dwellings prior to inhabitation in order to minimize the exposure of inhabitants to hazardous VOC. In this dwelling, during the first exposure the maximum allowable concentrations were exceeded for benzene and *m*-xylene, while the concentration of toluene was close to the threshold value. The concentrations of the other monitored analytes were very low. It should be noted, however, that the quality of indoor air was estimated for the dwelling which has not been yet inhabited. Therefore, it can be concluded that the emission of pollutants is caused mostly by building materials and ambient air. Subsequent measurements in dwelling 1 were carried out six months after inhabitation (exposure II). It was then noticed that the concentration of benzene was still high and exceeded the allowed value. Also, the concentration of styrene increased significantly, reaching the level exceeding the maximum allowable concentration by a factor of 1.5. Compared to concentrations obtained during the first exposure, the concentrations of butyl acetate and ethylbenzene were also increased, although their concentration levels were far below the allowed values. The sources of butyl acetate and ethylbenzene in indoor air are, among others, paints, varnishes, and glues, *i.e.* the products used both in the manufacture of elements of equipment of dwellings and in finishing of dwellings. It follows from the data shown that during the second exposure the deterioration of indoor air quality resulted from the presence of elements of equipment of the dwelling and human activity, while the effect of building materials on the emission of the analytes has decreased.

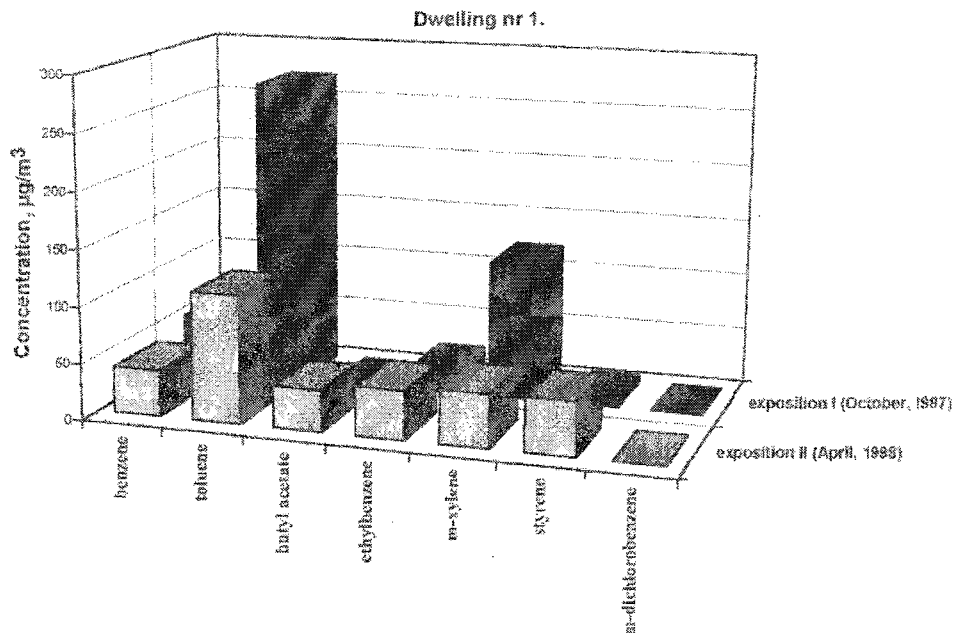


Figure 1. Graphical representation of time dependence of the concentrations of selected VOC determined in the indoor air of flat 1 using passive sampling

