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"*Cocktails and dreams*". The indoor air quality that people are exposed to while sleeping.

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Abstract

People spend more than 90% of their time indoors and a very big part of that time inside their bedrooms, suggesting that the quality of the air that people breathe during sleeping is of particular importance and can play an important role in our overall exposure to chemicals, but also in our wellbeing. The bedrooms' air quality is, according to the Authors' opinion, rather neglected in most studies, and with this opinion paper we try to bring this research question into more attention of the scientific community and also of the society and public authorities. Even though there are always more papers dealing with indoor air quality (IAQ) and new or emerging chemicals, the number of studies that address the IAQ in bedrooms is not proportionally increasing, let alone the fact that even studies that monitor air quality in bedrooms, sometimes do not take place during the sleeping periods in order to simulate exactly what are the IAQ problems during an entire night.

Herein we explain why, in our opinion, the air quality in bedrooms should be addressed in a different way than other microenvironments and why this kind of research should be further intensified in order to help authorities and environmental agencies correctly assess the exposure of individuals to indoor toxic pollutants.

Keywords: Indoor air quality, exposure, bedroom, sleeping

1. Introduction

During the last years, the number of studies that address the issue of indoor air quality (IAQ) are continuously increasing and a plethora of chemical compounds have been identified at various concentration levels, depending on various aspects, including indoor temperature and humidity, occupants' habits etc.

One can find many scientific papers reporting chemicals concentrations in various indoor micro-environments, yet the specific indoor microenvironments that are less often studied are probably the sleeping areas (dormitories, bedrooms etc.), even though this part of a house might be the most important. People spend in these micro-environments more than 7-8 (continuous) hours a day (more than a third of their lives according to Strøm-Tejsen et al., [1]), and in conditions that may favor lower IAQ. The latter is easily understandable if one takes into account that during the sleeping hours, the occupants tend to “improve” their sleeping conditions by reducing noise (according to Vilcekova et al., [2], bedrooms are the least noisy indoor environments), however the latter actions result also in minimising the air exchange rate by closing windows, doors, or by turning off other ventilation options. Such an example was the study of Militello-Hourigan et al. [3], who measured CO_2 in bedrooms, with occupants sleeping and with doors and windows closed, and one of the outcomes of that study was that "*ventilation practices were inadequate*". The fact that bedrooms are not as studied as other parts of a house, can easily be seen in literature and is evident in some recent review articles (e.g. in Lucattini et al. [4]; Salthammer et al. [24]), among hundreds of cited papers on semi volatile organic compounds (SVOCs) and indoor air quality, only very few

refer to concentrations in bedrooms. In addition, it is even more rare that Authors (contrarily to the afore-mentioned study of Militello-Hourigan et al. [3, 28]) declare whether the sampling/monitoring in bedrooms areas has taken place during real sleeping conditions, or during a different moment of the day. In some cases [25], studies with passive samples take place, yet these studies give time-weighted results, which might not represent exactly the occurrence of contaminants during the nocturne hours.

Therefore, with the present opinion paper, we aim at extracting key points and information from the relevant recent literature on air pollutants detected at bedrooms, at reporting the classes of chemicals that are emitted by household materials typically found in bedrooms, and at briefly summarising others that are present in these environments due to the occupants behaviour, in order to give a complete picture of what kind of compounds can be found in this "cocktail" of chemicals to which all individuals are exposed for the biggest part of our lives. According to the present Authors, the in-depth exposure assessment to this contaminants mixture during sleeping (in terms of chemical pollutions) has not been deeply investigated and is an issue that has not yet received the importance that it merits, and therefore the ultimate aim of this paper is to trigger further research on this topic. Given the limitations of this type of articles, the present article is not an exhaustive, comprehensive review, but a general presentation of this scientific gap, and through this paper, the Authors call for more actions and efforts to address this issue.

2. Chemicals detected in indoor air at bedrooms

While there are many chemicals that are typical indoor air pollutants, in this paper we concentrate on organic compounds, letting aside classical indoor air pollutants, like NO_2, radon, CO, biocontaminants etc. [21-22, 26]. Historically, the organic chemicals that were

