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# Monitoring of indoor air quality in Macedonian homes during summer season

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**Abstract**

Measurements of indoor air quality (IAQ) factors in Macedonian homes were aimed at the determination of indoor air temperature, relative humidity, sound pressure level, particulate matters (PMs) and total volatile organic compounds (TVOC). IAQ monitoring were performed in 25 houses during summer period. Results pointed out that sound pressure level were high in most of the houses with mean values of 66.60 dB (A) - 55.30 dB (A). Limit value of 40 dB (A) was exceeded in 72% of houses. Mean values of indoor air temperature and relative humidity ranged from 21.6°C to 28.6°C and from 35.8% to 60.2%, respectively. Mean concentrations of particulate matter concentrations ranged between 9.75 µg/m$^3$ - 71.73 µg/m$^3$ and 23.63 µg/m$^3$ - 145.10 µg/m$^3$ for $PM_{2.5}$ and $PM_{10}$, respectively. Level of $PM_{10}$ were high in 30% of the monitored houses. 56% of houses achieved higher concentration of $PM_{2.5}$ than permissible value of 25 µg/m$^3$. Excessive presence of TVOC was recorded in monitored homes with mean values from 260 ppm to 791 ppm. Results show that high exposure by noise, concentrations of TVOC and PMs in indoor air can affect family house users. Therefore, the indoor air quality needs to be investigated and people need to be informed about possible health consequences.

**Key words:** indoor air, monitoring, air temperature, relative humidity, sound pressure level, PM, TVOC

## 1 Introduction

Healthy indoor environment prioritized in sustainable buildings is described by factors such as thermal comfort, sufficient lighting, low noise, and good indoor air quality [1]. Managing the outdoor air exchange rate is one strategy how to reduce energy demand of buildings, as mechanical ventilation requires energy input to fans and may contribute to heating, cooling, and dehumidification needs, depending on site- and time-specific environmental conditions [2]. Thanks for an increasing concern for energy saving, contemporary buildings are much more airtight than older buildings, potentially leading to an increased build-up of pollutants indoors. As basic strategies for improving IAQ we can consider the reduction of pollutant sources and the use of efficient ventilation systems in buildings [3]. The human right to a healthy indoor environment includes the right to breathe clean air [4]. Another important aspect is the acoustic comfort, which is not commonly used, while ensuring good acoustic environment is linked to the prevention of occurrence of discomfort. [5]. Building structures are linked with a range of health hazard, such as those attributable to thermal discomfort, indoor air pollution, noise, diseases caused by airborne particles or mould contamination [6]. Study [7] shows that long-term as well as short-term exposure to $PM_{2.5}$ has been associated with increased respiratory and cardiovascular morbidity. Study [8] points out that major contributor to indoor TVOC in residences are household's products, combustion processes and environmental tobacco smoke, deodorizers as well as off-gassing of building materials. These chemicals can cause a lot of health problems such as irritation of eyes or nose, dizziness, nausea, headaches and allergic reactions and some of them are carcinogenic [9, 10]. Deng et al. [11] revealed that exposure to new furniture and home redecoration during pregnancy significantly increased childhood asthma.

Emphasizing that the level of indoor air quality in living spaces is not sufficient in the home is a major contribution to the paper presented. Investigation of indoor air quality in selected houses in Prilep, Macedonia is focused on measuring the indoor air temperature, relative humidity, total volatile organic compounds, particulate matters and sound pressure level during summer season.

## 2 Materials and methods

### 2.1 Monitored homes

Measurements were made in 25 homes specifically in the town of Prilep, located in the southwestern part of Macedonia. Characteristics such as: type of building (single-family houses and apartments in multi-family buildings); age of building (construction finished in years from 1960 to 2005); renovation (years of 2000 – 2013); smoking; and heating system (central system – pellets, wood; electric energy; wood stove; heat pump) are presented in study [12].

### 2.2. Measurement of indoor air quality factors

Measurements of physical factors (indoor air temperature, relative humidity, sound pressure level) and chemical compounds (particulate matters, total volatile organic compounds) were carried out in the selected family houses in the period from August 2016 until September 2016. Outside air temperature was between 15°C - 31°C and the external relative humidity ranged from 15% to 91%.