The next investigated dwelling was flat 2. In this flat air samples were collected using both the passive and the dynamic technique. Since in this flat finishing work was carried out during the first exposure, the dynamic sampling method was used to determine to what extent this work affected the quality of monitored air. The quality of indoor air was evaluated based on triplicate measurements. TWA concentrations and standard deviations for the selected analytes obtained during successive exposures in flat 2 are listed in Table 5. The Table 5 also lists the maximum and minimum concentrations obtained during the investigations. The first exposure in flat 2 lasted 4 weeks. The dynamic technique of air sampling using sorption tubes was employed 34 times which constituted 61% of the exposure time of passive samplers. The temporal distribution of concentrations of the analytes in the monitored dwelling based on 12-hour sampling of the VOC is shown in Figure 2. By comparing only TWA concentrations determined using the two sampling techniques it was concluded that during the first exposure the analytes occurred at high concentrations, exceeding the allowed values several times. However, a detailed examination based on the results obtained by the dynamic sampling technique leads to the conclusion that the high concentration levels of the analytes result from the intensive finishing work carried out during the first exposure, especially between the ninth and fourteenth day of the exposure. During this period the analyte concentrations exceeded the maximum allowable concentrations for indoor air more than ten times; for example, the concentrations of butyl acetate and *m*-xylene were $1905.8 \mu\text{g}/\text{m}^3$ and $2638.6 \mu\text{g}/\text{m}^3$, respectively. After

Table 5. Comparison of concentration of selected VOC measured in newly erected building (flat 2) using two different methods of sample collection

| Analyte | Method of sample collection | Exposure No. | | | | | | | | | | | |
|---------------------------|-----------------------------|----------------------------------|------------------|--------|-------|---------------------------|------|-------|------|------------------------|------|-------|-------|
| | | I, August 1997 (n = 34) | | | | II, October 1997 (n = 30) | | | | III, May 1998 (n = 40) | | | |
| | | Mean | STD [†] | max | min | Mean | STD | max | min | Mean | STD | max | min |
| | | Concentration, µg/m ³ | | | | | | | | | | | |
| Benzene | Passive | <0.1 | - | <0.1 | <0.1 | 47.1 | 14.2 | 68.7 | 39.6 | <0.1 | - | <0.1 | <0.1 |
| | Dynamic | <0.5 | - | <0.5 | <0.5 | 81.6 | - | 404.4 | 24.4 | 17.6 | - | 68.2 | 1.8 |
| Toluene | Passive | 130.4 | 20.3 | 149.7 | 106.3 | 95.8 | 6.7 | 102.4 | 87.5 | 148.8 | 34.2 | 186.7 | 112.7 |
| | Dynamic | 53.7 | - | 513.8 | 5.0 | 57.0 | - | 188.2 | 10.4 | 55.4 | - | 97.3 | 4.9 |
| Butyl Acetate | Passive | 109.2 | 7.9 | 121.1 | 104.6 | <0.1 | - | <0.1 | <0.1 | <0.1 | - | <0.1 | <0.1 |
| | Dynamic | 142.5 | - | 1905.8 | 0.5 | 3.3 | - | 9.7 | 1.2 | 9.7 | - | 22.4 | 0.9 |
| Ethylbenzene | Passive | 332.8 | 70.5 | 407.2 | 262.2 | 1.7 | 2.6 | 2.0 | 1.4 | 26.4 | 4.3 | 33.5 | 22.9 |
| | Dynamic | 95.4 | - | 805.3 | 1.3 | 9.7 | - | 24.8 | 2.0 | 8.3 | - | 31.3 | 0.5 |
| <i>m</i> -Xylene | Passive | 438.9 | 82.3 | 535.8 | 356.3 | 16.5 | 2.5 | 20.0 | 14.3 | 25.9 | 1.9 | 28.8 | 23.8 |
| | Dynamic | 339.2 | - | 2638.6 | 5.4 | 23.7 | - | 60.9 | 5.8 | 18.8 | - | 132.8 | 2.5 |
| Styrene | Passive | 198.0 | 25.6 | 226.6 | 169.7 | 5.4 | 0.6 | 6.1 | 4.9 | 0.5 | 0.63 | 1.5 | 0.1 |
| | Dynamic | 65.5 | - | 530.6 | 0.5 | 4.7 | - | 60.6 | 0.8 | 0.8 | - | 7.5 | 0.9 |
| <i>m</i> -Dichlorobenzene | Passive | <0.1 | - | <0.1 | <0.1 | <0.1 | - | <0.1 | <0.1 | <0.1 | - | <0.1 | <0.1 |
| | Dynamic | 2.1 | - | 67.5 | 2.0 | 7.5 | - | 174.1 | 1.7 | 2.1 | - | 21.4 | 1.1 |

