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Evaluation of quality and efficiency of ventilation equipment by scanning electron microscopy

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Abstract. The aim of this research is an evaluation of the quality and function of ventilation equipment in basement rooms. There was analysed the function of ventilation system in relation to the quality of outdoor and indoor environment. The concentration of air dust was measured by exact instrument DustTRAK II Model 8530 aerosol monitor inside and outside the building. Using the special impactors the PM_1, $PM_{2.5}$, PM_4, PM_{10} size fractions were also measured. Particles separated from the ventilation equipment were examined with SEM (scanning electron microscopy) using a microscope TESCAN MIRA 3 GMX. Obtained results of measurements were evaluated by statistical instruments and concentrations of different size of dust particles were analysed. The size of particles outlet the ventilation equipment was ca. of 55% lower than the size of the particles inlet the ventilation equipment. The difference in tested sizes of the dust particles in the ventilation equipment and outlet the ventilation equipment, i.e. in the place of cleaned air inlet into the basement room, was statistically proved. The diversity of impurities caught by the ventilation equipment and impurities moving in the air in the tested room is obvious from the results of SEM analysis.

Key words: dust, fraction, scanning electron microscopy, ventilation.

INTRODUCTION

Dust is one of the most common pollutants, which people face in everyday life and in their work activities. By dust we understand air pollution particles of matter that dispersed in the air create aerosols. Dust is characterized by a concentration, size and properties of dispersed particles. On all of those characteristics depends the influence on health. The harmful effect of dust on humans is very wide. Evaluation of dust depends on the origin, nature and size of the dust particles, on its concentration in the air, but also on the length and conditions of action, and on the human individual sensitivity to dust.

The attention to dust is paid in many research works, e.g. Skulberg et al. (2004), Bouillard et al. (2005), Mølhave (2008), Mølhave et al. (2009), Buchholz et al. (2011), Nõu & Viljasoo (2011), Brodka et al. (2012), Traumann et al. (2013), Traumann et al.

(2014), Kic (2015), Kic (2016). The methodology and the results of measurements correspond to the research topic, especially to factors that are specific to studied space. There are studied e.g. the impact of outdoor particulates transferred into the indoor space, the impact of processed and handled material, the influence of floor surface, the influence of sports equipment, particles released from special plastic materials used indoor etc.

The quality of indoor environment in some buildings and rooms depends on the efficient function of ventilation systems and equipment. The rooms, corridors and other spaces situated in basements of buildings are completely depending on the well-functioning forced ventilation with filtration of intake air. The quality and efficiency of the ventilation is partly depending on the elimination of undesirable dust particles and microorganisms transported together with fresh air by air streams in the air inlet from outside.

Basement spaces in many university buildings are because of the worse microclimate conditions most commonly used for warehouses in which workers or students cannot be. In many buildings there are also problems occurring with the underground moisture that penetrates from the surrounding terrain into the external walls which thus become wet (Krofova & Kic, 2016a).

Spaces which depend on the ventilation equipment are located in various offices, institutions etc. Filters are used for the elimination of dust particles from outdoor environment. The filter is an equipment which separates solid dust particles from the airstream going through the ventilation equipment during the filtration process. The function of the filter is to hold the impurities on its fibres by means of the filtration mechanisms. The elimination of the dust particles is essential not only owing to the health protection of persons in a given space but also at the production processes which are prone to the contamination from outside (Krofova & Müller, 2015; Krofova & Kic, 2016a; Krofova & Kic, 2016b).

The aim of this research is an evaluation of the quality and function of ventilation equipment in basement rooms. There was analysed the function of ventilation system in relation to the quality of outdoor and indoor environment.

MATERIALS AND METHODS

The indoor air quality depends also on the efficient function of filters installed in air inlet part of ventilation system for cleaning of intake air. To study the quality and function of filters this research was focused on the composition of particles separated by the filter. Tested filters are of G4 level. The filter G4 is used for catching and holding most gross dust particles.

The dust particles were removed from filters by shaking. A preparation of particles for the analysis by the scanning electron microscopy includes bonding of separated dust particles on a special carbon tape and gilding by a thin layer of gold in the apparatus Quorum Q150R ES.