Indoor air temperature and relative humidity were measured by a temperature and humidity meter. Noise level was determined by using sound level meter. Total volatile organic compounds were measured with gas detector used advanced PID (photoionization detector) sensor. Gas detector can continuous detect aromatic hydrocarbons, unsaturated hydrocarbons, ketones, alcohols as well as aldehydes. Particulate matters were measured by the nephelometer, which continuously indicates the concentration of thoracic, inhalable and respirable particles down to 0.1 $\mu g/m^3$. In environmental mode, it indicates TSP, $PM_{10}$, $PM_{2.5}$ and $PM_1$ concentrations. A pump continuously draws an air sample through the nephelometer which analyses the individual particles as they pass through a laser beam (Table 1).

The data from all the instruments were downloaded to a computer for further analysis. During the measurements, all of the instruments were placed approximately in the middle of the living room in the height of 1.1 m above the floor.

The measurement lasted for 1 hour and 30 min during normal occupancy of the houses. Each measurement was repeated three times. Living rooms were selected as reference rooms because of spending substantial part of day in these spaces. Doors and windows were closed throughout the measurement. More data concerning the instruments used is shown in Table 1.

Table 1: Instruments used for IAQ monitoring.

| No. | Measuring instrument | Technical data |
|---|---|---|
| 1 | Anemometer type AR846 | speed: 0.3 - 45.00 m/s<br>accuracy: ± 3% ±0.1 m/s<br>flow: 0-999900 m3/min |
| 2 | Temperature and humidity meter - type AR847 | Temperature: -10 - +50°C<br>accuracy: ±1°C<br>Humidity: 5 % RH - 98%RH<br>accuracy: ±3,5 %RH |
| 3 | Sound level meter - type SL-5868P | noise: 30-130 dB<br>frequency from 20 to 12500 Hz<br>accuracy: ±1 dB |
| 4 | TURNKEY DustMate kit | PM 1; 2,5; 10; total dust<br>measuring range: 0 - 6000 $mg/m^3$<br>accuracy: ± 0.01 mg/m3 |
| 5 | TVOC gas detector - K60 | detection range: 0-10,000ppm<br>resolution: 1000ppb<br>response time: <3s |

## 3 Results and discussion

### *3.1. Physical factors*

Average values of indoor air temperature and relative humidity range from 21.6°C to 28.6°C and from 35.8% to 60.2%, respectively. Values of indoor relative humidity correspond with the required range of 30%–70%. Standard deviations for indoor air temperature and relative humidity range from 0.07 to 0.22 and from 0 to 0.14, respectively. Levels of indoor air temperature in our study are higher compared to the study [13] in which the average indoor temperature was found to be 21.4°C and 22.5°C in 157 single-family houses and 148 apartments, respectively.

Sound pressure level values range from 33.6 dB (A) to 55.3 dB (A). Limit value according to the Macedonian Regulation [14] is 40 dB (A), which was exceeded in 72% of the houses. In study [15] was found that bedrooms were generally the quietest (less than 30–33 dB (A)), except in two investigated houses (up to 48 and 36 dB (A), respectively). Higher noise level is shown in kitchens and drawing rooms in which the mean values were 53.6 and 55.7 dB (A), respectively in rural and urban houses in India [16].

Table 2 presents minimum, maximum and mean values of measured physical factors. Figure 1 is a box plot showing the values of sound pressure level.

Table 2: Physical factors.

| No. | Temperature [°C] | | | Relative humidity [%] | | | Noise [dB(A)] | | |
|---|---|---|---|---|---|---|---|---|---|
| | min. | max. | mean | min. | max. | mean | min. | max. | mean |
| 1 | 25.3 | 25.9 | 25.6 | 51.8 | 51.9 | 51.9 | 36.4 | 44.5 | 39.2 |
| 2 | 23.0 | 23.7 | 23.3 | 53.1 | 53.4 | 53.2 | 34.8 | 49.6 | 43.1 |
| 3 | 27.6 | 28.1 | 27.8 | 41.2 | 41.4 | 41.3 | 44.5 | 51.9 | 48.9 |
| 4 | 25.0 | 25.4 | 25.2 | 48.7 | 48.9 | 48.8 | 41.8 | 59.4 | 53.9 |
| 5 | 25.0 | 25.4 | 25.2 | 49.8 | 49.9 | 49.9 | 47.5 | 63.4 | 54.3 |
| 6 | 28.5 | 28.9 | 28.6 | 37.5 | 37.8 | 37.7 | 33.7 | 59.4 | 46.0 |
| 7 | 23.6 | 24.0 | 23.8 | 54.6 | 54.8 | 54.7 | 43.2 | 48.7 | 46.0 |
| 8 | 26.3 | 26.5 | 26.4 | 42.1 | 42.2 | 42,2 | 37.8 | 48.7 | 43.5 |
| 9 | 26.0 | 26.3 | 26.1 | 42.4 | 42.5 | 42.5 | 38.9 | 58.4 | 47.0 |
| 10 | 23.9 | 24.3 | 24.1 | 38.9 | 39.1 | 39,0 | 32.4 | 42.2 | 36.3 |
| 11 | 25.2 | 25.4 | 25.3 | 44.1 | 44.2 | 44.2 | 34.5 | 49.8 | 40.9 |
| 12 | 27.6 | 27.9 | 27.8 | 40.2 | 40.3 | 40.3 | 42.8 | 55.8 | 47.9 |
| 13 | 28.0 | 28.3 | 28.2 | 35.7 | 35.8 | 35.8 | 29.8 | 36.5 | 33.6 |
| 14 | 26.2 | 26.5 | 26.4 | 38.7 | 39.1 | 38.9 | 37.8 | 49.8 | 42.6 |
| 15 | 25.7 | 26.1 | 25.9 | 36.4 | 36.6 | 36.5 | 40.8 | 56,4 | 47.3 |
| 16 | 24.8 | 25.0 | 24.9 | 38.7 | 39.0 | 38.8 | 31.6 | 48.2 | 36.0 |
| 17 | 24.6 | 24.9 | 24.7 | 38.2 | 38.4 | 38.3 | 41.2 | 56.6 | 48.2 |
| 18 | 27.5 | 27.8 | 27.7 | 40.2 | 40.3 | 40.2 | 50.7 | 59.8 | 55.3 |
| 19 | 26.0 | 26.3 | 26.1 | 44.4 | 44.6 | 44.5 | 35.6 | 44.6 | 40.6 |
| 20 | 26.7 | 26.9 | 26.8 | 38.8 | 39.0 | 38.9 | 32.1 | 44.5 | 36.8 |
| 21 | 24.7 | 25.1 | 24.8 | 44.2 | 44.4 | 44.3 | 42.3 | 55.6 | 48.0 |
| 22 | 23.7 | 24.3 | 24.0 | 51.2 | 51.4 | 51.3 | 34.8 | 48.7 | 42.3 |
| 23 | 23.7 | 24.1 | 23.9 | 60.2 | 60.3 | 60.2 | 33.5 | 44.5 | 39.6 |
| 24 | 22.2 | 22.5 | 22.4 | 40.1 | 40.1 | 40.1 | 31.2 | 36.9 | 34.9 |
| 25 | 21.4 | 21.8 | 21.6 | 41.3 | 41.3 | 41.3 | 42.3 | 59.4 | 51.7 |

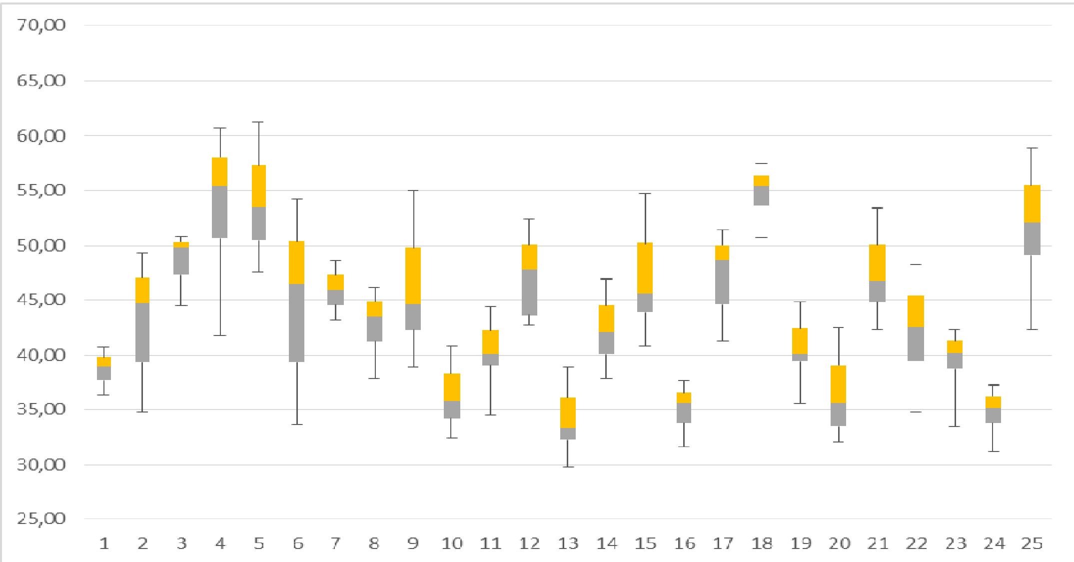


Figure 1: Box plot of sound pressure level.

