Air purifier – individual protection against indoor particulate matter

Oczyszczacz powietrza – indywidualna ochrona przed pyłem powietrza wewnętrznego

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Abstract
The research work presents the findings of testing air purified using two commercial air purifiers available on the local market. Tests were carried out in the office and bedroom of a residential building. The results obtained show a high (75–93%) yield of air purification from particulate matter. Particulate matters fractions such as: PM1, PM2.5, PM4.0, PM10 and total suspended particulates (TSP) were analysed by means professional dust meter. A very strong correlation of particulate matter (PM) contents were found in individual particle classes during equipment operation. Obtained results approve high efficiency of equipment operation in the total range of measured values. This study is one of the first in the topic of assessing the effectiveness of PM purification, taking into account various dust fractions. This study should be useful for individual customers and for public utilities during purchase decisions.

Keywords: pollutants, treatment, allergens, PM10, PM2.5

Introduction

In Poland there were a lot of outdoor air pollution programs implemented in the past and some of them are still available nowadays, such as: *PONE, PGN, POŚ, KAWKA, RYŚ, SMOG STOP*, but air quality in Poland is still bad, especially in the so-called heating season. The above statement applies especially to Lesser Poland, including Tarnów City [1]. The growing awareness of the impact of air quality on human health. Technical progress have recently seen started a growing of interest in air purifiers. Their high availability, price range and additional functions, such as: humidification, air quality indicators, dust content in the air, relative humidity indications, odors absorption, toxic formaldehyde and harmful volatile organic compounds may be very useful for potential users. The ability to remote control of air quality, start and stop time devices in flats by applications related to a mobile phone are some of the most important their innovations. Nowadays, their manufacturers outdo each other in the number of filtration levels, with the ability to retain not only dust, but also ensure the right microbiological quality of the air (by maintaining adequate humidity). Many potential users are wondering if these devices really are capable of effective air purification. Many people suffer that the problem of smog. It is currently important media topic. Many people thing that indoor air quality is definitely better than outdoor, but in many cases it is not true. That is why a lot of people consider this purchase. Currently available on the Polish market, air purifiers are technically advanced devices capable (according to producers) to remove up to 99.97% of PM and chemical pollution of the air and by control of air humidity can reduce the biological pollution of air by 99% [2]. In order to protect children from air pollution, programme "I can! Stop smog" was established [3]. Under this programme 500 devices were available, while in the Lesser Poland voivodship the program of purchasing air purifiers for kindergartens was launched in 2018 [4]. Although some money were granted to purchase these devices, in practice kindergartens who applied for a purchase usually received one purifier per building, which probably did not resolve their problem comprehensively. Nowadays, there is a little scientific information verifying the effectiveness of air purifiers. Especially in conditions of typical use, which, however, may differ from the laboratory conditions in which these devices were tested in accordance with relevant standards. The presented research results relate to two air purifiers, for which research with their participation was conducted in the office and in the bedroom of a sin-

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gle-family home with a child allergy to domestic dust. Airborne dust can be very diverse in terms of chemical composition and distribution of individual dust fractions [5]. However, as a rule, fine dust fractions are more harmful to the body compared to coarse fractions. Therefore, the problem of removing very small dust fraction seems to be of particular interest. Atmospheric dust is a carrier of harmful chemicals such as polycyclic aromatic hydrocarbons (PAH) [6], heavy metals (especially Hg, Pb and Cd) [7], polychlorinated dioxins and furans (PCDD/F) [8], persistent radicals [9] and therefore exposure to high concentrations of dust in atmosphere can be the reason for poisoning the organisms [10]. Dust of both natural and anthropogenic origin is an important asthmatic [11] and allergic factor [12], because house dust is also a habitat of mites to which a number of people show allergic reactions [13].

