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Emissions of indoor air pollutants from six user scenarios in a model room

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HIGHLIGHTS

- User scenarios were performed under laboratory conditions in a model room.
- User activities clearly influence indoor air quality in various ways.
- Each pollutant shows maximum values clearly assignable to individual user scenarios.
- Emissions show a strong increase but decrease rapidly after removal of the source.

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ABSTRACT

In this study six common user scenarios putatively influencing indoor air quality were performed in a model room constructed according to the specifications of the European Reference Room given in the new horizontal prestandard prEN 16516 to gain further information about the influence of user activities on indoor air quality. These scenarios included the use of cleaning agent, an electric air freshener, an ethanol fireplace and cosmetics as well as cigarette smoking and peeling of oranges. Four common indoor air pollutants were monitored: volatile organic compounds (VOC), particulate matter (PM), carbonyl compounds and CO_2. The development of all pollutants was determined during and after the test performance. For each measured pollutant, well-defined maximum values could be assigned to one or more of the individual user scenarios. The highest VOC concentration was measured during orange-peeling reaching a maximum value of 3547 μg m^{-3}. Carbonyl compounds and PM were strongly elevated while cigarette smoking. Here, a maximum formaldehyde concentration of 76 μg m^{-3} and PM concentration of 378 μg m^{-3} were measured. CO_2 was only slightly affected by most of the tests except the use of the ethanol fireplace where a maximum concentration of 1612 ppm was reached. Generally, the user scenarios resulted in a distinct increase of several indoor pollutants that usually decreased rapidly after the removal of the source.

1. Introduction

According to the National Human Activity Pattern Survey of the USA adults are spending an average of 87% of their time in enclosed buildings and about 6% of their time in enclosed vehicles (Klepeis et al., 2001). As to improve energy efficiency, building design has changed leading to more airtight structures and to the accumulation of air pollutants in indoor air (Jones, 1999). Therefore, the exposure of humans to the indoor environment is of high concern. For the assessment of indoor air quality in living and working spaces various concepts have been developed like the WHO air quality guidelines (WHO, 2000, 2006) or the German indoor guide values (Umweltbundesamt, 2012). The WHO guidelines describe several pollutants like particulate matter or formaldehyde with regard to their health effects and define guide values. The German Committee on Indoor Guide Values also developed guide values for selected pollutants. Here, also cumulative values like the total volatile organic compounds (TVOC) as described in (ECA, 1997; Mølhave et al., 1997) are included (Seifert, 1999).

Indoor air quality in living or working spaces is influenced by a large number of possible pollution sources (Kostiainen, 1995; Parra

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et al., 2008; Wolkoff, 2013). These sources include outdoor air, building and furnishing materials as well as user activities such as cleaning, cooking, or smoking (Salthammer and Bahadir, 2009; Wolkoff and Nielsen, 2001). The strong influence of user behavior on indoor air quality is known from various studies (Nazaroff and Weschler, 2004; Petry et al., 2014; Steinemann et al., 2011). However, for a long time research activities mainly focused on continuous, persistent sources of indoor pollutants. An example are VOC and formaldehyde emissions from building products like floorings, wall coverings or paints and varnishes which have been studied thoroughly during the last decades (Bluyssen et al., 1997; Gehrig et al., 1994; Guo et al., 2004; Kim, 2010; Lin et al., 2009; Risholm-Sundman and Wallin, 1999). Based on this research accredited test procedures for the emissions of building products and furniture were developed and defined in international standards such as the ISO 16000 series (DIN, 2008, 2011b). Furthermore, various national and international regulation and classification schemes such as the German "AgBB-scheme" (AgBB, 2015) define threshold values for VOC emissions from building products to guarantee a minor impairment of indoor air quality. Until recently, no comparable effort has been made to investigate the possible influence of user activities on indoor air quality, although they are manifold. They vary from terpene emissions from the use of fragranced products (Steinemann, 2015) to increased particulate matter concentration due to, e.g. environmental tobacco smoke (Sahu et al., 2013). Distinct changes in both the concentration and the types of indoor pollutants were identified after the occupation of newly constructed buildings (Derbez et al., 2014; Järnström et al., 2006; Yamaguchi et al., 2006). Nowadays, more and more attention is paid to user activities and their role regarding indoor air quality (Bartzis et al., 2015; Nazaroff and Weschler, 2004; Steinemann, 2015). This even led to first attempts to develop reliable and reproducible testing procedures for various indoor pollutants emitted by consumer products (Bartzis et al., 2015). However, most investigations on emissions from consumer products are carried out in test chambers. The comparability of these chambers to the real room situation is limited, due to the fact, that they usually do not resemble real rooms in terms of size and configuration. Furthermore, examining consumer products and user activities as possible indoor emissions sources is difficult. Building products, for instance, are continuous emission sources and may therefore be examined under steady conditions for variable time periods (De Bortoli et al., 1999; Wolkoff, 1998, 1999). In contrast, user activities are temporary emission sources (Bartzis et al., 2015; Brown et al., 1994). Laboratory studies mainly focused on the emission of indoor pollutants during the use of a special consumer product or device (Derudi et al., 2012; Schripp et al., 2014), whereas measurements in real buildings also displayed the presence of indoor pollutants before and after a certain user activity is finished. However, tests in real indoor settings could neither exclude nor control any influences of environmental effects such as outdoor emissions or climate parameters (Guo, 2011; Järnström et al., 2007). Thus, an approach to combine both laboratory and real life measurements was chosen for the present study. Precisely defined user scenarios were performed in the new European reference room. This is a model room simulating a real room in terms of size and configuration, but under controlled environmental conditions. It was the aim of this study to gain further knowledge about the effect of user behavior on indoor air quality. Therefore, four important indoor pollutants including VOC, carbonyl compounds, particulate matter, and CO_2 were investigated before, during and after each scenario. This choice of pollutants was mainly based on the pollutants defined in the WHO air quality guidelines (WHO, 2000, 2006) and the German indoor guide values (Umweltbundesamt, 2012).

