Science of the Total Environment 642 (2018) 168–179

Contents lists available at ScienceDirect

Science of the Total Environment

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

Indoor air quality in two French hospitals: Measurement of chemical and microbiological contaminants

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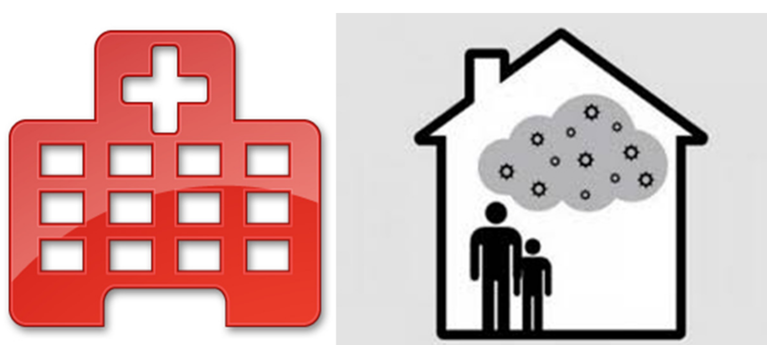
HIGHLIGHTS

- Chemical and microbiological contamination assessment of indoor air in hospitals
- Implementation of sampling and analysis methods adapted to hospital environment
- Chemical complex mixture related to healthcare and human activities and uses
- Low pollution level compared to dwellings environment due to high air rate exchange

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 12 April 2018
Received in revised form 4 June 2018
Accepted 4 June 2018
Available online xxxx

Editor: D. Barcelo

Keywords:
Indoor air
Hospital
Pollutants
Spatial and temporal variability
Air sampling methodology

ABSTRACT

In addition to being influenced by the environment, the indoor air pollution in hospitals may be associated with specific compounds emitted from various products used, health care activities and building materials. This study has enabled assessment of the chemical and microbiological concentrations of indoor air in two French hospitals. Based on an integrated approach, the methodology defined aims to measure concentrations of a wide range of chemical compounds (>50 volatile and semi-volatile organic compounds), particle concentrations (PM_{10} and $PM_{2.5}$), microorganisms (fungi, bacteria and viruses) and ambient parameters (temperature, relative humidity, pressure and carbon dioxide). Chemical and microbiological air concentrations were measured during two campaigns (winter and summer) and across seven rooms (for spatial variability).
The results have shown that indoor air contains a complex mixture of chemical, physical and microbiological compounds. Concentrations in the same order of magnitude were found in both hospitals. Compared to dwelling indoor air, our study shows low, at least equivalent, contamination for non-hospital specific parameters (aldehydes, limonene, phthalates, aromatic hydrocarbons), which is related to ventilation efficiency. Chemical compounds retrieved at the highest concentration and frequencies are due to healthcare activities, for example alcohol – most commonly ethanol - and hand rubbing (median concentration: ethanol 245.7 μg/m^3 and isopropanol 13.6 μg/m^3); toluene and staining in parasitology (highest median concentration in Nancy laboratory: 2.1 μg/m^3)).

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https://doi.org/10.1016/j.scitotenv.2018.06.047

1. Introduction

Indoor air quality knowledge in vulnerable environments such as healthcare institutions is a crucial issue. Microbiological indoor air quality monitoring and control in hospitals is currently a necessary and integral part of prevention strategies against hospital-acquired infections (Zahar et al., 2017). Bacterial, viral and fungal infections are frequently acquired via inhalation, among them pulmonary aspergillosis and pneumocystosis still represent high disease burden (Gangneux et al., 2016). However, knowledge of the chemical and physical (particles) pollution of indoor air in hospitals, and its well-established interaction with microbial pollution is scarce - yet the subject is only rarely studied. This pollution may be associated with a wide range of specific compounds emitted from various products such as disinfectants and sterilizers (ethylene oxide, glutaraldehyde, formaldehyde, alcohols, etc.), limonene-based cleaning products, anesthetic gases, laboratory and pharmaceutical products and materials (Bessonneau et al., 2013). It may however also be influenced by building materials and the outdoor environment. To investigate the distribution of indoor air pollutants in different areas of hospitals and in different healthcare institutions such as Elderly Care Centers or Dentistry Clinics, the parameters usually measured are carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), particulate matter of different diameter (mainly $PM_{2.5}$ and PM_{10}), sulfur dioxide (SO_2), airborne bacteria and fungi, and among indoor chemical pollutants, total volatile organic compounds (TVOC), including formaldehyde (Jung et al., 2015; Mendes et al., 2015; Almeida-Silva et al., 2014; Helmis et al., 2007). Cleaning solutions and detergents are used in these healthcare institutions to reduce risk of infection - thus increasing the TVOC levels (Bessonneau et al., 2013; Jung et al., 2015). Aldehyde compounds (formaldehyde and glutaraldehyde) used in medical treatment (as disinfectants for cold sterilization) may also contribute to increased aldehyde levels in indoor hospital air (Jung et al., 2015; Dascalaki et al., 2008).

