Impact of Material Surface Roughness on the Concentration of Particulate Emission

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Abstract. In this study, the influence of horizontal surface materials roughness is observed in term of the concentration of particulate emission in the indoors. The indoor particular matter concentration and it’s deposition depends on physical and chemical interactions between the indoor air and the material surfaces. The tested horizontal surface materials were glace ceramic flooring, laminated flooring, PVC linoleum, ragged ceramic flooring, cork flooring and plush carpet. The flooring materials were tested divided into three categories – smooth (Ra<100 μm), slightly rough (100 μm <Ra<1000 μm) and rough (Ra>1000 μm). The observed results illustrate that the concentration of PM10 is significantly larger for the smooth flooring surface material than for the rough and slightly rough material surfaces. The choice of building materials and their surface finish considerably affects the sense of comfort and indoor air quality of the buildings.

1. Introduction

The indoor environment is a basic criterion of building quality because people spend 90% of their time indoors. In accordance with the basic principles of sustainable construction, it is necessary to ensure a quality indoor environment with regard to the physical, chemical and biological factors of the internal environment. Many materials used in the buildings, either as structural materials or as furnishings, are mostly the indoor air pollution sources. Indoor air pollution (IAP) is a serious problem worldwide, specifically in developing countries and heavy industrial areas. Indoor pollution is associated with feelings of discomfort of the occupants of buildings. The society is paying more and more attention to indoor particulate pollution [1-3]. Particle pollution we can find everywhere - not just in haze, smoke, and dust, but also in the air that looks clean. Particle pollution can occur year-round and presents air quality problems at concentrations found in many major cities also throughout the Czech Republic. The Ostrava region is one of the most heavily affected areas in the Czech Republic. This is due to the mining industry and metallurgy.

The term aerosols means solids (dusts) or liquid particles (fogs) dispersed in the air. Dust particles come into the interior both from an outdoor environment from natural sources and also they are formed directly inside the building as a result of human activity. An aerosol microclimate is a component of an internal environment formed by aerosol flows in the field of transmission that act on the subject and co-create its overall state. Exposure to particulate emission poses a variety of health concerns. Fine particulate matter (PM) emission is responsible for the than of more than a million people annually [4]. Particle pollution, also known as particulate matter or PM, is a general term for a mixture of solid and liquid droplets suspended in the air. This complex mixture includes both inorganic (e.g. ammonium
sulphate, ammonium nitrate, and sodium chloride) and organic substances. Particulate matter PM$_{10}$ are small solid particles of diameter less than 10 micrometres, which are able to move freely in the atmosphere.

The particle size is a major factor affecting people's health. The biological effect depends primarily on the flow, exposure time and aerosol concentration. It also depends on the chemical composition and physical properties (particle size, shape and, strength, electrical charge, solubility in biological fluids). The dimensional particle fractions concerning to effects on health are defined in CSN ISO 7708 (1998) [5]. The smaller the particles are, the more dangerous are. The inhalation fractions include particles that are close to the nose and mouth. These particles are easy inhale. The subsystem of this fraction is the so-called extratoracal fraction or tracheal fraction, which includes particles that are able to penetrate the larynx. Next fraction of particles is thoracic fraction, which include particles with the extraordinary health impact because they are able to reach beyond the larynx and through the area of the trachea and bronchus to the alveolar pulmonary system. This fraction is commonly referred to as PM$_{10}$. The respirable fraction is a high-risk subfraction of the thoracic fraction including particles that are able to penetrate into the lungs. This fraction is also referred to as PM$_{2.5}$ and includes particles with an aerodynamic diameter of less than 2.5 μm. The PM$_{1}$ fraction includes appreciable amounts of even smaller particles that can penetrate into the bloodstream [4, 6-8].