[†]In case of dynamic method of analyte collection from indoor air samples, standard deviation was not determined for the respective sets of results due to inability of collecting parallel samples.

completion of the finishing work the concentrations of the analytes have dropped significantly, and for most of the analytes reached a level of several $\mu\text{g}/\text{m}^3$. It should be noted that during the first exposure the presence of benzene was not detected in the investigated dwelling.

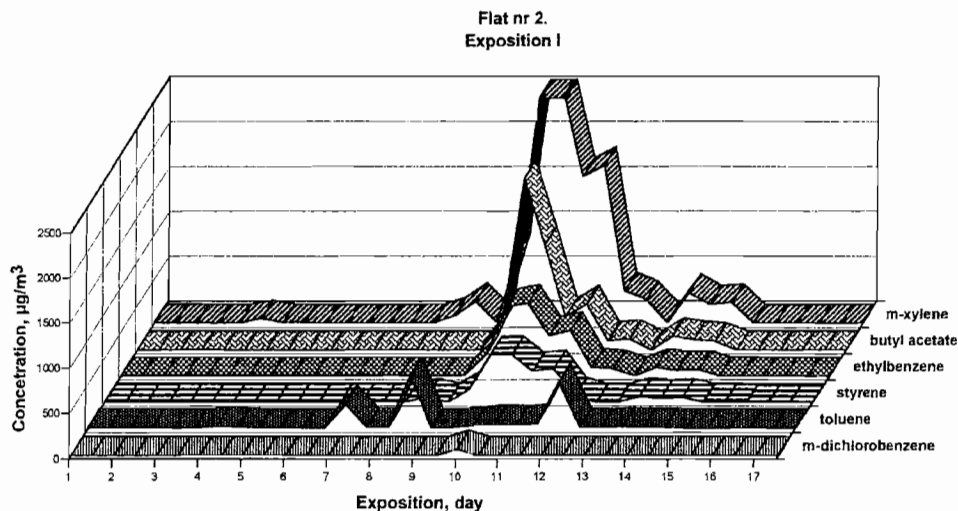


Figure 2. Temporal distribution of 12-hour concentrations of selected VOC determined during exposure I in flat 2

If passive sampling alone were to be used to determine TWA concentrations of the analytes in the two newly built flats, the cause of such large differences in concentrations of the analytes would be difficult to find.

During the second and third exposure in dwelling 2, TWA concentrations of the analytes were significantly lower. Even the maximum concentrations of the analytes did not exceed the threshold values for indoor air. For the majority of the analytes, no significant differences in concentration levels of the analytes were found for successive days of exposure based on the results of 12-hour sampling of indoor air (Fig. 3 and 4). The largest fluctuations in concentration were observed for benzene. However, taking into consideration the absence of benzene during the first exposure and the surrounding of the house in which the investigated dwelling is located (see Tab.2) it can be presumed that benzene originates from ambient air.

Table 6 shows the results of investigations of indoor air for dwelling 3 for four consecutive exposures in terms of TWA concentrations determined by the two techniques of air sampling. During the first two exposures, air samples were collected dynamically (using sorption tubes) four times at the beginning and five times at the end of the exposure period of passive samplers. On the other hand, both techniques of air sampling were used to monitor dwelling 3 on a continuous basis during the third and fourth exposure. During the third exposure air samples were collected dynamically 60 times which was equal to 100% of the exposure period for passive samplers while during the fourth exposure indoor air was monitored by the dynamic method 60% of

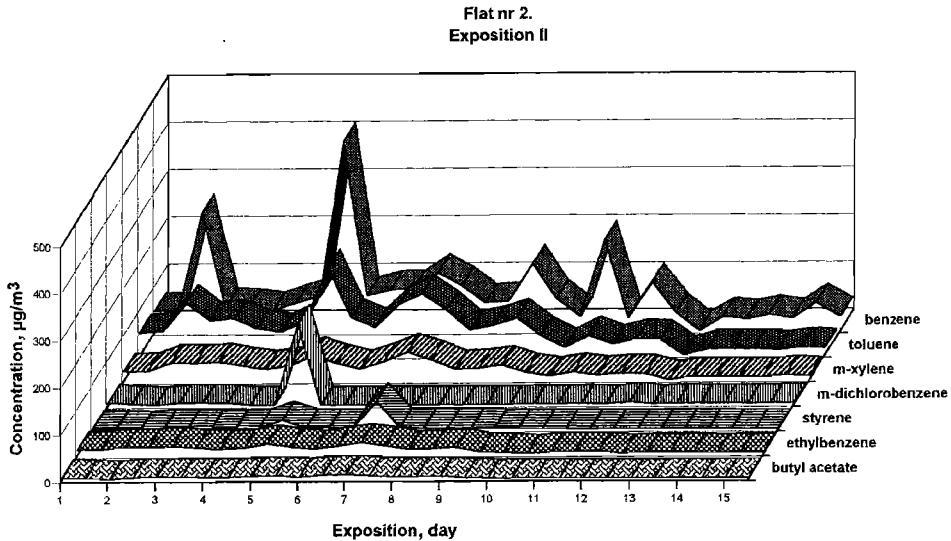


Figure 3. Temporal distribution of 12-hour concentrations of selected VOC determined during exposure II in flat 2

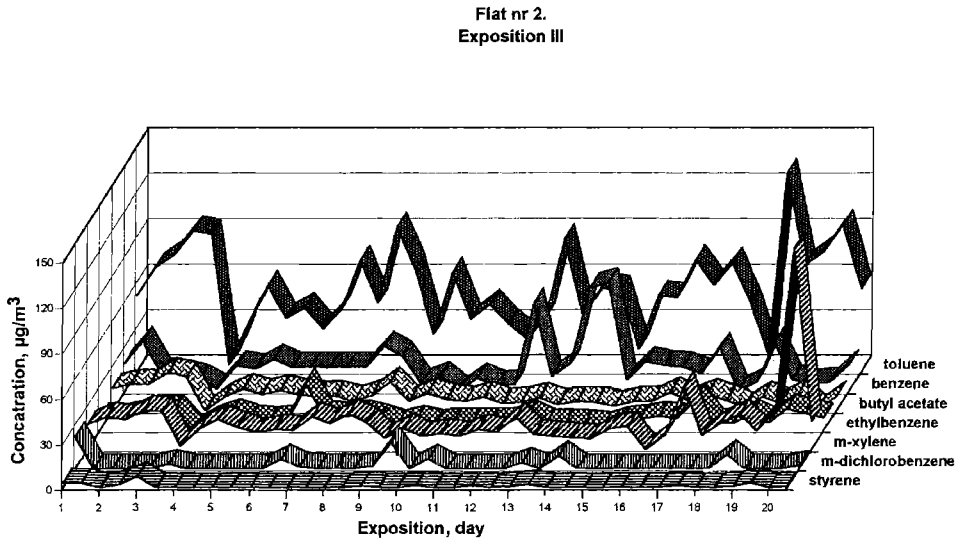


Figure 4. Temporal distribution of 12-hour concentrations of selected VOC determined during exposure III in flat 2

the exposure period for passive samplers. Despite the fact that a major renovation took place in this dwelling, the allowed concentration was exceeded only for benzene. It should be pointed out, however, that in this dwelling benzene was present at a concentration exceeding the allowed values during all four exposures. Most probably, both the presence of benzene and its high concentration results from the location of