The aim of the paper is to assess the suitability of air purifiers for improving indoor air quality. Test devices have been used for over a month, so subjective observations and conclusions regarding their use are also included. Comparative studies were conducted for five consecutive days, and the results presented represent typical values that have been achieved. Due to the very variable dustiness in the office related to renovation works of various nature at work, the results of measurements on the day of highest dustiness are presented. The overriding purpose of presenting the results obtained is to provide basic quantitative data on the effectiveness of indoor air purification taking into account various dust fractions. From the analysis of scientific literature and Internet information (except for manufacturers' data), there is currently no reliable information that would be helpful in the decision-making process before purchasing this type of equipment, whose average unit cost is about 2,000 PLN.

Materials and methods

During the tests, the purifier with the air humidification function model AC3829/10 and the equivalent of another manufacturer model KC-G60EU-W were used. Table 1 presents basic technical data for both models.

Dusts in the rooms were tested using a Met One Instruments laser dust meter model Aerocet 831. The measurements were made in the form of two series, each series lasted 60 seconds. Averaged values from two measurement series were set as the measurement result. The air temperature and humidity was monitored using a *VOLTCRAFT CO-60* meter, the relative humidity indications measured by the built-in hygrometer.

The tests were carried out in rooms with areas: office room 15 m^2, bedroom 13 m^2. In each of the rooms, the temperature and relative humidity were initially determined. Then the PM content was determined using a professional dust meter. During the measurements, the detector was 1.5 m above the floor. Statistical analysis of measurement data was performed using the *Statistica* software ver. 13.

Results

The example below illustrates the situation of an office room in the vicinity of which renovation works were carried out. These works lasted few days and the employees felt discomfort concerned with high PM concentration in the air. The dust was hydroscopic, which additionally resulted in low relative humidity of H <20%. Table 2 presents the results of measurements before (measurement 1) and after starting the air purifier.

The obtained results of air purification using both air purifiers show a strong correlation (R^2> 0.9), which is presented in Tables 3 and 5.

Principal component analysis (PCA) for the results of measurements of dustiness in the office indicates that one main component (factor 1) describes as much as 99% of the variance of the results obtained (Fig. 1). This means that providing only one measurement quantity characterizing the air quality, e.g. PM2.5 dust, is quite sufficient to determine the air quality in the total measuring range, i.e. 0.1–15 μg/m^3. The position of individual points on the chart of points on the factor plane (Fig. 1) and their relative location probably result from the way the purifier works, which in automatic mode, depending on dustiness, selects the appropriate air flow, which translates into the

Table 1. Comparison of technical parameters of air purifiers used *

Parameter	Model AC3829/10	Model KC-G60EUW
Max. CADR or airflow [m^3/h]	310	408
Recommended max. area [m^2]	38.75	51
Recommended max. volume [m^3]	96.87	12.5
Noise [dB]	32	24; 48; 53
Power [W]	45	6.5; 40; 55
Prefilter	Yes	Yes
Activated carbon filter	Yes	Yes
HEPA filter	Yes	Yes

*(manufacturers data)

Table 2. PM during the operation of purifier A in the office (T=20°C, H=18%)

Working time [min]	PM1 [µg/m³]	PM2.5 [µg/m³]	PM4 [µg/m³]	PM10 [µg/m³]	TSP [µg/m³]
0	4.7±0.5	19.3±1.9	43.3±4.3	74.1±7.4	135.2±14
3	4.3±0.4	19.7±2.0	41.3±4.1	70.5±7.1	138.5±14
5	3.4±0.3	14.5±1.5	31.5±3.2	48.4±4.8	101.0±10
7	2.3±0.2	10.5±1.0	21.7±2.2	33.0±3.3	64.4±6.4
11	1.9±0.2	9.1±0.9	17.4±1.7	29.8±3.0	60.1±6.0
13	1.5±0.1	6.7±0.7	14.9±1.5	24.8±2.5	50.1±5.0
15	1.2±0.1	4.6±0.5	10.7±1.1	28.9±2.9	38.1±3.8
400	0.8±0.1	3.6±0.4	7.3±0.7	18.3±1.8	27.5±2.8

Table 3. Correlation matrix of various dust fractions (measurements in the office)

	PM1	PM2.5	PM4	PM10	TSP
PM1	-	0.991	0.999	0.954	0.989
PM2.5	0.991	-	0.994	0.935	0.987
PM4	0.999	0.994	-	0.958	0.993
PM10	0.954	0.935	0.958	-	0.976
TSP	0.989	0.987	0.993	0.976	-

multiplicity of air exchange. In the situation of very poor air quality, which occurred at the beginning, the device operates at maximum fan speeds, which is associated with a quick reduction of dust. Then the filtration rate is reduced, which means that the changes in dust are not so significant.

Also in the example of dust measurements in the bedroom (Tab. 4) a significant improvement in air quality can be observed very quickly. This air is much better purified, however, this is due to the smaller volume of wrinkle and the smaller initial pollution than was observed in the office.

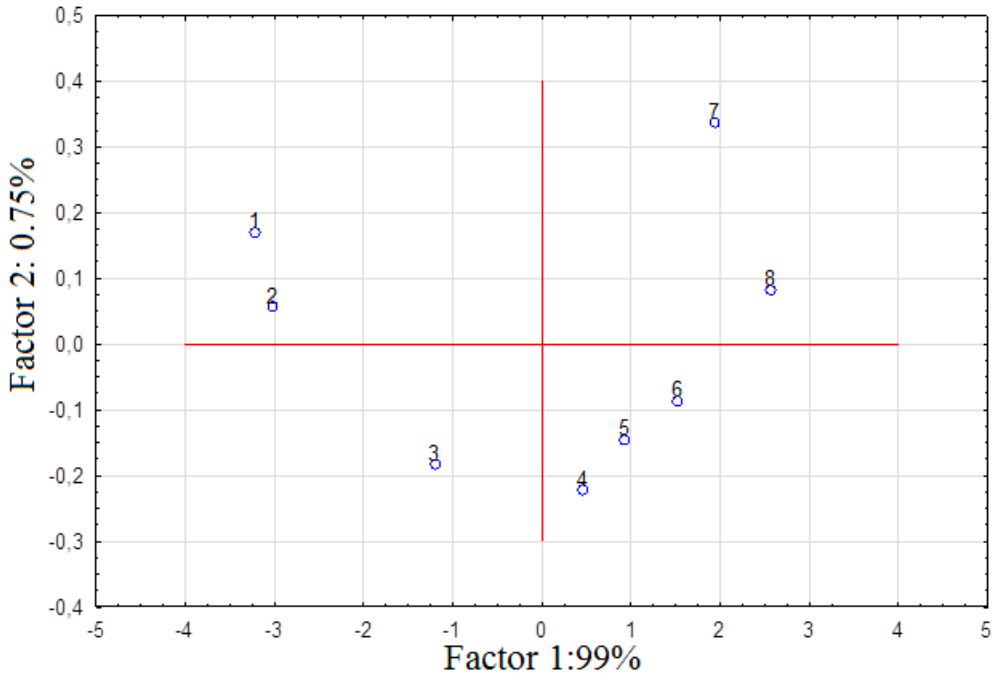

Figure 1. Analysis of the main components for measurements of dust in the office

Table 4. Air quality during purifier B operation in the bedroom (T=20°C, H=46%)