2. Material surface and roughness

The surface material is never perfect but always contains deviations and differences. The shape of the surface of almost all materials is complicated with continuous repeated peaks and valleys. The three main properties – roughness, waviness, and form define the final surface texture. Roughness as a function of the machining process describes the surface texture of the materials. Surface roughness most commonly refers to the variations in the height of the surface relative to a reference plane [9]. Average surface roughness (Ra [μm]) according to ISO 4287 is the arithmetic mean roughness value from the amounts of all profile values. A section of standard length is sampled from the mean line on the roughness chart. The value obtained with the formula on the right is expressed in micrometer [μm] [10] see Figure 1:

\[
Ra = \frac{1}{l} \int_0^l |z(x)| \, dx
\]  

Figure 1. Average surface roughness (parameter Ra) according to ISO 4287

The profile of surface material depends on the manufacturing processes the material surface finishing such as sawing, shaping, drilling, milling, honing, polishing, lapping, grinding, extruding, cutting and next. Figure 2 illustrates the examples of various surface profiles of materials.
3. Methods

The concentration of particulate matter for six various common flooring surface materials (glace ceramic flooring, laminated flooring, PVC linoleum, ragged ceramic flooring, cork flooring and plush carpet) were investigated in test room under the standardized condition - temperature 22±2°C, relative humidity 45±5%, and constant air change rate. The room was not occupied during the measurement. Furniture or equipment is not included in the room. The windows and the doors were closed during the experimental measurement. Measurements of the particulate matter concentrations for each surface material were repeated three times.

The concentration of PM$_{10}$ is determined by pumping air through the filter analyzed according to the CSN EN 12 341 Ambient air - Standard gravimetric measurement method for the determination of the PM$_{10}$ or PM$_{2.5}$ mass concentration of suspended particulate matter (2014) [11]. The quantity of captured aerosol is intended gravimetrically by weighing. The samples are collected on nitrocellulose filter Synpor with pore size 0.8 μm and with the diameter of 35 mm. The samples are analyzed by Envitech VPS 2000 with constant airflow 900 l/hour. The airflow is recorded before and after each sampling period. The measuring device is placed in the middle of the test room. The sampling equipment is at the height of 1 050 mm from the floor. This height is typical for breathing zone of sitting persons. The nitrocellulose filters are kept in desiccators at a constant temperature and relative humidity (RH=50%) for 24 hours before sampling. The filters are again kept in desiccators for 24 hours after sampling. The filters are weighed before and after sampling. The particulate matter mass concentration of PM$_{10}$ is determined by the gravimetric method on the base of the difference of measured weights. The morphology, the origin, and the composition of the dust particles are not the subject of this study [6].

4. Results and discussions

Table 1 shows an overview of tested materials including their roughness class. Observed particulate concentration in PM$_{10}$ for smooth material with $R_a$ smaller than 100 μm, such as glace ceramics flooring, laminated flooring, and PVC flooring, are in the range of 32-36 μg/m$^3$ with the mean value of 34.38 μg/m$^3$. The roughness class of slightly rough represents cork flooring and ragged ceramic flooring. The mean value of the PM$_{10}$ concentration in this roughness class is 31.3 μg/m$^3$ (range 29.0 - 33.0 μg/m$^3$). The mean value of the concentration suspended particulate matter for the rough surface material (plush carpet) is 24 μg/m$^3$. 

Figure 2. Various surface profiles
Table 1. Flooring materials concerning to roughness

| Roughness          | $R_a$ [μm] | Flooring material                      |
|--------------------|------------|----------------------------------------|
| Smooth             | < 100      | Glace ceramic flooring                  |
|                    |            | Laminated flooring                     |
|                    |            | PVC linoleum                           |
| Slightly rough     | 100 – 1000 | Ragged ceramic flooring                 |
|                    |            | Cork flooring                          |
| Rough              | > 1000     | Plush carpet                           |

Figure 3 illustrates the relationship between the average surface roughness of the selected horizontal indoor material and concentration of PM$_{10}$. The values of the average surface roughness are determined in the range of 0.00 μm to 1000.00 μm.

