Building and Environment 125 (2017) 528–555

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Human exposure to indoor air pollutants in sleep microenvironments: A literature review

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ARTICLE INFO

Article history:
Received 14 May 2017
Received in revised form
8 August 2017
Accepted 26 August 2017
Available online 30 August 2017

Keywords:
Bedroom
Mattress dust
Allergens and microbes
Volatile and semi-volatile organic compounds
Sleep quality
Human exposure
Particle resuspension

ABSTRACT

We spend approximately one-third of our lives sleeping, yet little is known as to how human exposure to indoor air pollutants during sleep impacts human health and sleep quality. This paper provides a literature review of the current state-of-knowledge pertaining to human inhalation and dermal exposures while sleeping. An analysis of the duration of sleep exposure periods is provided, demonstrating that the sleep microenvironment is the predominant indoor space where humanity spends most of its time. Mattress dust is found to contain a diverse spectrum of biological particles and particle-bound chemical contaminants and their concentrations in dust can span many orders of magnitude among bed samples. These dust particles can become airborne through particle resuspension associated with body movements in bed. Mattress foam and covers, pillows, and bed frames can emit a variety of volatile and semi-volatile organic compounds, including phthalate plasticizers and organophosphate flame retardants, and emission rates can increase due to localized elevations in surface temperature and moisture near the bed due to close contact with the human body. This literature review demonstrates that human exposures to mattress-released pollutants can be amplified due to the source-proximity effect inherent to the sleep microenvironment, where the human body and breathing zone are in close and intimate contact with potential pollutant sources for prolonged periods. Given the findings of this review, human exposures to indoor air pollutants in the sleep microenvironment should receive more attention and future research is needed to fully understand how sleep exposures affect human health and sleep quality.

Contents

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http://dx.doi.org/10.1016/j.buildenv.2017.08.050

1. Introduction

Many particulate and gaseous pollutants that are potentially health hazardous originate from indoor sources and concentrations are often much higher indoors than outdoors [133]. Since people spend about 80–90% of their time indoors [77,113,137], human exposures in the indoor environment are often substantially greater than exposures occurring outdoors. Across the world, adults typically sleep 8–9 h per day [46,77,114,159], virtually always indoors, which corresponds to one-third of their lifetime, making the sleep microenvironment particularly important in contributing to both their acute and chronic exposures to indoor pollutants. Mattresses, pillows, bedding materials, and bed frames are possible pollutant sources unique to sleep microenvironments. People are likely to be exposed to elevated concentrations of various chemical contaminants and biological particles since they are in close and intimate contact with these items. Early-life exposures to mattress-released pollutants are a particular concern, given the extended sleep periods of infants (12–14 h per day) and their low body weights [30,50,85,86].

The sleep microenvironment can be defined as the space encompassing a mattress, pillow, bedding materials, bed frame and the volume of air above these items that includes an individual's breathing zone (BZ) and buoyant thermal plume [15,16,88]. The seemingly innocuous sleep microenvironment can be home to a diversity of pollutants that have been shown to impact human health. Mite and animal allergens, human- and animal-associated bacteria, fungi, and semi-volatile organic compounds (SVOCs) can accumulate in settled dust on mattresses, pillows, and bed sheets (see references in Table 1). The materials used to manufacture mattresses and bedding products, such as polyurethane foam and vinyl mattress covers, are possible sources of a myriad of chemical contaminants, including volatile organic compounds (VOCs), plasticizers, flame retardants, and unreacted (free) isocyanates (NCO) (see references in Table 2).

Measuring indoor air pollutant concentrations at a reference location in the bulk air of a room may not be sufficient to characterize indoor exposures (e.g. Ref. [180]). This discrepancy, which is known as the source-proximity effect, is mainly due to the non-uniform distribution of pollutants that arises due to source location, the buoyant human thermal plume, occupant movements, and the overall airflow pattern and mixing conditions within a space [29,43,60,128,130,131]. The source-proximity effect is an important characteristic of the sleep microenvironment, where the human body and BZ are in close proximity to potential pollutant sources for extended periods of time. Therefore, people may be exposed to elevated concentrations of pollutants via inhalation and dermal pathways as they sleep. Research on the underlying physical processes governing the source-proximity effect of the sleep microenvironment is limited.

Human exposure in sleep microenvironments is important, but has not been extensively researched in contrast to exposures in other types of indoor environments, such as classrooms, kitchens, and occupational workplaces. Therefore, it offers challenging research opportunities to advance our understanding of the pollutants commonly found in sleep microenvironments, the mechanisms by which pollutants are transported around the human body to an individual's BZ, pollutant concentrations and exposure levels that individuals experience while sleeping, and the total amount of pollutants that are inhaled or absorbed via dermal exposure. This knowledge is important to investigate subsequent health effects and to develop strategies to promote healthy bedrooms. As a key step in the advancement of this knowledge, we provide a literature review of the current understanding of human exposure in sleep microenvironments, including: exposure characteristics, a summary of the biological and chemical composition of mattress dust, an overview of chemical emissions from mattresses and bedding materials, the potential for elevated exposures due to the source-proximity effect, and the use of personalized ventilation and air cleaning systems for beds.

2. Sleep exposure characteristics

2.1. Exposure pathways

Inhalation exposure can be defined as the contact between an agent (pollutant) and a target (person) [179]. The contact between a pollutant and a person occurs at an exposure point, which we can define as a person's BZ. The inhalation exposure concentration can be defined as the mass of a pollutant (e.g. # of particles or μg of a VOC) in a person's BZ divided by the BZ volume. The volume of the BZ is variable, has been shown to be dependent on the transport dynamics of a specific pollutant e.g. Ref. [97], and is likely influenced by physical obstructions, such as a pillow for a person sleeping in the prone position [89]. However, it is generally defined as a hemisphere with a radius of 30–50 cm, with its center of origin at the mouth or the nose [72,132]. An expression for the time-integrated inhalation exposure, $E_{i,j}$, of a specific pollutant, i, in a particular microenvironment, j, is: