

THE USE OF CARBON FILTER IN THE PORTABLE CLEANING DEVICE FOR FILTRATION AND STERILIZATION OF INDOOR AIR

Walter MUCHA ^{a*}, Józef S. PASTUSZKA ^b

^a Dr.; Faculty of Energy and Environmental Engineering, The Silesian University of Technology, Akademicka 2, 44-100, Gliwice, Poland

*E-mail address: *Walter.Mucha@polsl.pl*

^b Prof.; Faculty of Energy and Environmental Engineering, The Silesian University of Technology, Akademicka 2, 44-100, Gliwice, Poland

Received: 08.05.2010; Revised: 25.05.2010; Accepted: 17.11.2010

Abstract

Indoor air is frequently polluted by bioaerosol. Exposure to bioaerosols may be especially hazardous in outpatient clinics and hospitals. Hence, it is very important to clean air in such places, especially in operating rooms. For this purpose various portable air cleaners can be used. The Electron Wind Generator (EWG) is such an air purification device which uses a sophisticated combination of electrode topology which produces high voltage. Previous studies have shown that this portable air cleaner can be successfully used for disinfection of indoor air. Unfortunately, due to the high voltage significant emission of ozone has been observed during the cleaner operation. Therefore, the carbon filter in the EWG device has been applied to reduce the emission of ozone. This paper presents preliminary results of the study on the effectiveness of ozone removal by the applied filter. Obtained data indicate that the tested carbon filter guarantees the 60-80% reduction of ozone emission during the continuous work of the studied device up to six hours. During longer term of work, a filter with higher mass density of activated carbon needs to be used.

Streszczenie

Powietrze wewnętrzne jest często zanieczyszczone bioaerozolem. Narażenie na bioaerozole może być szczególnie groźne w przychodniach zdrowia i w szpitalach. Z tego względu bardzo ważne jest oczyszczanie powietrza w takich pomieszczeniach, a zwłaszcza w salach operacyjnych. Do tego celu mogą być wykorzystane różne przenośne oczyszczacze powietrza. Takim oczyszczaczem powietrza jest urządzenie zwane elektronowym generatorem wiatru (EWG), wykorzystującym specyficzną topologię elektrod wytwarzających wysokie napięcie. Poprzednie badania wykazały, że tenże przenośny oczyszczacz powietrza może być pomyślnie wykorzystany do dezynfekcji powietrza. Niestety, ze względu na występujące w tym urządzeniu wysokie napięcie, w trakcie pracy oczyszczacza obserwowano znaczącą emisję ozonu. Aby zmniejszyć emisję ozonu zainstalowano w urządzeniu EWG filtr węglowy. Niniejszy artykuł przedstawia wstępne wyniki efektywności usuwania ozonu przez zastosowany filtr. Otrzymane dane wskazują, że testowany filtr węglowy gwarantuje 60-80% redukcję emisji ozonu w czasie ciągłej pracy badanego urządzenia aż do sześciu godzin. Dłuższy okres pracy wymaga zastosowania filtra o większej gęstości masowej węgla aktywnego.

Keywords: Sterilization device; Carbon filter; Ozone emission; Indoor air.

1. INTRODUCTION

The health associations of respirable aerosol particles have drawn considerable attention to the indoor air quality. On the other hand, a research on time distribution of the general population shows that from about 50% up to about 80% of time is spent indoors, mostly

in dwellings (see, for example, [1]). Therefore, reduction of exposure to the indoor airborne particles, including bacteria and fungi, represents a particular challenge [2-4]. This problem is becoming particularly vital in rooms which should be characterized by high cleanness, even sterility of air i.e.: operating rooms at

hospitals, clinical waiting rooms, production halls of pharmaceutical and food industry, etc. Due to the fact that allergens comprise many ingredients of particulate matter and bioaerosol, it is often necessary to ensure above the standard air cleanness in habitable rooms. Hence, designing appliances for rapid and efficient indoor air purification becomes very important. With respect to particulate aerosol, this task is performed by different types of air purifiers which take in and filter the air. In fact, there is a number of commercially available portable devices designed for cleaning air in a confined space. Most popular are, certainly, HEPA filter models using HEPA filters which are highly efficient particulate arresting filters made of densely packed submicron-diameter fibers that are pleated for extended surface area. So called "electric (or electrets) filters" are made of electrically polarized polyester mesh to trap dust particulates [5]. In electrostatic precipitators, particles are charged by passing over a high voltage thin wire followed by collection on electrically polarized metal plates. Ionizers electrically charged particles which are then attracted to surface at or near ground potential such as walls, table tops, draperies, occupants, etc. Some years ago Mayya *et al.* [6] formulated a system of equations by considering various processes responsible for aerosol removal in the presence of the ionizers.