Table 6. Comparison of concentration of selected VOC measured in remodeled dwelling (flat 3) using two different method of sample collection

| Analyte | Method of sample collection | Exposure No | | | | | | | | | | | |
|---------------------------|-----------------------------|-----------------------|-------------------|------|------|------|------|----------------------|------|------|-----|-----|-----|
| | | I, March 1997 (n = 9) | | | | | | II, May 1997 (n = 9) | | | | | |
| | | Mean | STD ^{§)} | max | min | Mean | STD | max | min | Mean | STD | max | min |
| Benzene | Passive | 82.7 | 3.8 | 88.1 | 79.5 | 39.9 | 3.3 | 43.2 | 35.6 | | | | |
| | Dynamic | 6.0 | – | 9.6 | 1.4 | 23.5 | – | 25.9 | 20.9 | | | | |
| Toluene | Passive | 42.4 | 5.5 | 48.2 | 36.9 | 61.3 | 33.9 | 104.1 | 28.4 | | | | |
| | Dynamic | 18.8 | – | 36.8 | 13.0 | 14.2 | – | 19.9 | 12.2 | | | | |
| Butyl acetate | Passive | <0.1 | – | <0.1 | <0.1 | <0.1 | – | <0.1 | <0.1 | | | | |
| | Dynamic | <0.5 | – | <0.5 | <0.5 | 4.7 | – | 8.2 | 0.5 | | | | |
| Ethylbenzene | Passive | 0.1 | – | <0.1 | <0.1 | <0.1 | – | <0.1 | <0.1 | | | | |
| | Dynamic | 1.8 | – | 2.8 | 1.0 | 1.4 | – | 1.7 | 1.2 | | | | |
| <i>m</i> -Xylene | Passive | 16.1 | 0.8 | 16.6 | 15.1 | 8.4 | 0.4 | 8.9 | 7.8 | | | | |
| | Dynamic | 6.3 | – | 9.2 | 4.7 | 4.9 | – | 6.0 | 4.1 | | | | |
| Styrene | Passive | 3.8 | 7.3 | 14.7 | 1.0 | 0.1 | – | 0.1 | 0.1 | | | | |
| | Dynamic | 1.4 | – | 2.8 | 1.4 | 1.1 | – | 1.2 | 1.0 | | | | |
| <i>m</i> -Dichlorobenzene | Passive | 20.3 | 3.1 | 24.0 | 16.3 | 17.5 | 0.9 | 18.5 | 16.4 | | | | |
| | Dynamic | 6.7 | – | 12.2 | 3.3 | 34.4 | – | 38.8 | 30.7 | | | | |

Table 6 (continued)

| Analyte | Method of sample collection | Exposure No | | | | | | | | | |
|----------------------------------|-----------------------------|-------------------------|-------------------|------|------|------|-------------------------|-------|------|--|--|
| | | III, June 1997 (n = 60) | | | | | IV, March 1998 (n = 30) | | | | |
| | | Mean | STD ^{Φ)} | max | min | Mean | STD | max | min | | |
| Concentration, µg/m ³ | | | | | | | | | | | |
| Benzene | Passive | 14.3 | 8.2 | 22.4 | 10.7 | 25.6 | 3.1 | 31.4 | 23.0 | | |
| | Dynamic | 6.7 | - | 22.2 | 2.2 | 24.7 | - | 31.8 | 5.6 | | |
| Toluene | Passive | 73.4 | 6.5 | 90.1 | 73.2 | 16.2 | 0.4 | 16.8 | 15.8 | | |
| | Dynamic | 20.1 | - | 32.3 | 9.6 | 29.7 | - | 72.7 | 10.3 | | |
| Butyl acetate | Passive | 19.3 | 5.3 | 22.8 | 12.2 | 23.6 | 14.5 | 34.2 | 23.7 | | |
| | Dynamic | 5.6 | - | 10.4 | 0.6 | 5.4 | - | 16.6 | 1.7 | | |
| Ethylbenzene | Passive | 14.3 | 4.7 | 20.4 | 13.2 | 23.4 | 1.8 | 26.2 | 21.3 | | |
| | Dynamic | 3.0 | - | 22.7 | 0.7 | 5.5 | - | 23.7 | 2.9 | | |
| <i>m</i> -Xylene | Passive | 25.0 | 4.3 | 32.2 | 21.0 | 24.8 | 5.5 | 31.6 | 17.2 | | |
| | Dynamic | 14.0 | - | 37.7 | 2.5 | 19.1 | - | 114.8 | 9.5 | | |
| Styrene | Passive | 5.2 | 0.8 | 6.6 | 4.3 | >0.1 | - | <0.1 | <0.1 | | |
| | Dynamic | 10.1 | - | 31.3 | 2.0 | 1.5 | - | 9.7 | 0.5 | | |
| <i>m</i> -Dichlorobenzene | Passive | 14.5 | 7.3 | 25.9 | 5.5 | >0.1 | - | <0.1 | <0.1 | | |
| | Dynamic | 2.6 | - | 6.8 | 0.9 | 6.6 | - | 127 | 0.6 | | |

^{Φ)}In case of dynamic method of analyte collection from indoor air samples, standard deviation was not determined for the respective sets of results due to inability of collecting parallel samples.

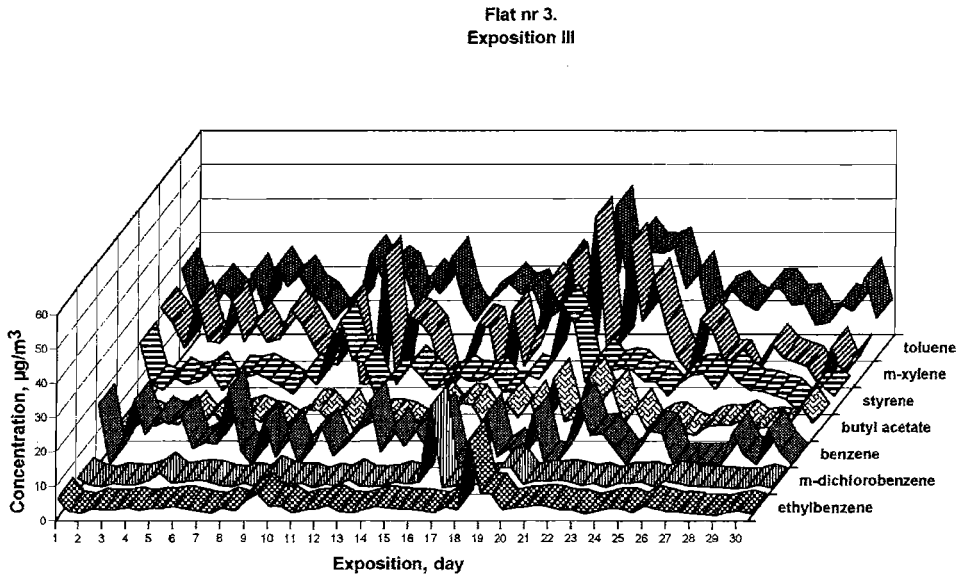


Figure 5. Monthly distribution of 12-hour concentrations of selected VOC determined during exposure III in flat 3

