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Indoor air quality during sleep under different ventilation patterns

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ABSTRACT

Sleep plays a crucial role in the human welfare. This preliminary study aimed to characterise the indoor air quality (IAQ) during sleep, which has been scarcely studied, to better understand the occupant's exposure. Comfort parameters along with indoor air pollutants were assessed in one bedroom during the sleeping period of the occupant. Four scenarios of natural ventilation in the bedroom were studied regarding IAQ. The ventilation setting with door and window closed (CDCW) promoted the lowest air change rate (0.67 ± 0.28 h^{-1}) and the highest levels of carbon dioxide (CO_2), carbon monoxide (CO) and volatile organic compounds (VOCs). Irrespective of ventilation condition, particulate matter levels (PM10, PM2.5) were always high, although maximum values were recorded under CDCW. The simultaneous opening of door and window supplied the highest air change rate (4.85 ± 0.57 h^{-1}). Several pollutants were found to be in concentrations above the established Portuguese guideline for assuring IAQ, namely VOCs, formaldehyde and PM2.5, in specific ventilation settings.

1. Introduction

Indoor air has been a major focus of scientific research worldwide due to evidences of adverse health effects (Sundell, 2004) along with increase of human mortality (Kumar et al., 2005). Moreover, in developed countries, people spend more than 90% of their daily time in indoor environments: home, school, workplace and other indoor places where extra and leisure activities are developed (Almeida-Silva et al., 2014).

Scientific research within the indoor air field has been shifting to evaluate exposure of susceptible groups, based on understandable higher negative impacts that indoor air may play on them, such as children (Annesi-Maesano et al., 2013; Canha et al., 2016), sports practitioners (Ramos et al., 2014, 2015) and elderly (Almeida-Silva et al., 2015; Almeida et al., 2016). However, this research has been focused on micro-environments where people are only during daytime, often neglecting the exposure of occupants during sleeping period, which corresponds around to one third of the lifetime of a person and may have a significant contribution to the total exposure of an individual.

Moreover, sleeping environments are usually characterised by lower ventilation rates (Bekö et al., 2010), promoting pollutants' accumulation (Canha et al., 2016), along with specific exposures taking into account that the breathing area is closer to potential sources of pollutants. In bedrooms, typical specific sources, such as mattresses, emit phthalates, isocyanates and formaldehyde and contribute to the total material emissions (Kemmlein et al., 2003). Additionally, mattresses, pillows and bed linens are often heavily treated with flame-retardants and contain residual detergent components and other substances that are known to have an impact on human health (Anderson and Anderson, 2000; Hoffmann and Schupp, 2009). The mattress is also known to be a great biotope for dust mites (Wu et al., 2012), the faeces of which are a source of allergenic particles. The bed arrangements (blankets, pillows, and mattresses) are also considered as major sources of

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accumulated dust particles, which may become airborne through a process known as resuspension (Spilak et al., 2014). Besides bedding arrangements, sleeping position and human metabolism were also found to have a significant impact on the exposure of the sleeping person (Laverge et al., 2013).

Sleep is essential to help the body recover from both physical and psychological fatigue suffered throughout the day and helps restore energy to maintain bodily functions. A comfortable sleep is also necessary for high productivity during daytime. Several studies have showed the impact of sleep's quality on to the daytime sleepiness (which is a risk factor and promotes lower productivity) in different types of jobs, such as truck drivers (Catarino et al., 2014) and airline pilots (Reis et al., 2016). Athletic performance has also been shown to be negatively associated with sleep deprivation whereas sleep extension promoted its improvement (Thun et al., 2015).

Sleep quality is affected by many factors, such as health and emotional states, bedding conditions, and different environmental conditions (Pan et al., 2012), including noise levels (Halperin, 2014; Pirrera et al., 2014) and temperature (Lin and Deng, 2008; Okamoto-Mizuno and Mizuno, 2012; Lan et al., 2016). Some studies have focused on the impact of outdoor air pollution on sleep. For instance, Fang et al. investigated the association between black carbon (BC), a marker of traffic related air pollution, and sleep parameters among 3821 residents in Boston area and found that BC long-term exposure may be associated with shorter sleep duration in men and those with low socioeconomic status, but also with longer sleep duration in blacks (Fang et al., 2014). Zanobetti et al. also found that sleep efficiency (percentage of time in bed actually asleep) was reduced in relation to short-term elevations in outdoor PM10 in a cross-sectional study using objective measures of sleep (Zanobetti et al., 2010).