Generally, to reduce the health risk from bioaerosols exposure, various controlling technologies [7], including photocatalytic oxidation have been investigated [8-10]. Also combinations of different techniques were developed to clean indoor air. For example, the ionization was found to significantly enhance the filter efficiency in removing viable biological particles from the airflow [11].

Sterilization of indoor spaces in the presence of people is also tried to be performed by means of, so called, closed germicidal lamps. They consist of ultraviolet fluorescent bulbs UV-C placed in a closed shell with two openings. The bulbs do not contain luminophore and are manufactured of ultraviolet pervasive kind of glass. As a consequence of operation of a blow-out fan, which is placed in the shell in front of the escape opening, air containing microorganisms is forced to circulate through the inlet opening. The air that has been taken in travels along fluorescent bulbs where it becomes exposed to ultraviolet radiation and subsequently leaves the appliance through the escape opening [7]. These appliances are mainly applied to microbial sterilization. Their effectiveness in eliminating microscopic fungi from the air is considerably lower [7].

The Electron Wind Generator (EWG) purifier that has been designed in the USA works on a completely different basis. It is a small device, which generates strong electric field. Thanks to appropriate electrode topology, the apparatus generates continuous circulation of air through the net of electrodes. The air that is drawn in this way is sterilized in the electric field. Since the above mentioned functioning of the EWG apparatus brings about ionization of particulate matter, it can be expected that the apparatus will clean the air from both coarse and fine aerosol particles, including, for example, tobacco smoke particles. It is worth mentioning, that tobacco smoke contains mainly submicron particles which are very difficult to eliminate from the environment by means of traditional filtration. Although the sophisticated topology of the electrodes applied in the EWG device is rather unique, the unipolar ion generators are commonly used for lowering particulate levels in indoor environments [11-14]. These systems are preferred in domestic applications because they do not involve extensive filtration systems and require minimum supervision. Most air ionizers consist of an array of sharp needles maintained at a negative potential with respect to the ground (from about 5 to 15 kV) [11], although sometimes, cylindrical wire arrangements have also been used [13]. Quite recently Yu *et al.* [15] studied the removal of bioaerosol particles by means of a photocatalytic filter and negative air ions combination.

Concerning the EWG device it should be noted that study that has been carried out so far, shows that the application of EWG sterilizer appears to be very promising, because there in its chamber, almost all bacteria and fungi are killed in a high voltage field. This is possible because of irreversible damage to cell pellicle and disturbance in replication of microbes as a result of double DNA strand breaks. The operation of EWG appliance considerably reduces the concentration of alive airborne bacteria and fungi in rooms. However, the effectiveness of purification process/sterilization depends on internal sources of emission of bioaerosols but first and foremost on the number of people staying in a room, air circulation (air exchange rate) and room cubature. The best results have been achieved in small spaces with a low air exchange rate, e.g. in an office room of 30 m³ or in a small three-person patient room [16]. With windows closed and only occasionally opened door, the initial concentration of microbial aerosol in this type of spaces has been going down: it halved after 2 hours of the device working against the initial concentration and after 10-26 hours of the device working to 15% of the initial concentration [16]. Unfortunately, the

functioning of this sterilizer is connected with ozone emission. In fact, in the eighties and the nineties of the last century there was an increased interest in devices that are generally called ozone-generating machines. These air cleaners were designed to emit ozone gas to reduce contaminant levels in the space [5]. It is well known that emission of ozone can additionally decrease the concentration of alive microorganisms in the air, however the increase of ozone concentration in rooms affects people's health negatively. A general overview of health effects related to ozone exposure [17] indicates that both acute and chronic health effects may be caused by ozone exposure.

In normal circumstances, ozone is a pungent, explosive gas of pale blue color and powerful oxidizing features. Gaseous ozone condenses below the temperature of -119.0°C and below the temperature of -192.7°C it becomes solid. The most probable structure of an ozone molecule is of a form of two identical bonds oxygen-oxygen with a distance of $0.1278 \pm 0.003 \text{ nm}$ and the angle between them of $116^{\circ}49' \pm 30''$ [18]. In natural circumstances, ozone affects human respiratory system (produces irritation to the throat, evokes coughing, burning eyes, nausea, dizziness), when exposed to it for longer time, it can cause extensive and irreversible changes, especially in lungs [19].

Acceptable concentration rate for indoor spaces intended for humans' stay in Poland amounts to: A category rooms – 0.1 mg/m^3 , B category rooms –

0.15 mg/m^3 [20, 21]. The Highest Permissible Concentration (NDS) at a work place equals – 0.15 mg/m^3 [21].

The above described problem of high emission of ozone from the EWG device should be solved to build the improved version of fully safe EWG sterilizer. It was assumed in this work that the ozone emission from a portable, high-voltage air sterilizer could be reduced by applying a carbon filter.

Activated carbon, commonly used in air protection systems as an adsorbent for different pollutants removal, is a porous material whose structure is formed by a set of randomly laid graphite plates. It is made from various materials: coal, peat, wood and coconut shell. Majority of kinds of carbon applied in air protection are produced from coal. Graphite plates have a very large specific surface area (one gram of activated carbon has a surface area of up to 900 m^2), which provides excellent adsorption for organic pollution removal.

It seems that the EWG sterilizer could be equipped with a carbon filter and also a cloth filter which would captivate coarse particles. However, then it would be essential to increase the air stream that is taken in, which can be achieved by means of a small fan. Figure 1 shows a diagram of such a hybrid system serving the purpose of particle matter removal and a sterilizer.

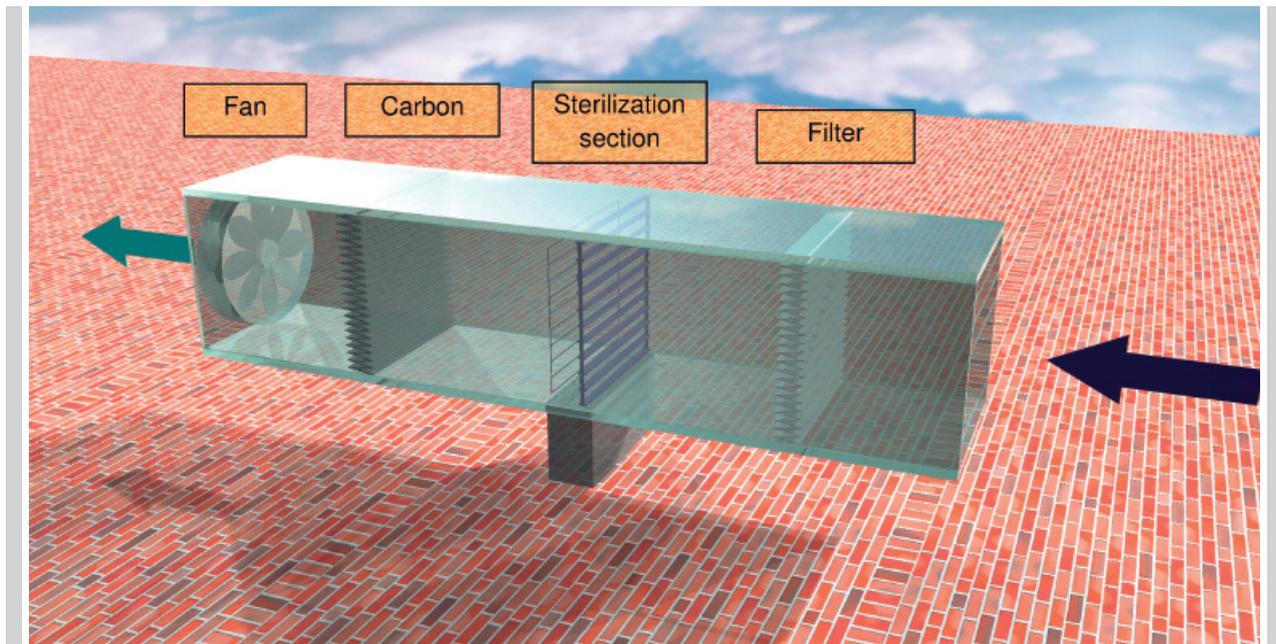


Figure 1.
Diagram of a the sterilizing hybrid system with a carbon filter

In this paper, the results of the study of ozone emission from this hybrid device compared with the original EWG sterilizer are presented.