Working time [min]	PM1 [µg/m³]	PM2.5 [µg/m³]	PM4 [µg/m³]	PM10 [µg/m³]	TSP [µg/m³]
0	0.7±0.1	2.8±0.3	8.7±0.9	22.3±2.2	45.7±4.6
3	0.5±0.1	1.6±0.2	6.3±0.6	18.9±1.9	34.3±3.4
5	0.5±0.1	2.0±0.2	5.7±0.6	14.6±1.5	30.6±3.1
7	0.5±0.1	1.9±0.2	5.1±0.5	12.5±1.2	21.8±2.2
11	0.3±0.1	1.3±0.1	3.7±0.4	10.2±1.0	12.6±1.3
13	0.3±0.1	1.3±0.1	3.2±0.3	9.0±0.9	15.2±1.5
15	0.2±0.1	1.0±0.1	2.9±0.3	8.1±0.8	8.7±0.9
150	0.1±0.1	0.2±0.1	0.9±0.1	2.4±0.2	6.1±0.6

The analysis of the correlation matrix (Tab. 5) indicates a strong correlation of the majority of measured dust fraction content in the air. Only the correlation between the PM2.5 fraction and total dust (TSP) is less correlated than the others, but it is still a strong correlation [14].

Based on the PCA analysis of the results of PM measurements approx. 97% of the variance of results can be described using only the first component, the second information obtained is such that the first and especially the second measurement are weakly correlated with the others (Fig. 2) of PM from the bedroom.

Table 6 shows the results of the maximum efficiency of air purification using two different air purifiers.

Table 5. Correlation matrix of various dust fractions (measurements in the bedroom)

	PM1	PM2.5	PM4	PM10	TSP
PM1	-	0.970	0.988	0.952	0.956
PM2.5	0.970	-	0.949	0.910	0.895
PM4	0.988	0.949	-	0.977	0.977
PM10	0.952	0.910	0.977	-	0.965
TSP	0.956	0.895	0.977	0.965	-

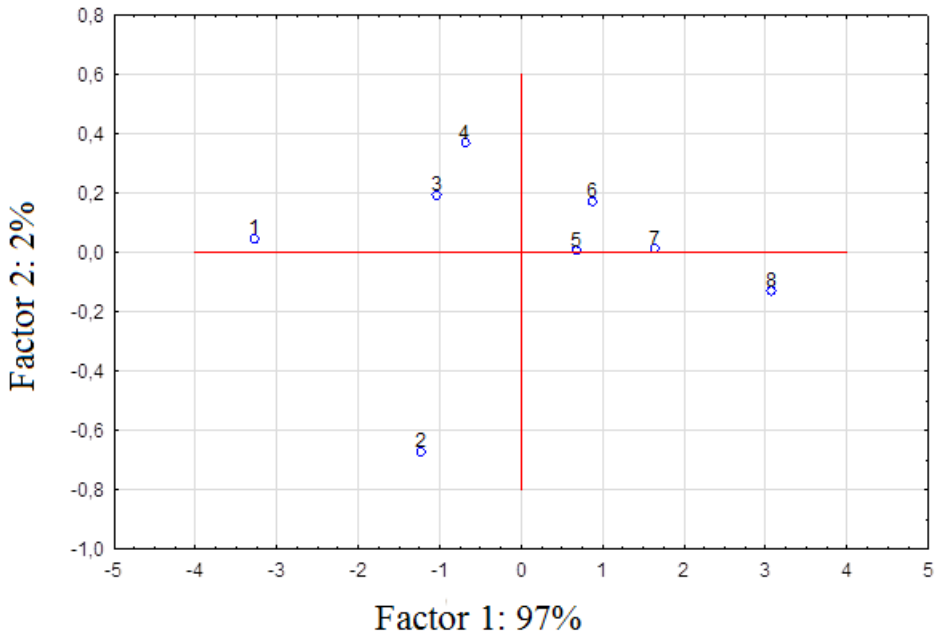

Figure 2. Analysis of the main components for measurements of air dust in the bedroom

Table 6. Maximum efficiency of purifiers, including dust fractions

Device	PM1 [%]	PM2,5 [%]	PM4 [%]	PM10 [%]	TSP [%]
A	83	81	83	75	80
B	86	93	90	89	87