Particles separated from the ventilation equipment were examined with SEM (scanning electron microscopy) using a microscope TESCAN MIRA 3 GMX at the accelerating voltage of the pack (HV) 15 kV or 5 kV, the working distance WD was 15.02 mm. The difference of the saturation of the various types of particles from the filter G4 was observed by SEM (scanning electron microscopy).

The spectral analysis (EDX) was performed at the filter by means of the auto-emission scanning electron microscope managed by the computer SEM (Tescan Mira 3 GXM). The EDX method detects X-ray and it is used for a quick analysis of a chemical composition of samples.

10 mm target with a carbon adhesive tape determined for testing of samples in SEM was placed in the tested basement room (without windows) in the inlet place of the cleaned air, i.e. from the ventilation equipment, for a comparison of the effectivity of the function of the ventilation equipment staffed with the filter G4 (Fig. 1). The particles moving in the basement room were sedimented on this plate during 7 days. A common working was during 7 days in the basement room (a laboratory of the Department of material science and manufacturing technology), i.e. it came to alternating on and off the ventilation equipment according to the needs. Sampling of dust particles in the indoor basement room is visible in Fig. 2. Collected samples were analysed by SEM according to the above mentioned procedures.

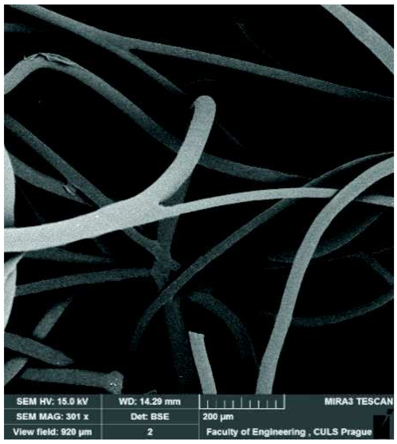

Figure 1. SEM images of filter G4 (MAG 301x).

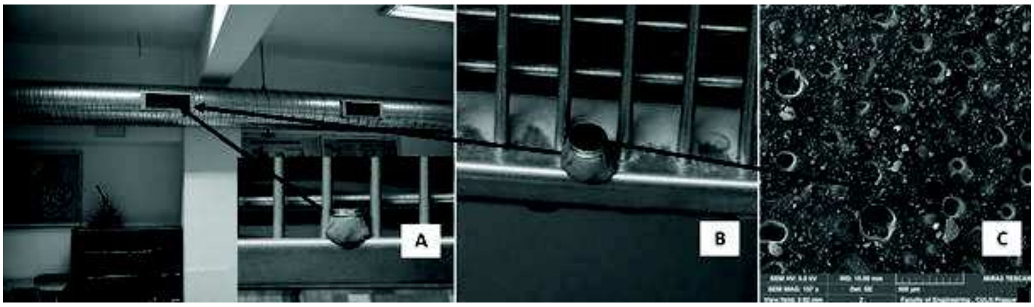

Figure 2. Sampling from indoor basement room: A: Inlet part of ventilation – exit from ventilation equipment and placing of sampling target, B: detailed view on dust particle sampling, C: SEM images of target area (MAG 137x).

An evaluation of the shape and the dimensions of impurities gained by SEM analysis was performed using the program Gwyddion. The program Gwyddion visualizes and analyzes data form microscopy. The results of measuring were statistically analysed by *Anova F-test*.

The total concentration of air dust was measured by special exact instrument Dust–Track II Model 8530 aerosol monitor. After the installation of different impactors the PM_{10}, PM_4, $PM_{2.5}$, PM_1 size fractions of dust were also measured. The 90 data of dust concentration for total dust as well as of each fraction size outside and inside the empty room were collected, in representative places, which can be used for measurement without technological problems. The position of measuring instrument was usually at

75 cm above the floor. The dust measurements were carried out first without ventilation and the same dust measurements were carried out later with standard ventilation.