2. METHODS

Measurements have been carried out during four days in the room of 85 m³. This room had a natural ventilation system. Air samples were taken every hour for the period of seven hours starting at 8:00 am. Meteorological conditions were comparable for all these days. The temperature varied from 21.5 to 22.5°C, relative humidity ranged from 56 to 59%, and air pressure was equal to 996 hPa.

Quantitative determination of the ozone level has been performed using colorimetric method with dimethyl-p-phenyldiamine. Ozone concentrations in the absorption fluid have been measured by means of a scanning spectrophotometer UV-VIS by Shimadzu.

3. RESULTS AND DISCUSSION

The main parameters of the used sterilizer EWG are presented in Table 1 while Figure 2 shows the time dependence of ozone concentrations in the studied room. As it can be seen, when the activated carbon was not used the concentration of ozone in the room was going up quite fast during the first 3 hours of the sterilizer operation to reach almost 2.8 µg/m³ and then after 4 hours passed it stabilized to the concentration level of slightly over 3 µg/m³. When the filter was in place, the ozone concentration was increasing considerably slower and stabilized to a considerably lower level of about 1.2 µg/m³.

On the basis of the measurements of the ozone concentration and velocity of the ozone – containing air, blowing up from the sterilizer outlet, it was possible to calculate the emission of ozone. The obtained result is presented in Table 2.

As it can be seen, temporal emission of ozone from the

EWG sterilizer amounted to 9 µg/min., whereas when the carbon filter was installed the emission was reduced to the level of about 4 µg/min. Hence, the effectiveness of the carbon filter preventing ozone from escaping amounted to 60%. As a rule, however, such efficiency of absorbing filter is calculated on the basis of data obtained simultaneously in front of and behind the activated carbon filter. The results of the next experiment when the concentrations of ozone were measured in front of and behind the activated carbon filter are presented in Figure 3. The background concentration of ozone in the studied room is also shown there.

It can be seen that the “pierce” phenomenon when the mass of ozone adsorbed on the carbon filter reached the maximum level has been observed after about 6 hours of work. It means that the significant emission of ozone appeared later what caused rapid increase of ozone concentration. Although the obtained result indicates the important limitation for using this developed EWG cleaner, there are two ways to make the sterilization for a long time (24-hours for example): stop the operation of this device for 2-3 hours (filter can self-clean from the ozone after some hours) or use the filter having higher mass density of activated carbon.

Calculated emission level averaged for the period of 6 hours during this experiment was 0.207 µg/s and 0.044 µg/s in front of and behind the activated carbon filter, respectively, which means that the efficiency of the carbon filter preventing ozone from escaping was 78.6%. It should be noted that obtained effectiveness in ozone removal is significantly higher compared to other filtration materials. For instance, Zhao and associates [23] achieved the effectiveness of ozone removal for filters used in HVAC appliances within the range of 0 to 9% when the filters were clean and 10 to 41% when they were contaminated with particulate matter.

Table 1.
Basic parameters of the sterilizer

Parameter	Value
Mass of the activated carbon filter	90 g
Granulation of the activated carbon filter	0.5 ÷ 1.0 mm
Specific surface of the activated carbon filter	900 m ² /g
Cross-sectional area of the activated carbon filter	0.042 m ²
Average velocity of air stream behind activated carbon filter	2.2 m/s
Air stream going through the sterilizer	0.0924 m ³ /s

Table 2.
Calculated ozone emission levels

Experimental design	Result
Ozone emission when activated carbon filter was not applied	9.175 µg/min
Ozone emission when activated carbon filter was applied	3.77 µg/min