Discussion

Obtained results of air purification under normal operating conditions indicate that the purification efficiency is between 75–93%. From the data provided by one of the purifier manufacturers, it is known that the purification efficiency with this device is 99.97% for the PM0.3 dust fraction. Unfortunately, it is difficult to verify, because neither the purifiers used, although they have a dust sensor (only PM2.5) nor routinely used dust meters, measure this particular dust fraction. However, usually the efficiency of cleaning air from smaller particles is worse than larger, so it is doubtful that under the conditions in which the devices were tested, such a result could be obtained. During use (after 4 weeks of operation) one of the air purifiers underwent a serious technical failure. However, this failure was removed within 3 weeks under the manufacturer's warranty. A very useful technical solution that these devices is a built-in dust sensor (PM 2.5 only). Based on the indications of this meter, the user is informed about the PM2.5 dust content in the air, in addition, the colour of the display frame (four indicator colours) informs about the air quality (Fig. 3).

Figure 3. Display informs about air quality and PM concentration

Statistical assessment of the results obtained shows that there is a strong correlation between individual dust fractions, even between PM1 and TSP. This proves that the HEPA filter is properly selected, which is effective not only for coarse dust, but also for submicron dust (PM1). This is important because as the particulate matter increases, its harmfulness and the ability to penetrate the body increases. From a technical point of view, it seems that in the case of one producer, the carbon filter could contain a larger amount of filling (activated carbon), because the currently used packing (Fig. 4) means that filtration does not take place over the entire filter surface. It is even expected that the main air stream will pass over the sorbent due to the lower flow resistance.

Figure 4. Packing the carbon filter of the air purifier

The cleaners in standby mode (they do not clean, do not humidify, they are only connected to the electric network) consume about 1 W electricity, work in the night mode consumes about 8 W, work in automatic mode without air humidification is about 18 W consumption, with air humidification approx. 24 W. It is much less than the rated power of the device provided by the manufacturers (however, usually the device does not work at the maximum parameters of purification and humidification at the same time). The use of three-stage air filtration seems to be the best possible application. The pre-filter retains larger dust particles, thanks to which the user extends the HEPA filter's period by cleaning it periodically. The carbon filter is designed to stop chemical impurities such as formaldehyde and volatile organic compounds. The HEPA filter is the basic purifying element that allows the removal of solid particles in a wide fraction range (Fig. 5).

Conclusions

Air purifiers available on the Polish market is a good idea that should be considered, but there are still expensive. Despite the high social awareness and governmental and local government activities, the outdoor air in our country is still far from the quality observed in many European countries. For this reason, the market for air purifiers is reacting very dynamically, even it is possible to hire such devices from the manufacturer. Although