### *3.2. Chemical factors*

Table 3 presents minimum, maximum and mean values of measured chemical factors. Mean concentrations of $PM_{2.5}$ and $PM_{10}$ range from 9.75 µg/m$^3$ to 71.73 µg/m$^3$ and from

23.63 μg/m$^3$ to 145.10 μg/m$^3$, respectively. Standard deviations for $PM_{2.5}$ and $PM_{10}$ range from 0.42 to 5.02 and from 0.87 to 4.97, respectively. It can be stated that 14 houses, i.e. 56% of them achieved higher concentration of $PM_{2.5}$ than the permissible value of 25 μg/m$^3$ and the permissible value of 50 μg/m$^3$ for $PM_{10}$ was exceeded in 7 houses, i.e. 28%. According to study [17] the mass concentrations of $PM_{2.5}$ ranged from 6 to 28 μg/m$^3$ are to be similar to our results. Huang et al. (2016) [18] conducted a case-control study with home inspection among 454 children in Shanghai, China. This investigation pointed out that more than 70% of the child′s bedrooms had ≤ 75 μg/m$^3$ $PM_{2.5}$ and ≤ 150 μg/m$^3$ $PM_{10}$.

As can be seen in table 3, mean values of TVOC concentrations range from 260 ppm to 791 ppm. The lowest mean level (260 ppm) was measured in house (House 11) with a mean relative humidity of 44.2% and 25.3°C. Very high levels of TVOC concentrations in family houses were recorded in our study. According to study [19] the mean TVOC concentrations in rural houses in severe cold region of China was 0.29 ppm which is considerably less than in our study. As well as in the study [20] the concentrations of TVOC in low-income multi-family housing complex of approximately 800 apartments in USA were less, i.e. interquartile ranged from 0.24 to 0.61 ppm. Measurements of TVOC in 12 low income single-family homes renovated to a deep energy retrofits or energy star standard also confirms such levels, i.e. 0.198 ppm [21].

Table 3: Chemical factors.