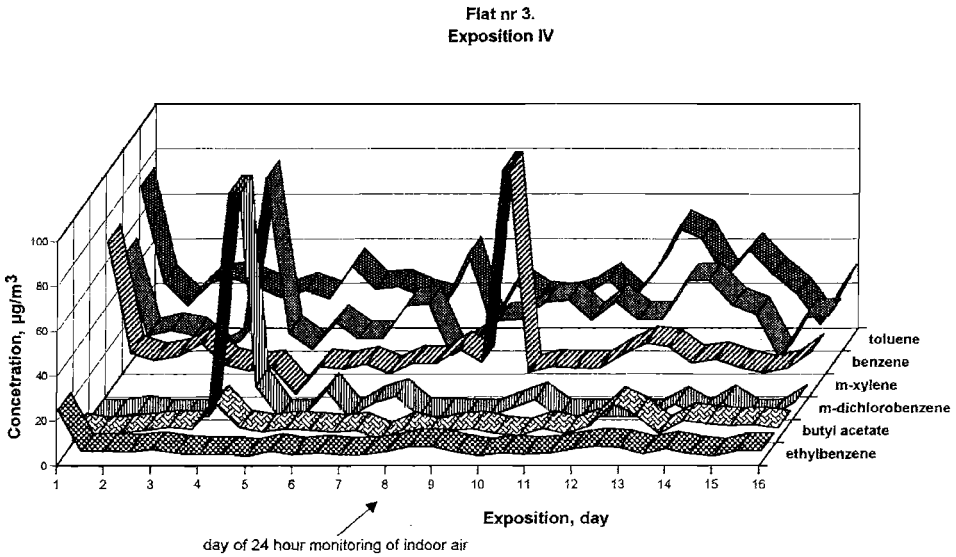


Figure 6. Temporal distribution of 12-hour concentrations of selected VOC determined during exposure IV in flat 3

the dwelling – near a major highway connecting Gdańsk with the interior of Poland. However, this assumption cannot be proved, because no parallel investigations of the quality of ambient air were conducted.

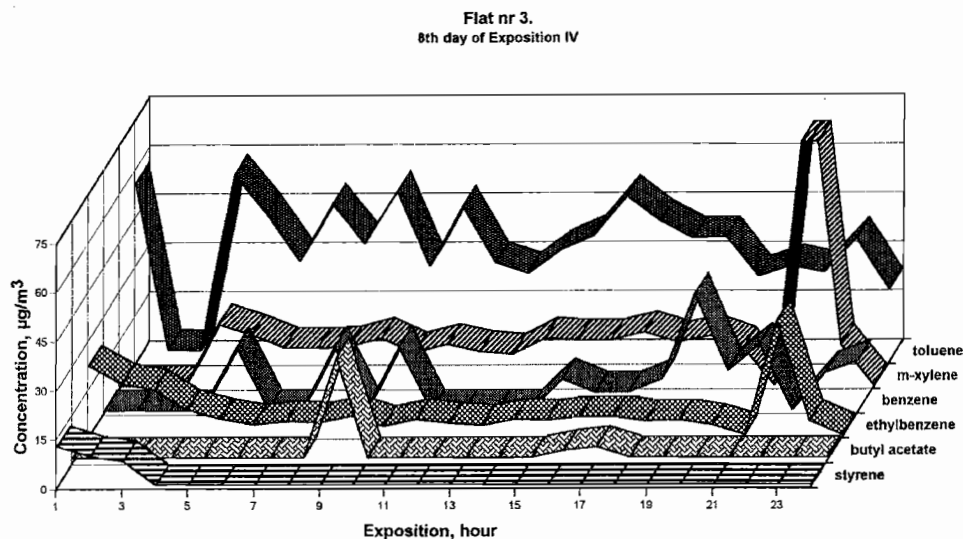


Figure 7. Daily distribution of one-hour concentrations of selected VOC determined during the eighth day of exposure IV in flat 3

A monthly distribution of concentrations of selected VOC obtained during the second exposure is shown in Figure 5. No significant fluctuations in concentrations of the analytes were observed during the third exposure. Similarly, during the fourth exposure the concentrations of the analytes remained relatively constant (Figure 6). Only during the fourth and fifth day of the exposure a substantial increase in concentrations of benzene and *m*-dichlorobenzene was observed, and during the tenth day of the exposure the concentration of *m*-xylene reached a value of $114.8 \mu\text{g}/\text{m}^3$, thus exceeding the maximum allowable concentration for this analyte. In addition, investigations of one-hour changes in concentrations of the analytes were carried out on the eighth day of the fourth exposure in dwelling 3. The results of these investigations are shown in Figure 7. The studies of indoor air quality in dwelling 3 reveal that the major renovation of the flat, in which materials with high emission rates of organic compounds were used, did not significantly deteriorate the quality of indoor air.