![Graph showing the relationship between average surface roughness and PM$_{10}$ concentration.](image)

**Figure 3.** Dependence of the average surface roughness and the concentration of PM$_{10}$

Among other things, the Figure 3 also shows a logarithmic trendline. The logarithmic trendline is an ideal for data set when the rate of change in data increases or decreases quickly. Equation of the logarithmic trendline ($y = -2512 \ln(x) + 8855.7$) can be used for predict values outside the range of the calculation. The value of the reliability ($R^2$), range between $<0; 1>$, indicates how accurately the value
of the trendline correspond to the actual data. The expressed value of the reliability 0.8679 indicates a good fit to the original data line.

5. Conclusions
Healthy living is a topical issue of the society in the context of sustainable development especially to Particulate matter concentration. The flooring surface roughness and its effect on the indoor concentrations of PM$_{10}$ were the object of the presented study. The results of experimental measurements show the roughness of the flooring material has a significant effect on the concentration of dust particles. The concentration of PM$_{10}$ in the test room with smooth flooring (R$_a$ < 100 $\mu$m) oscillates around 35 $\mu$g/m$^3$. The PM$_{10}$ concentration is about 23 $\mu$g/m$^3$ for rough floors (R$_a$ > 1000 $\mu$m). Based on the presented results, it can be determined that the rising of the roughness of the surface materials causes the decreasing of PM$_{10}$ concentration. The choice of building materials and their surface finish considerably affects the sense of comfort and indoor air quality.

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References
[1] X. Wang, X. Bi, G. Sheng, H, Fu, “Hospital indoor PM10/PM2.5 and associated trace elements in Guangzhou, China,” Science of The Total Environment, vol. 366, issue 1, pp. 124-135, 2006.
[2] A. D. Kappos, P. Bruckmann, T. Eikmann, N. Englert, U. Heinrich, P. Hönne, E. Koch, G. H. M. Krause, W. G. Kreyling, K Rauchfuss, P. Rombout, V. Schulz-Klempl, and W. T. Wichmann, “Health effects of particles in ambient air,” International Journal of Hygiene and Environmental Health, vol 207, issue 4, pp. 399-407, 2004.
[3] S. E. Chatoutsidou, J. Ondráček, O. Tesar, K. Tørseth, V. Ždímal, and M. Lazaridis, “Indoor/outdoor particulate matter number and mass concentration in modern offices,” Building and Environment, vol .92, pp. 462-474, 2015.
[4] M. Junaid, J. H. Syed, N. A. Abbasi, M. Z. Hasmi, R. N. Malik, and D-S. Pei, “Status of indoor air pollution (IAP) through particulate matter (PM) emissions and associated health concerns in South Asia,” Chemosphere, vol. 191, pp. 651–663, 2018.
[5] CSN ISO 7708, Air quality - Particle size fraction definitions for health-related sampling, Prague, 1998.
[6] M. Kraus, and I. Juhaszova Šenitková, “Particulate Matter Mass Concentration in Residential Prefabricated Buildings Related to Temperature and Moisture,” IOP Conference Series: Materials Science and Engineering, vol. 245, 042068, 2017.
[7] A. Peters, H. E. Wichmann, T. Tuch, J. Henrich, and J. Heyder, “Respiratory effects are associated with the number of ultrafine particles,” Am J Respir Crit Care Med., vol. 155(4), pp. 1376-1383, 1997.
[8] J. I. Levy, J. K. Hammitt, and J. D. Spengler, “Estimating the mortality impacts of particulate matter: what can be learned from between-study variability?,” Environ Health Perspect., vol. 108(2), pp. 109-117, 2000.
[9] B. Bhushan, “Surface Roughness Analysis and Measurement Techniques,” Modern Tribology Handbook, Two Volume Set, chapter 2, pp. 49-120, 2000.
[10] CSN EN ISO 4287, Geometrical product specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters, Prague, 1999
[11] CSN EN 12 341, Ambient air - Standard gravimetric measurement method for the determination of the PM10 or PM2,5 mass concentration of suspended particulate matter, Prague, pp. 1-56, 2014.