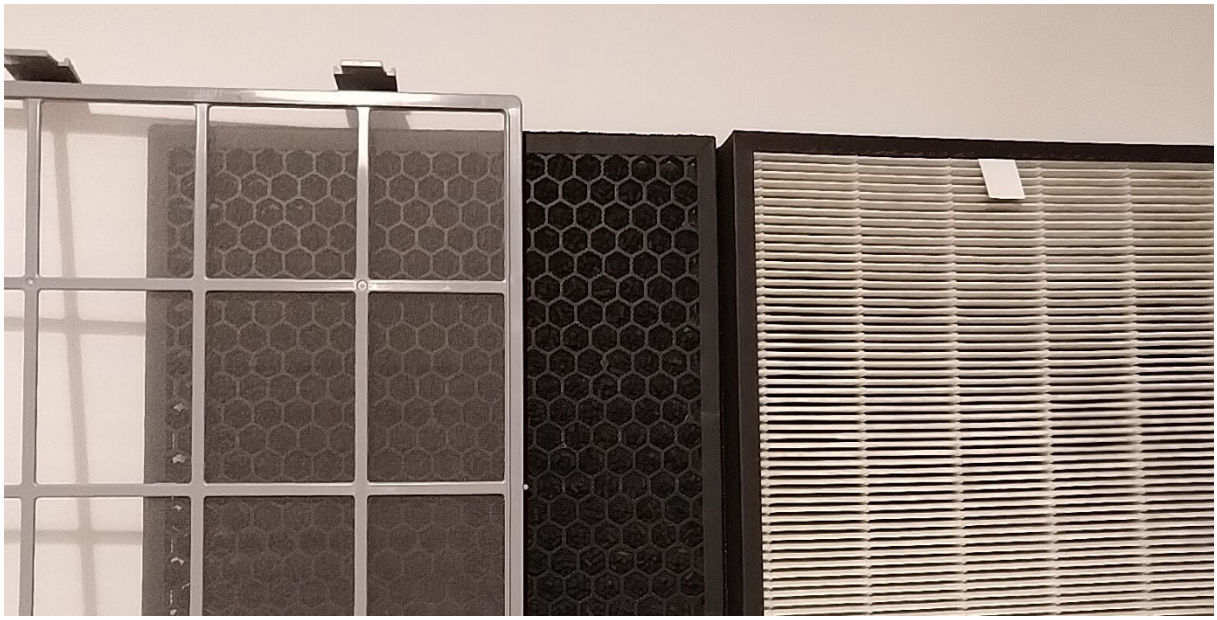

Figure 5. Filters (from the left): preliminary, carbon, HEPA

the carried out experiments did not achieve such impressive purification efficiency as reported by the producers, however, satisfactory air purification efficiency was obtained in both considered cases. However, the basis for the proper operation mode of the device is care for the technical condition of the filters. This also applies to the moisturizing system. Lack of hygiene practise in this activity, as well as contamination of the prefilters can affect to secondary air pollution. Often, as soon as the purifier is turned on, the dust concentration increases, because the air flow passing through the filtration system introduces particles of dust impurities deposited on the walls, floor, furniture or lamps. The disadvantage of these devices is the relatively high price of filters, depending on the manufacturer, model and type of filters, respectively: carbon filter 180–280 PLN, moisturizing filter 40–300 PLN, HEPA filter 70–460 PLN, prefilter 35–100 PLN. For moistening purposes, manufacturers recommend tap water, while using deionized water would significantly extend the lifetime of this element.

The use of this type of air purifiers in schools and kindergartens does not seem to be the optimal solution, as this device does not treat the air in relation to its carbon dioxide (CO_2) pollution, which, as the author's unpublished work indicate. Carbon dioxide high concentration is a permanent problem in Polish educational institutions. In such situations, instead of invest money in air purifiers by local governments, should be launched a new program to buy air purifiers drawn from the outside by a wall mounted cleaner or external air purification using a mechanical ventilation system (unfortunately, few buildings still have one).

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Streszczenie

W artykule zaprezentowano wyniki badań powietrza poddanego oczyszczaniu za pomocą dwóch urządzeń komercyjnych dostępnych na polskim rynku. Badania przeprowadzono w pomieszczeniu biurowym i sypialni domu mieszkalnego. Otrzymane wyniki wskazują na wysoki (75–93%) stopień oczyszczenia powietrza. Analizom poddano takie frakcje pyłowe jak: PM1, PM2,5, PM4,0, PM10 i pył całkowity (TSP). Stwierdzono bardzo silną korelację zawartości pyłów w poszczególnych klasach ziarnowych pyłów podczas pracy urządzeń. Oznacza to wysoką skuteczność pracy urządzeń w całym zakresie mierzonych zawartości zanieczyszczeń pyłowych. Opracowanie to jest jednym z pierwszych w zakresie oceny skuteczności oczyszczania pyłów z uwzględnieniem różnych frakcji pyłowych i może stanowić materiał pomocniczy dla użytkowników indywidualnych oraz decydentów rozważających zakup urządzeń oczyszczających powietrze dla jednostek oświatowych.

Słowa kluczowe: zanieczyszczenia, uzdatnianie, alergeny, PM10, PM2,5