VOCs Emission Simulation of Common Flooring Materials

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Abstract. The objective of the paper is to investigate the environmental and health impacts of the common flooring materials. The paper presents a numerical simulation of volatile organic compounds (VOCs) emissions from flooring surface covering. VOCs emissions are mostly dangerous pollutants with a negative health impact on the human body and carcinogenic risk. The comparative simulation of emission for single flooring materials under standard test conditions was performed. The significant VOCs emissions from nylon carpet, linoleum, vinyl, laminate and hardwood flooring are compared. The results of a chemical analysis simulation confirmed that commonly used flooring surfaces fall into the category of polluting materials.

1. Introduction
People from developed countries spend the majority of their lives indoors Almost 2/3 of people in developed countries complain about health problems related to poor indoor air quality in buildings. This phenomenon is known as Sick Building Syndrome [1]. Volatile organic compounds emissions are considered to be the main cause of indoor air pollution in new or renovated houses. At present, volatile organic compounds are considered to be a category of pollutants commonly found in building interiors. These may negatively affect human health in the long run. Some have allergic, others toxic, some may be potentially carcinogenic. It is therefore important to inquire about the composition and materials as well as the surface finish, etc. when selecting floors. Volatile organic compounds from materials are emitted into the indoor environment throughout the entire life cycle of the building [2]. The problem of VOCs emissions persists although there are a number of low-emitting materials on the market [3]. These substances easily evaporate under normal conditions and become gaseous. They have a typical and distinctive aroma. There are several ways to reduce VOCs emissions and improve indoor air quality. Depending on the nature of the action of VOCs on the body, health effects may be acute, toxic, allergic, carcinogenic, neurological (behavioral disorders) and nephrotoxic.

The highest concentrations of pollutants are normally monitored immediately after the building is finished and after commissioning. Over time, the concentration of volatile organic compounds decreases in most cases. The concentration of volatile organic compounds depends mainly on the operational hygiene and ventilation system. Concentrations of organic substances in living areas normally exceed concentrations in the exterior. These hazardous pollutants are released into the indoor air from building structures and furniture. Some materials, such as gypsum boards, are characterized by high absorption capacities of these organic substances [4]. The source is also a human and their activities. Volatile organic compounds have attracted attention in the context of increasing energy demand for buildings and increasing airtightness [5].
2. Common flooring materials
A floor is a structure that rests on the top of a ceiling or other substrate and can be single or multi-layer. Ordinarily, floors shall be assessed for thermal properties, waterproofing properties, deflection, impact resistance, concentrated load resistance, water and moisture resistance, light reflection coefficient, cleanability, abrasion, water absorption, frost resistance, fire resistance, chemical resistance, flexibility and other.

2.1. Residential nylon carpet
Carpets in the interior fulfill several basic functions. Above all, they absorb dust and dirt much more than tiles or floating floors. Furthermore, the carpet flexes while walking, reducing noise and improving room acoustics. Last but not least, carpets also have an aesthetic function. The range of carpets includes a wide range of natural or synthetic fabrics in many designs, cuts, colors, prints, etc. Synthetic carpets include products made of polyamide (PA), polyacrylic (PAC), polypropylene (PP), polyester (PES), or mixtures of these materials, or a mixture of man-made fibers and natural fibers. Pure natural carpets are made of wool, silk, sisal, coir, or cotton. Nylon was originally a trading name for polyamide 6.6, introduced by DuPont in the 1930s. Nylon carpet and another synthetic carpet can be reused or recycles [6].

2.2. Laminate
Laminate flooring is one of the most widespread floorings used in residential buildings. Their indisputable qualities include fast and easy assembly, resistance to load, abrasion, color stability, easy maintenance and hygiene. The base is an HDF board, on its photos or direct print decoration, all safely stored under a protective top layer, called an overlay. It is laid in a floating way.

2.3. Linoleum
Natural linoleum is one of the classic floorings. It features durability, ease of maintenance, a pleasant surface and a large selection of designs and colors. Linoleum is made up of linseed oil, resin, wood flour and limestone. The mixture is formed by natural pigments, which are processed under high pressure on jute fabric. Linoleum is considered as a flooring material with a very low environmental impact [7].

2.4. Vinyl
Vinyl flooring properties guarantee long life and great thermal insulation properties. Vinyl is suitable against water and moisture and therefore does not deform by moisture. Vinyl has very good acoustic properties, low thermal resistance, is dimensionally stable and interactively warm on the surface. Contemporary modern vinyl floors contain no heavy metals (stabilizers or dyes), toxic plasticizers or formaldehyde. They often have antistatic, electrostatic and non-slip surface finishes and are also resistant to sunlight.

2.5. Hardwood
Wooden floors are warm, flexible and aesthetic. Their disadvantage is the volume instability, which may cause expansion of the joints. Wooden floors are suitable for dry plants, for common and living rooms. According to the elements that make up wooden floors, we distinguish between deck, frieze, parquet and panel floors. Wood floors are natural and fully recyclable. For the final surface treatment of wooden floors, it is suitable to use varnishes, glazes and impregnates based on natural resins and linseed oil or wax.

3. Experiment conditions
The comparative simulation of emission between single flooring materials was performed. The 10 m² floor test chamber is used to simulate volatile organic compound emissions. The simulation is made for 5 typical floor coverings – nylon carpet, laminate, linoleum, vinyl and hardwood flooring. The
ceiling and walls are made of glass. The clear height of the chamber is 2.5 meters. The volume of the room is 25 m$^3$ of air. Ventilation is considered constant. The recommended ventilation intensity (0.5 ACH) according to CSN EN 15 665/Z1 is considered.