2. Material and methods

Six selected scenarios were performed in two model rooms. The construction of the model rooms is based on the requirements for the European reference room as defined by prEN16516 (CEN, 2015). The rooms were made of wood-based construction products as described in (Höllbacher et al., 2015). Both rooms had a volume of 30 m^3 and were equipped with interior fittings such as a carpet, curtains and furniture to resemble real rooms both in terms of size and configuration. The rooms were supplied with purified and conditioned air at an air exchange rate of 0.5 h^{-1}. Indoor climate parameters were set to 23 ± 2 °C and 50 ± 5% relative humidity. Indoor air was well mixed by using a fan. The performed tests as well as the applied materials and the test procedures are listed in Table 1. Each test is marked with an individual identification code (T1-T6). All materials used for the tests were customary consumer or household products and purchased from retailers. The liquid fuel used for the ethanol fireplace was purchased together with the fireplace according to the recommendation given by the retailer. Generally, the user scenarios were performed in the rear of the room underneath the fan. This was done to avoid incorrect measurements by performing the scenarios too close to the sampling points, which were located in the middle of the room.

Four common pollutants having an influence on indoor air quality were investigated for each user scenario: VOC, carbonyl compounds (including formaldehyde), PM and CO_2. PM and CO_2 were measured continuously. Sampling of VOC and carbonyl compounds was started simultaneously at the start of the test procedure for tests T2, T3, T4 and T6. As it was the aim to measure the influence of the cleaning agent and the cosmetics after their use, for T1 and T5 the measurements were started after the operator had finished the relevant user activity and left the room.

2.1. VOC

Volatile organic compounds were sampled on desorption tubes filled with Tenax® TA using calibrated air sampling pumps (Chematec ApS, Roskilde, Sjælland, Denmark; Markes International Ltd., Llantrisant, Wales, UK) at a flow rate of 100 mL min^{-1}. VOC sampling was always performed in duplicate in the same order:

- Empty – 1 h sampling prior to the test
- Sample 1–30 min sampling simultaneously with or immediately after the test
- Sample 2–30 min sampling immediately after Sample 1
- Sample 3–30 min sampling subsequent to Sample 2

Desorption tubes were analyzed according to ISO 16000-6 (DIN, 2011b) using a thermodesorption unit (TDAS 2000; Chromtech GmbH, Idstein, Hesse, Germany) linked to a gas chromatograph with mass spectrometric detection (7890A/5975C; Agilent Technologies, Santa Clara, California, USA) equipped with a HP-Pona column (Agilent Technologies; 50 m × 0.2 mm × 0.5 μm). Toluene-d8 and cyclodecane were used as internal standards. The detected substances were identified by comparison of the mass spectra to commercial spectral libraries (John Wiley & sons, Hoboken, New Jersey, USA) and quantified using authentic calibration standards (Sigma Aldrich Co. LLC, St. Louis, Missouri, USA). Substances which were not calibrated were quantified as equivalents of toluene-d8 and are marked with TE. The TVOC was calculated for each sample as the sum of all identified substances with a boiling point between 50 °C and 260 °C, according to the definition of VOC of the WHO (1989), and with a concentration ≥1 μg m^{-3}.