According to the Air Protection Act No. 201/2012 PM_{10} limit value in 24 hours is 50 µg m^{-3}, one year limit value is 40 µg m^{-3} and one year limit value $PM_{2.5}$ is 25 µg m^{-3}. The 90 data of dust concentration for total dust as well as of each fraction size in each room were collected. The obtained results of dust measurements were processed by Excel software and verified by statistical software Statistica 12 *(ANOVA* and *TUKEY HSD Test*). Different superscript letters (a, b, c) in common are significantly different from each other in the rows of the tables *(ANOVA; Tukey HSD Test;* $P \leq 0.05$*)*, e.g. if there are the same superscript letters in all the rows it means the differences between the values are not statistically significant at the significance level of *0.05*.

The level of filtration and quality of filter function is usually expressed by the efficiency of filtration and penetration of dust through the filter (Szekyova et al. 2006). In this paper these parameters are used for evaluation of function of the ventilation system from the point of view of quality of dust removal. The efficiency of air filter O_c describes how well an air filter removes microscopic particles. It can be calculated according to the Eq. (1).

$$O_c = \frac{c_e - c_i}{c_e} 100 \qquad (1)$$

where: O_c – total efficiency of air filter, %; c_e – concentration of pollutant in the inlet air before the filter, µg m^{-3}; c_i – concentration of pollutant in outlet air after filtration, µg m^{-3}.

The penetration of dust through the air filter P_c describes how many dust particles pass through the air filter. It can be calculated according to the Eq. (2).

$$P_c = \frac{c_i}{c_e} 100 \qquad (2)$$

where: P_c – penetration of dust through an air filter, %.

RESULTS AND DISCUSSION

Principal results of dust measurement are summarized and presented in the Tables 1, 2 and Figs 3, 4. The measurements were during the day of rather high dust concentration outside the building. The measurements inside the empty, but not ventilated room (Table 1) show us that total dust concentrations and also concentrations of all dust fractions were lower that outside, but higher than 0.050 mg m^{-3}, which is dangerous for the human health. From the Table 1 it is apparent a statistically significant effect of ventilation on dust reduction, nevertheless the total dust concentration and also the concentrations of $PM_{10,}$ PM_4, $PM_{2.5}$ and PM_1 dust fractions were higher than 0.050 mg m^{-3}.

The evaluation of filtration quality is presented in the Table 1. The efficiency of filtration was higher than 55% and penetration of dust through the filter was therefore lower than 45%. These results are influenced not only by the quality of filters, but also by the sedimentation of dust inside the room and low level of dust suction by the ventilation equipment.

Table 1. Total dust concentration and concentration of dust fractions PM_{10}, PM_4, $PM_{2.5}$ and PM_1 outside and inside the empty room without and with ventilation. Different superscript letters (a, b) are the sign of high significant difference between the dust concentration in ventilated and not ventilated room (*ANOVA; Tukey HSD Test*; $P \leq 0.05$)

Room	Total µg m^{-3} ± SD	PM_{10} µg m^{-3} ± SD	PM_4 µg m^{-3} ± SD	$PM_{2.5}$ µg m^{-3} ± SD	PM_1 µg m^{-3} ± SD
Outside	131.5 ± 3.4	127.8 ± 1.8	127.7 ± 1.6	126.4 ± 1.9	116.3 ± 1.3
Inside without ventilation	62.3 ± 2.6^a	61.6 ± 1.9^a	59.9 ± 1^a	58.1 ± 1.1^a	53.9 ± 0.9^a
Inside with ventilation	57.3 ± 1.9^b	57.1 ± 1.4^b	55.4 ± 1.2^b	54.6 ± 1^b	49.4 ± 0.8^b

SD – Standard deviation.

Table 2. The efficiency of air filtration O_c and penetration of dust through the ventilation system and the air filter P_c in the room, calculated from total dust concentration and concentration of dust fractions PM_{10}, PM_4, $PM_{2.5}$ and PM_1 outside and inside the empty room with ventilation

Parameter of dust filtration	Total %	PM_{10} %	PM_4 %	$PM_{2.5}$ %	PM_1 %
O_c	56.5	55.3	56.6	56.8	57.5
P_c	43.5	44.7	43.4	43.2	42.5

The Fig. 3 presents graph of the distribution of dust size of particles outside the building. The main parts (88%) of the dust in external air are the particles smaller than 1 µm (size fraction PM_1) and 8% are the particles bigger than 1 µm and smaller than 2.5 µm. The air contains the biggest dust particles in very low percentage (3% of the particles bigger than 10 µm, and 0.1% of the particles smaller than 10 µm and bigger than 4 µm).