The sleep has a vital role in the daily welfare of people but, however, the impact of the quality of the sleeping environment has been scarcely studied (Lan and Lian, 2016; Urlaub et al., 2015). The environmental characterisation enables to understand the factors that may contribute to the degradation of sleep's quality. Strøm-Tejsen et al. found that lower levels of CO_2 during sleep improved significantly the sleep quality and the perceived freshness of the bedroom air by the occupants, along with the next day performance (Strøm-Tejsen et al., 2016). In Peru, Accinelli et al. studied 82 children with lifetime exposures to indoor fuel pollution, from which a group benefited the installation of less-polluting cooking stoves (reduction of PM2.5 concentrations by 74% when compared to traditional stoves) (Accinelli et al., 2014). Accinelli et al. found that those children (with implementation and exclusive utilisation of improved kitchen stoves) showed significant improvements in sleep and respiratory related symptoms, such as difficulty falling asleep, sore throat and morning headache (Accinelli et al., 2014). However, studies focusing on a wider characterisation of indoor air quality during sleep are lacking in the literature. Deeper studies would allow to better understanding the occupants' exposure during this representative period.

The purpose of the present study was to contribute with preliminary information to append to the still emergent and scarce databases, by assessing the indoor air quality (IAQ) during sleep. Designed as a preliminary approach, the study was carried out in one bedroom with different ventilation settings and focused on several parameters, such as carbon monoxide (CO), carbon dioxide (CO_2), formaldehyde (CH_2O), total volatile organic compounds (VOCs), particulate matter (PM10, PM2.5 and PM1) and comfort parameters (temperature and relative humidity). The different ventilation settings were studied in order to evaluate their impact on the pollutant concentrations.

2. Materials/methods

2.1. Study site

The studied bedroom belonged to an apartment located on the third floor of a residential building of an urban area (parish of Pinhal Novo) of Setúbal district, Portugal (Fig. 1). The building was built in 1999 and is located in the vicinity of an avenue with moderate traffic. The inner and outside walls of the building were built with brick and possessed an air box and thermal insulation.

The apartment had an area of 110 m^2 and two bedrooms, as shown in Fig. 2. The floors of the living room, hallway and kitchen were tiled and both bedrooms had parquet wood flooring. All the rooms were equipped with single-hung aluminium windows. The apartment did not have any air supply mechanical system. The kitchen was equipped with a cooking stove and a water heater, both gas powered. The ground floor of the building was occupied by a restaurant.

The study was conducted in bedroom C (Fig. 2), which had an

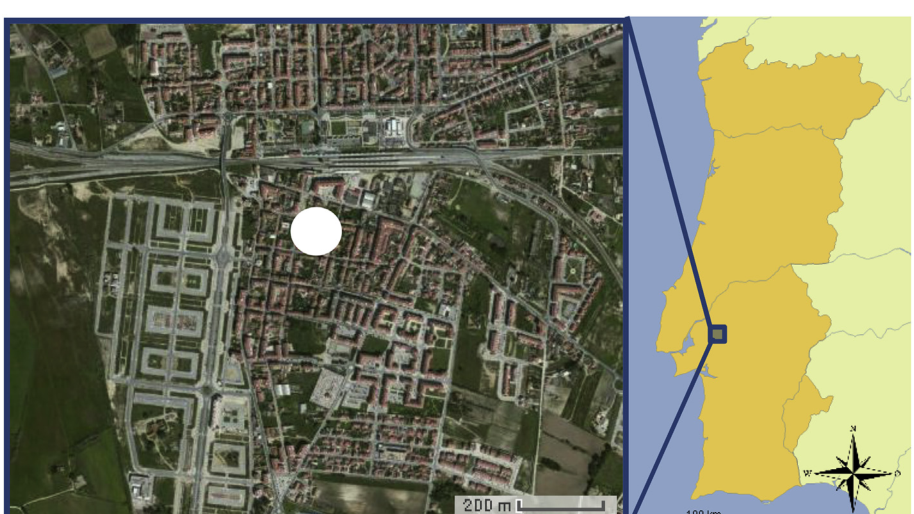

Fig. 1. Location of the apartment studied I in the urban area of Pinhal Novo (district of Setúbal, Portugal).

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