more frequently monitored in the indoor air were aldehydes (formaldehyde and acetaldehyde) and volatile organic chemicals (VOCs) and among those mostly the BTEXS, or benzene, toluene, ethylbenzene, xylene and styrene. Recently, many more chemicals present in the gas phase, attached on particulate matter, or dust have been reported in samples from indoor air, but still only in few cases from bedroom samples. Some examples of these studies include Bi et al. [5] and Fan et al. [6] who reported the occurrence of phthalates and organophosphates in bedroom samples and Kuang et al. [7] who reported legacy and new flame retardants, and in particular polybrominated biphenyl etheres, haxachlorocyclododecanes and other bromophthalates. Winkens et al. [8] reported perfluoroalkyl acids and their precursors from children bedrooms, while the very recent study of Wei et al. [9] (and references therein) showcase the simultaneous study of a very wide range of semi-VOCs, very helpful if one wants to properly assess the individuals' exposure to indoor air quality; they report phthalates, organochlorine pesticides, polycyclic aromatic hydrocarbons (PAHs), synthetic musks, dichlorvos, and tributyl phosphate, while Katsoyiannis et al. [10], apart from VOCs reported also terpenes, cyclic and linear volatile methylsiloxanes and particulate matter. The review article of Lucattini et al. [4] referred only to one study that monitored pyrethroids and another that reported concentrations of PCBs, PAHs and PBDEs. One characteristic of the afore-mentioned studies (and also of other similar ones not reviewed therein [4]) is also the very high percent of frequency of detection of the analysed chemicals, suggesting that these compounds are always present, and this fact, together with the continuous long-lasting exposure of occupants in bedrooms are two factors that should be taken always into account in exposure assessment studies.

3. Bedroom materials/products and behaviour related emissions

Bedrooms can be decorated in various ways and this suggests that the furniture inside a bedroom can include wardrobes made of various materials, mattresses, carpets, wallpaper, candles etc., while in the case of children bedrooms, books, personal computers, printers and toys can be present. Besides, the behaviour of the occupants can also be linked with emission or release of some additional classes of chemicals. Such behaviours can include smoking, the use of air-freshners, the frequent painting/renovation of the room, the use of cleaning materials, the frequency of cleaning, the co-existence of pets, the level of ventilation, use of deodorants, moth balls, mosquito repellents etc. All the potential emissions or releases are likely to be increased during the cold periods of the year, due to the fact that heating is almost continuously on. For the latter, it should be taken into account that while the aim of heating is that of reaching a room temperature of around 20 ^{o}C, the temperature next to radiators can be much higher, creating favourable conditions for the volatilisation of semi volatile organic compounds.

The indoor air quality in bedrooms can further be impacted by chemicals emitted in other parts of the house/residence, like for example during cooking, use of fireplaces, emissions from vehicles when the house has a communicating door with the garage, by any type of outdoor air pollutants that could infiltrate, and or by secondary emissions, like for example when a reaction takes place inside the room (e.g. ozonolysis).

Knowledge of the chemicals that are emitted from each of the afore-mentioned materials and/or activities is very important and can help direct better a bedroom-air-quality study. For example, and as already mentioned, scientists would usually study for VOCs and aldehydes/ketones, but it has been shown that the following chemicals are regularly emitted from specific materials/activities and in significant rates. Some examples are as follows:

- Deodorants: Volatile Methyl Siloxanes [11];
- Carpets: 4-phenylcyclohexene and 2,2-butoxyethoxy-ethanol [12];
- Books: acetic acid, formic acid, furfural, 4-hydroxy benzoic acid and 4-hydroxy acetophenone [13 and references therein];
- Cleaning products: terpenes and secondary organic aerosols [14];
- Moth balls: naphthalene and para-dichlorobenzene [15];
- Computer: flame retardants [4 and references therein];
- Cooking, fireplace, etc.: particulate matter, PAHs [4 and references therein];
- Painting/renovation-retrofitting: solvents, VOCs [16], PCBs (older buildings, yet still relevant [17]; terpenes, hexaldehyde [27]
- Candles: PAHs, aromatic species, aerosols, short-chain aldehydes [18];
- Joint sealants: PCBs in very high concentrations [19];
- Smoking, and/or off-gassing (or outgassing) from clothes after having been in a smokers' environment: Environmental Tobacco Smoke that is a mixture of several thousands of chemicals [20, 23].
- Mattresses: pyrethrins and pyrethroids used to control bugs and other pests [26];

4. Conclusions

The indoor air quality is one of the factors that can expose people to almost any toxic chemical, in concentrations higher than in the outdoor air. During sleeping, people breathe passively and are exposed for several hours to air that may contain thousands of known

141 organic chemicals, some of which are particularly toxic, yet this aspect has not been given the
142 relevant importance from scientists to date.

143 The indoor air in bedrooms can be less diluted as a result of the tendency of occupants to try
144 decrease air exchange rates in order to have energy-tight, rumor free buildings and therefore
145 improve their “sleeping environment”, but this has an impact on the bedroom air
146 concentrations for hundreds of chemicals.

147 A particularity of this research field is that wealth and good economic conditions can lead
148 people to increased indoor exposure, as a result of more frequent complete or partial house
149 renovations/retrofitting, purchase of carpets, use of candles, sprays and other household
150 products and goods.

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