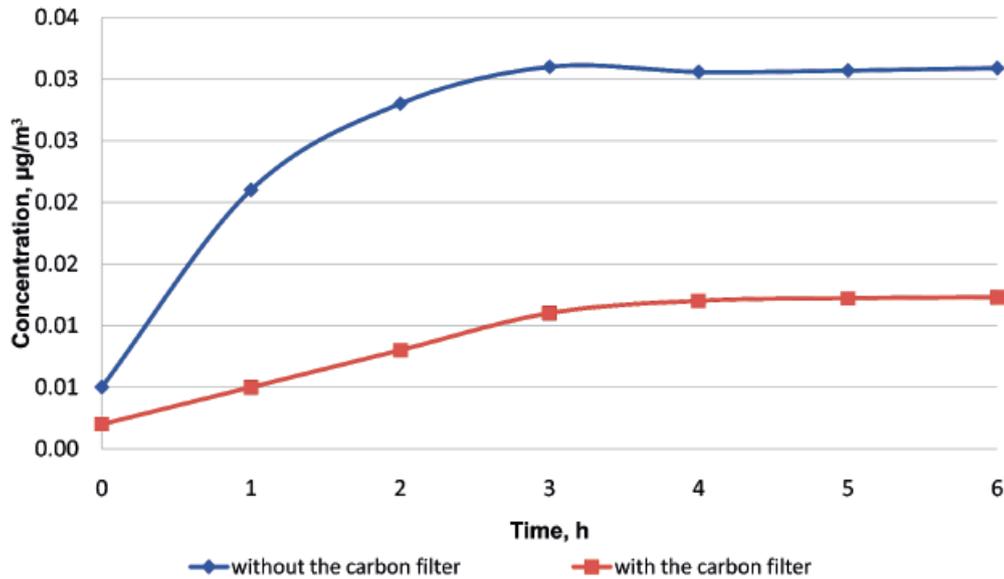


Figure 2.
Time dependence of the concentration of ozone in the room which is being sterilized by the EWG device

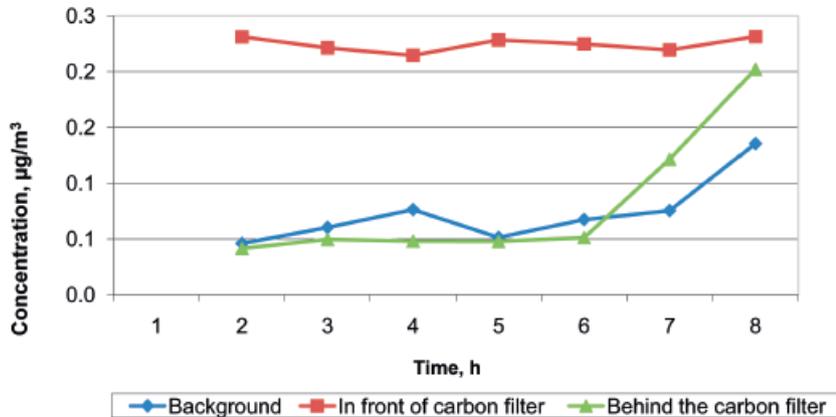


Figure 3.
Background concentration of ozone in the studied room, as well as in two sites inside the EWG device: in front of and behind the activated carbon filter

4. CONCLUSIONS

The application of an activated carbon filter into a portable, high voltage air sterilizer (EWG) cuts the emission of ozone from this appliance down by 60-80%. Such significant fall of emission leads to ozone

concentration in air to being reduced about three times, after several hours of operation of the sterilizer equipped with a carbon filter in a naturally ventilated room of 85 m³, compared to the concentration of ozone which is produced when the sterilizer is working without the carbon filter.

Tested carbon filter guarantees the reduction of ozone emission during the continuous work of the studied device up to six hours. During longer term of work, a filter with higher mass density of activated carbon needs to be used.

REFERENCES

- [1] *Zabiegała B., Patryka M., Namieśnik J.*; Jakość powietrza wewnętrznego – analiza i monitoring, (w:) Nowe horyzonty w analityce i monitoringu środowiskowym (Quality of indoor air – analysis and monitoring, (in:) Challenges in Analysis and Environmental Monitoring, Centrum Doskonalenia Analityki i Monitoringu Środowiskowego, Gdańsk, 2003 (in Polish)
- [2] *Pastuszka J.S.*; Exposure of the General Population Living in Upper Silesia Industrial Zone to the Particulate, Fibrous and Biological (Bacteria and Fungi) Aerosols (In Polish), Wrocław Technical University, Wrocław, Poland, 2001
- [3] *Douwes J., Thorne P., Pearce N., Heederik D.*; Bioaerosol health effects and exposure assessment: progress and prospects. *Annals of Occupational Hygiene* 47, 2003; p.187-200
- [4] *Pastuszka J.S., Paw U.K.T., Lis D.O., Wlazło A., Ulfig K.*; Bacterial and fungal aerosol in indoor environment in Upper Silesia, Poland. *Atmospheric Environment* 34, 2000; p.3833-3842
- [5] *Shaughnessy R.J., Levetin E., Blocker J., Sublette K.L.*; Effectiveness of portable indoor air cleaners: sensory testing results. *Indoor Air* 4, 1994; p.179-188
- [6] *Mayya Y.S., Sapra B.K., Khan A., Sunny F.*; Aerosol removal by unipolar ionization in indoor environments. *Journal of Aerosol Science* 35, 2004; p.923-941
- [7] *Kabata A., Pastuszka J.S.*; Efficiency of indoor air cleaning from particulate, fibrous and biological aerosols by using the portable air cleaner. (In Polish) *Ochrona Powietrza i Problemy Odpadów* 1, 1997; p.7-10
- [8] *Lin C.Y., Li C.S.*; Inactivation of microorganisms on the photocatalytic surfaces in air. *Aerosol Science and Technology* 37, 2003; p.939-946
- [9] *Keller V., Keller N., Ledoux M.J., Lett M.C.*; Biological agent inactivation in a flowing air stream by photocatalysis. *Chemical Communications* 23, 2005; p.2918-2920
- [10] *Vohra A., Goswami D.Y., Deshpande D.A., Block S.S.*; Enhanced photocatalytic disinfection of indoor air. *Applied Catalysis B: Environmental* 64, 2006; p.57-65
- [11] *Huang R., Agranovski I., Pyankov O., Grinshpun S.*; Removal of viable bioaerosol particles with a low-efficiency HVAC filter enhanced by continuous emission of unipolar air ions. *Indoor Air* 18, 2008; p.106-112
- [12] *Bohgard M., Eklund P.*; Effects of an ionizer on sub-micron particles in indoor air. *Journal of Aerosol Science* 29, 1998; p.S1313-S1314
- [13] *Grabarczyk Z.*; Effectiveness of indoor air cleaning with corona ionizers. *Journal of Electrostatics* 51-52, 2001; p.278-283
- [14] *Grinshpun S.A., Mainelis G., Trunov M., Adhikari A., Reponen T., Willeke K.*; Evaluation of ionic air purifiers for reducing aerosol exposure in confined indoor spaces. *Indoor Air* 15, 2005; p.235-245
- [15] *Yu K.P., Lee G.W.M., Lin S.Y., Huang Ch.P.*; Removal of bioaerosols by combination of photocatalytic filter and negative air ions. *Journal of Aerosol Science* 39, 2008; p.377-392
- [16] *Pastuszka J.S., Marchwińska-Wyrwał E., Wlazło A.*; Badanie skuteczności sterylizacji powietrza pomieszczeń przy pomocy oczyszczacza EWG – Elektron Wind Generator (Study of the efficiency of the sterilization of indoor air by using the EWG air cleaner device – Electron Wind Generator). Proceedings of the V Scientific Conference “Silesian Seminar on Environmental Protection” (Editor: A. Misiołek), Bytom, 2004, p.73-74 (in Polish)
- [17] *Lippman M.*; Health effects of ozone: a critical review. *Journal of the Air and Waste Management Association* 39, 1989; p.672-695
- [18] Karty charakterystyk substancji niebezpiecznych (List of hazardous substances with their characteristics), CIOP-PIB, Warszawa, 2003 (in Polish)
- [19] *Gawęda E.*; Szkodliwe substancje chemiczne emitowane przez wybrane urządzenia biurowe podczas ich pracy, Raport CIP-PIB, (Hazardous chemical substances emitted by the working selected office devices, Report COP-PIB), Bezpieczeństwo Pracy 2004; (4); p.19-23 (in Polish)
- [20] Zarządzenia Ministra Zdrowia i Opieki Społecznej z dnia 12 marca 1996r. w sprawie dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia (Order of the Minister of Health and Social Welfare of March 12, 1996 on the standard levels of harmful factors), *Mon. Pol.* Nr 19, poz. 231(in Polish)
- [21] Rozporządzenie Ministra Pracy i Polityki Społecznej z dnia 29.11.2002 r. w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia w środowisku pracy (Disposal of the Ministry of Labor and Social Policy of November 28, 2002 on the standard levels of harmful factors in the occupational environment). *Dz. U.* nr 217, poz. 1833 (in Polish)
- [22] *Skulberg K.R., Skyberg K., Kruse K., Eduard W., Levy F., Kongerud J., Djupesland P.*; The effects of intervention with local electrostatic air cleaners on airborne dust and the health of office employees. *Indoor Air* 15, 2005; p.152-159
- [23] *Zhao P., Siegel J.A., Corsi R.L.*; Ozone removal by HVAC filters. *Atmospheric Environment* 41, 2007; p.3151-3160