| No. | $PM_{2.5}$ [μg/m$^3$] | | | $PM_{10}$ [μg/m$^3$] | | | TVOC [ppm] | | |
|---|---|---|---|---|---|---|---|---|---|
| | min. | max. | mean | min. | max. | mean | min. | max. | mean |
| 1 | 11.50 | 22.40 | 16.36 | 32.10 | 44.10 | 35.89 | 381 | 382 | 381 |
| 2 | 22.10 | 37.80 | 29.57 | 30.20 | 46.20 | 39.13 | 386 | 389 | 387 |
| 3 | 68.30 | 75.60 | 71.73 | 64.80 | 71.20 | 68.90 | 451 | 452 | 452 |
| 4 | 25.50 | 29.10 | 27.15 | 140.30 | 146.20 | 145.10 | 400 | 403 | 401 |
| 5 | 24.50 | 27.50 | 26.16 | 116.00 | 126.80 | 122.03 | 398 | 404 | 399 |
| 6 | 42.90 | 50.90 | 47.14 | 30.70 | 37.60 | 34.59 | 432 | 438 | 435 |
| 7 | 15.50 | 17.80 | 17.05 | 39.50 | 48.90 | 44.11 | 362 | 364 | 363 |
| 8 | 8.70 | 11.50 | 9.75 | 22.40 | 25.10 | 23.63 | 384 | 387 | 385 |
| 9 | 9.90 | 12.70 | 11.54 | 21.70 | 25.80 | 23.71 | 385 | 387 | 386 |
| 10 | 30.70 | 38.40 | 33.33 | 63.70 | 72.60 | 67.17 | 283 | 285 | 284 |
| 11 | 15.80 | 20.70 | 17.72 | 29.70 | 33.50 | 31.24 | 259 | 261 | 260 |
| 12 | 42.80 | 49.80 | 47.13 | 58.90 | 69.90 | 64.86 | 626 | 629 | 628 |
| 13 | 15.20 | 16.50 | 15.99 | 30.20 | 33.20 | 31.28 | 379 | 382 | 381 |
| 14 | 16.70 | 20.40 | 18.62 | 36.50 | 42.10 | 39.09 | 309 | 311 | 310 |
| 15 | 22.30 | 27.80 | 25.18 | 40.30 | 48.70 | 43.09 | 587 | 594 | 592 |
| 16 | 34.80 | 39.50 | 36.52 | 45.50 | 50.70 | 48.44 | 277 | 281 | 279 |
| 17 | 15.90 | 24.50 | 21.56 | 30.80 | 40.10 | 36.43 | 435 | 437 | 436 |
| 18 | 43.60 | 49.90 | 46.36 | 68.10 | 77.60 | 72.14 | 790 | 793 | 791 |
| 19 | 24.10 | 25.90 | 25.16 | 43.10 | 49.80 | 46.46 | 764 | 765 | 764 |
| 20 | 28.70 | 35.60 | 32.40 | 38.20 | 42.50 | 40.42 | 420 | 422 | 421 |
| 21 | 44.10 | 48.50 | 45.52 | 36.40 | 39.80 | 37.81 | 402 | 404 | 403 |
| 22 | 20.60 | 22.80 | 21.56 | 38.70 | 41.60 | 40.12 | 365 | 367 | 366 |
| 23 | 24.50 | 28.20 | 26.47 | 37.40 | 41.20 | 39.13 | 410 | 411 | 410 |
| 24 | 14.70 | 16.20 | 15.28 | 26.80 | 32.30 | 29.74 | 435 | 437 | 436 |
| 25 | 35.40 | 44.50 | 40.72 | 66.80 | 72.40 | 69.98 | 387 | 392 | 390 |

Box plots of $PM_{2.5}$ and $PM_{10}$ concentrations are shown in Figures 2 and 3.

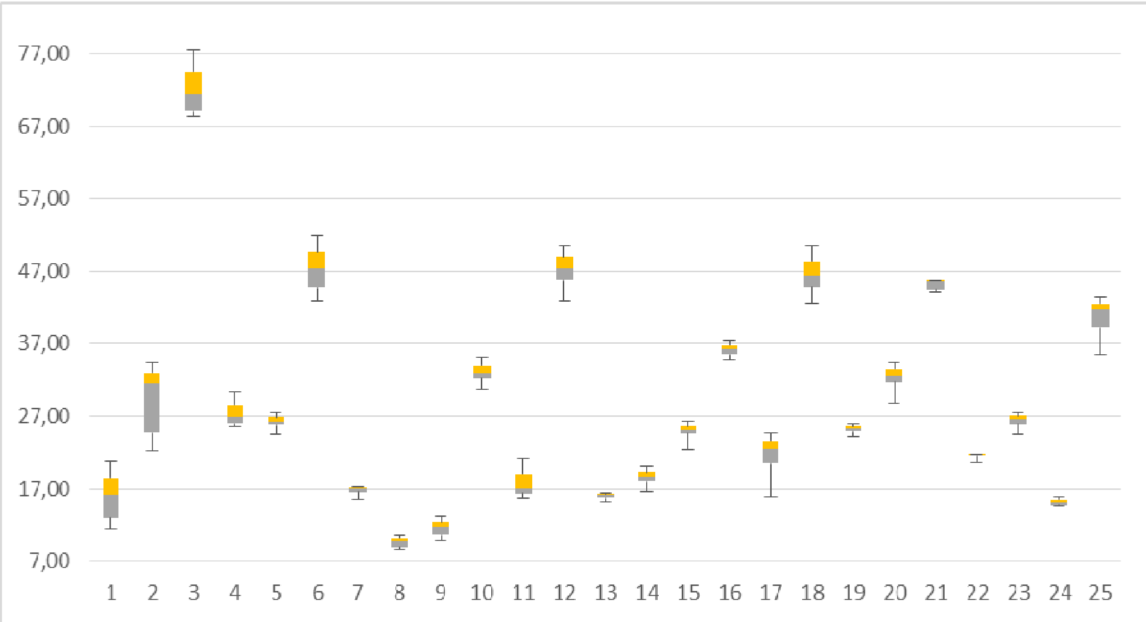


Figure 2: Box plot of $PM_{2.5}$ concentrations.