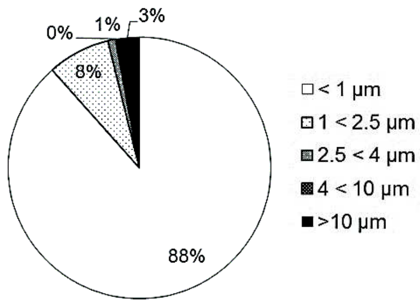

Figure 3. Percentage of dust fractions in the air outside the building.

The Fig. 4 presents the graph of the distribution of dust size of particles inside the room without and with the ventilation. The main parts (86%) of the dust in the room with and without ventilation are the particles smaller than 1 µm (size fraction PM_1), 7% are the particles bigger than 1 µm and smaller than 2.5 µm in non-ventilated, 9% in ventilated room. The air contains the biggest dust particles in very low percentage (1% of the particles bigger than 10 µm in non-ventilated and 0.1% in ventilated room). It is obvious that the small particles can move around freely in the air and the large particles settle down.

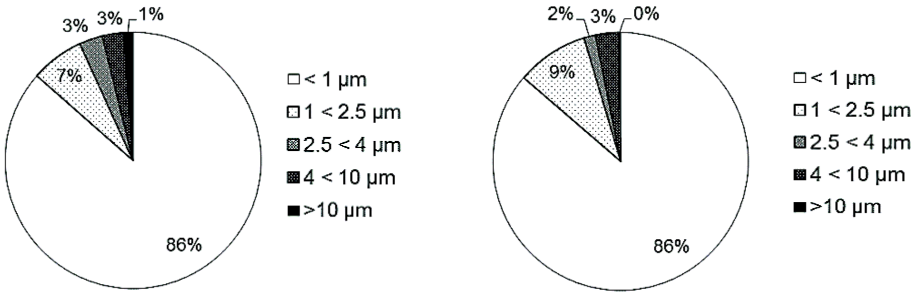

Figure 4. Percentage of dust fractions inside the empty room without ventilation (left) and with ventilation (right).

The fraction size caught by the filter G4 was measured as 37.8 ± 41.5 µm. Measured dust particles were distinguished for considerably different size. The size differed up of 109.8% (the variation coefficient). The fraction size caught in the exit of the filtration equipment, i.e. in the place of cleaned air inlet, was 20.8 ± 18.1 µm. The size differed up of 87.2% (the variation coefficient). The size of the dust particles in the exit was of ca. 55% lower than the size in the input. Results presented in the Fig. 5 provide more detailed view on the fraction size.

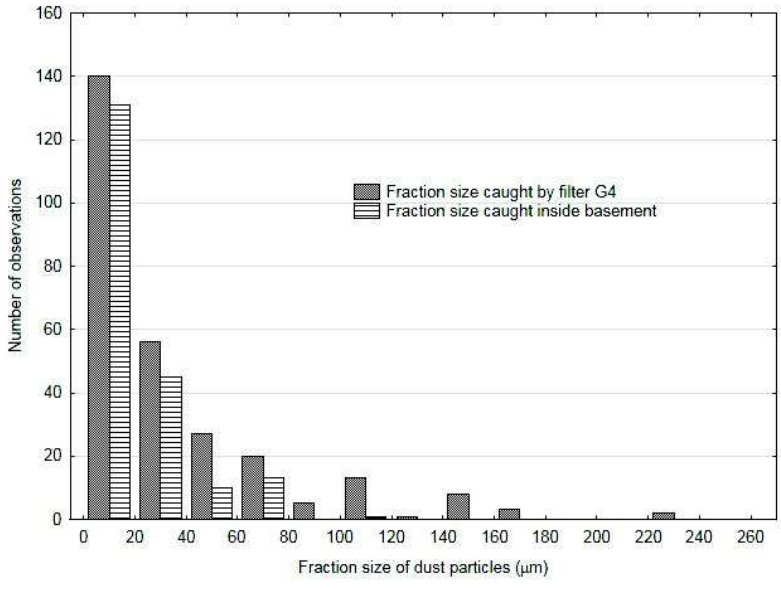

Figure 5. Histogram – dust particles.