Concentrations of volatile organic compounds and their sum (TVOC) were analyzed using the software tool IA-QUEST (Indoor Air Quality Emission Simulation Tool) developed by the National Research Council (NRC) [8]. A mass balance approach is used to calculate VOC emissions:

$$ V \cdot \frac{dC}{dt} = Q \cdot C - Q \cdot C_{in} + \sum_{i}^{n} E_{Fi} \cdot A_{i} $$

where C is VOCs concentration [mg/m$^3$], V is air volume [m$^3$], Q is ventilation rate [m$^3$/h], $C_{in}$ is VOCs concentration in ventilation air [mg/m$^3$], $A_{i}$ is the surface area of the $i^{th}$ source [m$^2$], $E_{Fi}$ is the emission factor of the $i^{th}$ source [m$^2$], and n is the number of sources [9, 10].

4. Results and discussions

The VOC concentration and emissions from various floor surface materials were studied. The five types of flooring cover were simulated for 100 hours after installation in the test chamber. The sink effect and sorption of the other materials are not considered.

Figure 1. The concentration VOCs emissions for carpet nylon flooring over time

Figure 1 illustrated results for nylon carpet. The occurrence of 1-3-dimethylbenzene, hexadecane, 1-4-dimethylbenzene, heptane, hexane, toluene, tridecane and undecane were found. The highest concentration is found for 1-3-dimethylbenzene and hexadecane. In the first hours, there is a sudden growth of pollutants. The maximum TVOC value (3.30 mg/m$^3$) was reached about 6 hours after commissioning. Concentrations of partial VOCs follow the overall trend of TVOCS. The exception is hexadecane. The maximum hexadecane concentration is reached at about 18.5 hours, then the concentration gradually decreases.

TVOC and individual emission of acetaldehyde, acetone, alpha-pinene, formaldehyde and toluene were monitored during 100 hours after placing the laminate floor in the test chamber. The results are shown in Figure 2. The process of partial concentrations and the total sum did not show any trend in
time and are highly unpredictable. TVOC concentration reaches its peak at about the 15th hour and then gradually decreases. An important compound detected acetone and formaldehyde. Commonly indoor concentration of formaldehyde ranges from 0.12 mg/m$^3$ to 3.7 mg/m$^3$ [11]. Moreover, its concentration is relatively stable over time.

**Figure 2.** The concentration VOCs emissions for laminate flooring over time

**Figure 3.** The concentration VOCs emissions for linoleum flooring over time

The emissions of VOCs from the linoleum flooring are illustrated in Figure 3. Individual compounds such as acetic acid, acetone, formaldehyde, hexanal, propanol, toluene and undecane are
observed in time. A significant increase in acetic acid concentration is evident at the beginning of the simulation. Acetic acid can cause allergies in long term exposure [12]. With continuous ventilation, the concentration decreases. In contrast, the acetone concentration continues to increase in observed time.

![Figure 4. The concentration VOCs emissions for vinyl flooring over time](image1)

![Figure 5. The concentration VOCs emissions for hardwood flooring over time](image2)
Figure 4 illustrates the concentration of VOCs emission for vinyl flooring. The significant occurrence of dodecane, tetradecane, toluene, tridecane, undecane and 2,2,4-Trimethyl-1,3-pentanediol disobutyrate is monitored for this type of flooring. The emission concentration over time is detailed in the graph.

In the case of hardwood flooring (Figure 5), acetic acid, acetone, decanal, octanal, pentadecane, tetradecane and toluene are monitored. Of these compounds, significant concentrations only reach acetic acid. The maximum concentration of acetic acid is approximately half that of linoleum. However, the decrease in time is slower. The acetic acid trend follows the concentration of the TVOC. Concentrations of other substances of concern are very low.

Figure 6 shows TVOC concentrations from observed flooring materials. If the TVOC concentration is less than 0.2 mg/m³, users do not experience any irritation or compromise of well-being. TVOC concentrations from 0.2 to 3.0 mg/m³ are characteristic of irritation or worsening of well-being. Exposure to TVOC concentrations greater than 3.0 mg/m³ leads to irritation, headache, etc. Significant concentrations of TVOC are achieved mainly by vinyl flooring and nylon carpet. TVOC Concentrations of other floor coverings are several times smaller. In the case of vinyl flooring, after the initial steep growth (3.30 mg/m³), TVOC decreases by up to one third in the monitored time (0.86 mg/m³). TVOC concentrations also rise steeply in the case of vinyl flooring. The maximum value is 3.11 mg/m³. The subsequent concentration of TVOC decrease is not so sharp. Within the observed time horizon, the TVOC concentration will decrease to about 2 mg/m³. Other floor coverings have a TVOC concentration of less than 0.2 mg/m³.

Figure 6. The TVOC concentration for flooring materials over time

5. Conclusions
The trend of ensuring the quality of the indoor environment and respecting the pollution of buildings through the control of emissions of selected chemicals is currently supported by European legislation on the indoor environment of buildings. The concentrations of volatile organic compounds have been determined for the various flooring materials. The results of simulation chemical analysis of floors
under standard test conditions confirmed that commonly used surfaces fall into the category of polluting materials. The sources of pollutants in buildings should be identified and appropriately minimized or eliminated. The next step, after checking the sources, is to design the required intensity of the air exchange solved by adequate ventilation.

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