CONCLUSION

The frequency of sampling or the number of samples taken at different times necessary to characterize the air in a given space depends on the individual case.

As occupant activities and ventilation characteristics may vary from day to day or display a seasonal pattern, no single sample taken at one particular time can give a reliable indication of the overall distribution of exposures. Only detailed observation and knowledge of the factors influencing the concentration level can give a clue to

whether a single sample represents the high, medium or low side of the exposure distribution. However, the benefits gained from taking a large number of samples over a certain period of time have to be looked at in the light of the increasing costs of sampling and analysis involved.

As the VOC are emitted by certain building materials, furnishing, consumer products and equipment, it is recommended to select materials and designs that minimize the emission of VOC.

The present work indicates that the parallel use of two different techniques of sampling analytes from indoor air, although more time- and labor-consuming, improves our knowledge of the quality of indoor air in monitored dwellings.

REFERENCES

1. Namieśnik J., Górecki T., Kozdroń-Zabiegała B. and Łukasiak J., *Building and Environ.*, **27**, 339 (1992).
2. Namieśnik J., Zygmunt B. and Kozdroń-Zabiegała B., *Pol. J. Environ. Stud.*, **3**, 5 (1994).
3. Cohen Y., *ASTM STP*, **1267**, 7 (1997).
4. Otson R. and Fellin Ph., *Volatile organics in the indoor environment: sources and occurrence*, in: *Gaseous Pollutants: Characterization and Cycling*, [Nriagu J.O., Ed.], John Wiley & Sons, Inc., 1992, pp 335–342.
5. Lagoudi A., Loizidou M. and Asimakopoulos D., *Indoor Built Environ.*, **5**, 348 (1996).
6. Lagoudi A., Loizidou M. and Asimakopoulos D., *Indoor Built Environ.*, **5**, 341 (1996).
7. European Concerted Action INDOOR AIR QUALITY & ITS IMPACT ON MEN, Environment and Quality of Life Report No. 6, Strategy for sampling chemical substances in indoor air, EUR 12617 EN, Luxembourg 1989.
8. Sheifert B., *Sampling and analysis of ambient and indoor air*, Chapter 9; in: *Environmental Carcinogens Methods of Analysis and Exposure Measurement* [L. Fishbein and I.K. O'Neill, Eds.], vol. 10, International Agency for Research on Cancer, Lyon 1988.
9. Kozdroń-Zabiegała B., Przyjazny A. and Namieśnik J., *Indoor Built Environ.*, **5**, 212 (1996).
10. European Concerted Action INDOOR AIR QUALITY & ITS IMPACT ON MEN, Environment and Quality of Life Report No. 10, Effects of indoor air pollution on human health, EU 14086 EN, Luxembourg 1991.
11. Kozdroń-Zabiegała B., Przyjazny A. and Namieśnik J., *Indoor Built Environ.*, **4**, 189 (1995).
12. Namieśnik J., Górecki T., Kozdroń-Zabiegała B. and Torres L., *Intern. J. Environ. Anal. Chem.*, **37**, 139 (1989).
13. Kozdroń-Zabiegała B., Namieśnik J. and Zygmunt B., *Chem. Anal. (Warsaw)*, **41**, 209 (1996).
14. Kozdroń-Zabiegała B., Przyk E., Zygmunt B. and Namieśnik J., *Chem. Anal. (Warsaw)*, in print.
15. Regulation of the Minister of Health and Social Security of Poland from March 12, 1996 on maximum allowable concentrations of pollutants emitted by building materials and furnishings in inhabited closed areas. Monitor Polski Nr 19, poz 231.

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