The level of particulate matter (PM) in the air can be affected by humans walking indoors (Zhang et al., 2008) as well as by outdoor air. Moreover, several studies suggest that indoor air chemistry, particularly related to reactions between terpenes originating from indoor sources (e.g. limonene-based cleaning products) and ozone (O_3) originating outdoor, can be an important source of indoor fine particles (Langer et al., 2008; Sarwar and Corsi, 2007). These airborne particles, with a diameter lower than 2.5 μm ($PM_{2.5}$) are widely investigated, due to their relation to adverse health effects from air (Jung et al., 2015; Loupa et al., 2006). In the Loupa et al. (2006) study, monitoring of indoor and outdoor $PM_{2.5}$ (and their trace element composition) provided a means of verifying the adequacy of a hospital's air filtration system – something particularly important in health care facilities. Indoor particle size distributions can be a good indicator of indoor air quality degradation, after the change of the quality of air filters.

Wang et al. have shown phthalates concentrations in Chinese hospitals to be higher than in newly-decorated homes (Wang et al., 2015). Total phthalate particle-phase concentration in hospitals was 1.2 times higher than in newly-decorated homes, though for gas-phase phthalates, the multiplier increased to 1.8. Phthalates and synthetic musks are semi-volatile organic compounds (SVOCs) widely used in many consumer products as plasticizers and fragrances (Dallongeville et al., 2016). They are common additives in paint, adhesives, cleaning agents and personal care products (Dodson et al., 2012), and are frequently found in air and dust samples from dwellings (Blanchard et al., 2014).

Little is known about geographical variations between establishments when using the same methodology. This study has therefore allowed us, for the first time, to assess the chemical and microbiological pollution of indoor air in two French hospitals. Based on two intensive sampling campaigns, a methodology has been defined with the aim of measuring concentrations of a wide range of chemical compounds, microorganisms and particles.

2. Material and methods

2.1. Experimental hospital sites

The University Hospital of Rennes (in Brittany, western France) is a 1952-bed tertiary hospital divided into two main hospitals: Hôpital Pontchaillou and Hôpital Sud. Our study was carried out in various buildings in Pontchaillou - two of which were built in the 1970s, while the other two date from recent years (2010s). It is an urban hospital in a location free of heavy traffic and distant from a highway, with a gas station located 500 m away. In 2012, we conducted preliminary work to estimate volatile organic compounds (VOC) pollution in this same hospital (Bessonneau et al., 2013).

The University Hospital of Nancy (in Lorraine, eastern France) is a 1920-bed health facility divided into two main entities: the Brabois hospitals and the urban hospitals, comprising four and five facilities respectively. Our study was conducted in the four facilities of the Brabois Hospitals. These, located on an upland at an altitude of 400 m, are flanked on two sides by a highway and a boulevard, both with heavy traffic. A forest is located beyond the highway. A gas station is located 500 m away. Two of the buildings date from the 1970s, while the other two are from very recent years (2010s), as with the Rennes hospital.

The ventilation system in both hospitals allows an air change rate ranging from 1 and 11 vol/h all year round.

2.2. Study design

In both hospitals, the study was conducted in June 2014 for the summer campaign and in February 2015 for the winter campaign. The campaigns were conducted twice over a period of four consecutive days (Monday morning to Friday midday) to account for every single activity taking place at the healthcare facility.

In each hospital, air samples were collected from seven sites – the Reception Hall (Hall), a Patient Room (Room), a Nursing Care Room (Care), the Parasitology and Mycology Laboratory (PML), a Post-Anesthesia Care Unit (PACU), a Plaster Cast Room (Plaster) and the Flexible Endoscope Disinfection Unit (FEDU) - in order to estimate spatial and temporal (related to the healthcare activities and between two hospitals) variability in chemical and microbiological contaminants in indoor air. These sampling locations were selected on the basis of their diversity of activities, the nature of manipulated chemical compounds and their representativeness of the hospital (Berrubé et al., 2013). The Reception Hall was selected as a control site where indoor air pollution is mainly due to sources unrelated to healthcare activities (e.g. building materials or outdoor air).

2.3. Parameters

During both campaigns, 34 VOCs including aliphatic, aromatic and halogenated hydrocarbons, alcohols, ketones, ethers and terpenes, were measured along with 7 aldehydes and 13 SVOCs including phthalates, musk and pyrethroids. Ambient parameters (temperature, relative humidity, atmospheric pressure and carbon dioxide) were measured continuously during both sampling campaigns. Fine particles ($PM_{2.5}$) were measured using a gravimetric method and particles counts (diameter from 0.3 to 10 μm) were measured at six of the seven sites (Plaster Room excepted). In the Plaster Room, coarse particulate matter (PM_{10}) was sampled using the gravimetric method in link with particles emission during plaster cutting. Finally, for the biological pollution assessment, bacteria (5), virus (3) and fungi (5) were also analyzed (Table 1). Airborne biological agents were selected for their relevance within a context of hospital-acquired infections and communicable diseases, particularly at occupational health facilities. Bacteria were selected for their ability to induce respiratory disease (*Streptococcus pneumoniae, Mycobacterium)* or cause risk of