Anova F-test was used for the statistical comparison of measured geometrical data of various sizes of dust particles gained from the input filter G4 and from the sediment of dust particles from indoor room (the exit from the ventilation equipment). The zero hypothesis H_0 shows the state when there is no statistically significant difference ($p > 0.05$) among single tested sets of data in terms of their mean values.

It is possible to say in terms of the statistical testing of the size of the dust particles gained from the input filter G4 and at the exit from the ventilation equipment, i.e. in the place of cleaned air inlet to the indoor room that the sizes are statistically non-homogeneous groups, i.e. there is a difference in the size of particles gained from outside filter and particles moving in the indoor room.

The hypothesis H_0 was not certified, i.e. there is a difference among single tested sets in the significance level, i.e. $p < 0.05$ ($p = 0.000$). The difference in tested sizes of dust particles in the ventilation equipment and in the exit from the ventilation equipment, i.e. in the place of the cleaned air inlet to the basement room was statistically proved.

It is obvious from the results that the filter catches all sizes of the particles. It entirely removes impurities higher than 100 μm from the ventilation equipment. It was ascertained by the analysis that ca. 11% of the impurities of the dimension higher than 100 μm was caught in the filter G4. On the contrary great amount of particles to 10 μm (ca. 30%) and 10 to 20 μm (ca. 36%) goes through the filter G4. However, the filter G4 should be efficient for the impurities ≥ 10 μm (according to EN 779). The percentage representation of impurities of higher dimension subsequently significantly decreases, i.e. it does not exceed 13%.

The specification of the particle dimension is essential, but it is also important to determine the chemical composition of impurities. This analysis was performed by means of the spectral analysis (EDX) - the auto-emission scanning electron microscope managed by the computer SEM (Tescan Mira 3 GXM) using the analyser Oxford X Max 7. The principle of measuring is visible from Fig. 6.

The result of EDX analysis is a detection of single chemical elements in the filters and their amount. EDX analysis set a presence 64.52% C, 28.65% O, 2.62% Si, 1.38% Ca, 0.88% Al, 0.68% Fe, 0.36% S, 0.27% K, 0.26% Na, 0.24% Cl and 0.15% Mg. The data are presented in mass percentage portion.

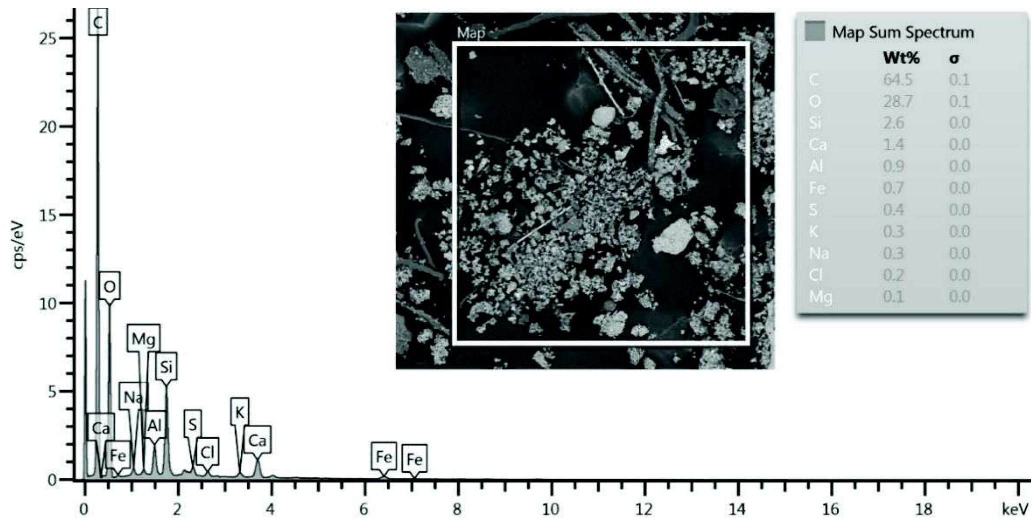

Figure 6. Results of EDX analysis of impurities in filter G4.

Fig. 7 and 8 show captured impurities. The impurities were heterogeneous according to the chemical composition as well as according to the geometrical shape.

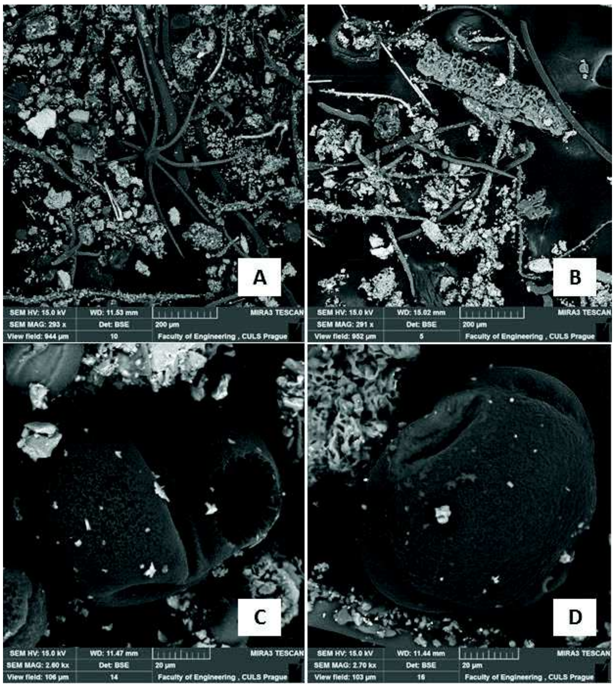

Figure 7. SEM images – impurities separated from filter G4: A: MAG 293x, B: MAG 291x, C: MAG 2.60kx, D: MAG 2.70kx.

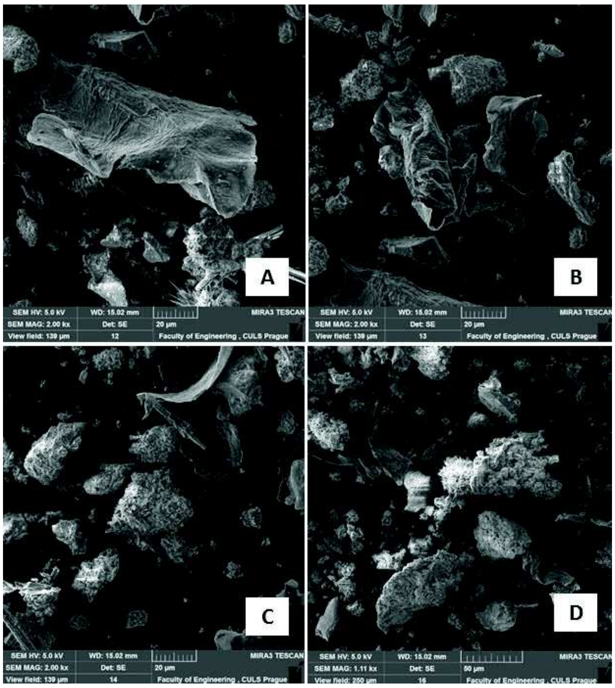

Figure 8. SEM images – impurities caught in exit from ventilation equipment: A: MAG 2.00kx, B: MAG 2.00kx, C: MAG 2.00kx, D: MAG 1.11kx.

CONCLUSIONS

The results of measurements of dust concentration showed that the ventilation system used in the tested basement room has sufficient system of air inlet and fresh air distribution, but the suction and outlet of polluted air from the room is situated (at the same level like inlet) near to the ceiling and therefore it is not able to remove sufficient quantity of dust particles, which are swirling inside the room.

The research with the aim to evaluate the quality and the function of the ventilation equipment by means of the analysis of impurities has following conclusions:

- The filter G4 is able to catch larger particles above all. The size of the particles in the exit was of ca. 55% smaller than the size in the input of the ventilation equipment. The filter G4 removes most of impurities over 100 µm. On the contrary, great amount of impurities smaller than 20 µm goes through the filter G4.
- The difference in tested sizes of the dust particles in the filter and in the exit from the ventilation equipment, i.e. in the place of cleaned air inlet to the basement room was statistically proved.

The heterogeneity (the shape, the chemical composition) of the impurities caught by the filter and the impurities moving in the air in the tested room is obvious from the results of SEM analysis.

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