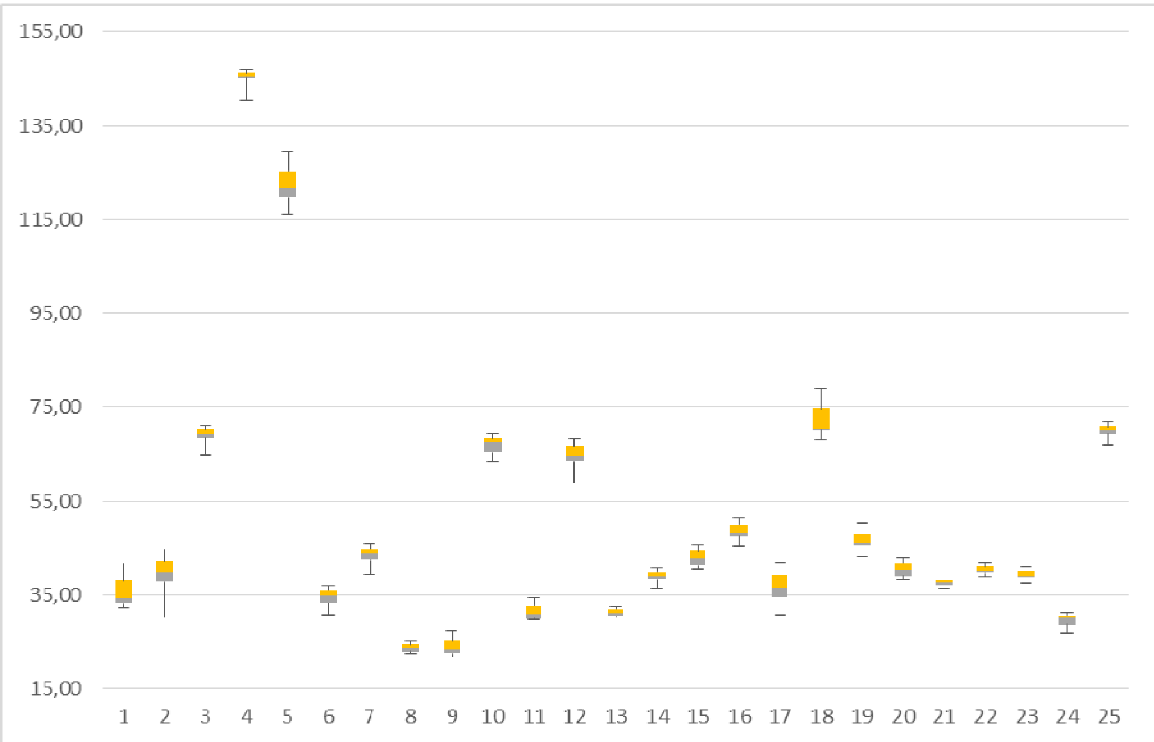


Figure 3: Box plot of $PM_{10}$ concentrations.

# 4 Conclusion

The results of the objective assessment of IAQ parameters confirmed the inadequate quality of the indoor environment in investigated houses in selected town of Macedonia. Results indicated that indoor relative humidity in homes meets the requirement of 30%–70%. The mean values of sound pressure level were high in most of the houses. It can be stated that very high levels of TVOC concentrations in family houses were recorded. Recommended value of 200 $\mu g/m^3$ for human exposure to TVOC was exceeded in 100% of the monitored houses. Limit values of 25 $\mu g/m^3$ for $PM_{2.5}$ and 50 $\mu g/m^3$ for $PM_{10}$ were exceeded in 56% and 28% of the investigated homes, respectively. This study shows that family house users are highly exposed to excessive noise, high concentrations of total volatile organic compounds as well excessive occurrence of particulate matters in the indoor air. It can be concluded that general knowledge of indoor air quality in family houses is often very low and the occupants do not know that exposure to these pollutants has an impact on their health and comfort. The use of electronic systems to alert users to the fact that indoor conditions do not meet the required or recommended criteria can be beneficial to ensure users comfort. It is also important to educate and raise people's awareness of the importance of the indoor environment for their health and well-being. This may motivate them to look at the conditions inside the buildings where they live, work and make their activities. Long-term measurements of indoor environmental parameters need to be performed in order for these parameters to be generalized.

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