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Indoor exposure to particles emitted by biomass-burning heating systems and evaluation of dose and lung cancer risk received by population☆

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A B S T R A C T

Homes represent a critical microenvironment in terms of air quality due to the proximity to main particle sources and the lack of proper ventilation systems. Biomass-fed heating systems are still extensively used worldwide, then likely emitting a significant amount of particles in indoor environments. Nonetheless, research on biomass emissions are limited to their effects on outdoor air quality then not properly investigating the emission in indoor environments.

To this purpose, the present paper aims to evaluate the exposure to different airborne particle metrics (including both sub- and super-micron particles) and attached carcinogenic compounds in dwellings where three different heating systems were used: open fireplaces, closed fireplaces and pellet stoves. Measurements in terms of particle number, lung-deposited surface area, and PM fraction concentrations were measured during the biomass combustion activities, moreover, PM_{10} samples were collected and chemically analyzed to obtain mass fractions of carcinogenic compounds attached onto particles. Airborne particle doses received by people exposed in such environments were evaluated as well as their excess lung cancer risk.

Most probable surface area extra-doses received by people exposed to open fireplaces on hourly basis (56 vvmm^2 vvh^{-1}) resulted one order of magnitude larger than those experienced for exposure to closed fireplaces and pellet stoves. Lifetime extra risk of Italian people exposed to the heating systems under investigation were larger than the acceptable lifetime risk (10^{-5}): in particular, the risk due to the open fireplace (8.8 vv× vv10^{-3}) was non-negligible when compared to the overall lung cancer risk of typical Italian population.

1. Introduction

1.1. Biomass burning as a main hazardous source

Biomass–burning heating systems are currently greeted as a worthy solution for indoor heating purposes due to the competitive running costs and the carbon neutrality of wood-biomass. Indeed, in the last years, government incentives and subsidies for residential heating with wood were offered also in developed countries, therefore the wood consumption for heating purposes is expected to increase (World Health Organization, 2015).

Nonetheless, the environmental issues associated with burning wood is not limited to the greenhouse gas emissions: the overall emissions of airborne contaminants should be considered. Combustion phenomena of solid fuels are more complex than gaseous fuels and produce significant emission of hazardous chemicals

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(Lackner et al., 2013). In fact, the growth of biomass consumption in some European countries was recently related to the increased ambient emissions of airborne particles and Polycyclic Aromatic Hydrocarbons (Viana et al., 2016): the European Environmental Agency (2016) reported a significant impact of residential combustion of biomass on local and regional-scale air quality with contributions up to 40% of the daily airborne particle mass concentration.

1.2. Airborne particles as a main pollutant

Airborne particles are considered a major component of outdoor air pollution, in fact, PM_{10} (mass concentration of particles smaller than 10 vvμm) was classified by the International Agency for Research on Cancer (IARC) as carcinogenic to humans (Beelen et al. (2014) International Agency for Research on Cancer (2013)) due to its recognized lung cancer effect. Carcinogenic potency of the airborne particles is strictly related to the toxic compounds attached onto particle surface: indeed, particle-bounded toxic compounds such as heavy metals, polycyclic aromatic hydrocarbons, and dioxins/furans may be easily carried into the lungs (Abdel-Shafy and Mansour, 2016; Eiguren-Fernandez et al., 2010; Li et al., 2015). The inhalation of such compounds depends on the size of the carrying particles: in particular, sub-micron and ultrafine particles (UFPs, particles with a diameter less than 100 vvnm), better described by surface area and number concentration metrics (Baldauf et al., 2016; Noël et al., 2016; Rizza et al., 2017), are characterized by a greater deposition probability in the lungs (International Commission on Radiological Protection, 1994) than larger particles (whose typical aerosol metric is the mass-based concentration, i.e. PM_{10} or $PM_{2.5}$ (Buonanno et al., 2009, 2010),). This hypothesis is supported by recent epidemiological and toxicological findings detecting a more significant dose-response relationship for UFPs (Landkocz et al., 2017; Longhin et al., 2016; Schmid et al., 2009; Strak et al., 2010) as well as by risk assessment studies reporting that combustion-generated UFPs (expressed as surface area dose) present a potential lung cancer risk much higher than the super-micron particle one (Liao et al., 2011; Sze-To et al., 2012).

1.3. Air quality in indoor microenvironments

On the basis of the abovementioned findings it clearly appears that biomass-burning phenomena could lead to serious indoor air quality concerns. Actually, biomass burning was deeply studied as a typical outdoor source of PM_{10} (and related particle-bounded compounds), as an example particle mass emission factors as a function of the heating systems were provided by the European Environmental Agency (2013), whereas a gap of knowledge still persists in terms of ultrafine particle emission (Díaz-Robles et al., 2014). Moreover, an even greater lack of information of the scientific community concerns the emission of biomass-burning heating system indoor environments: few research studies have been reported to characterized the emission of biomass burning phenomena in indoor environments and even scarcer data on the exposure levels in indoor micro-environments with biomass heating systems can be found (Carvalho et al., 2013; Kocbach Bølling et al., 2009; Moriske et al., 1996; Salthammer et al., 2014; Zhang et al., 2014). This is a main concern since indoor microenvironments represent critical environments mainly contributing to the overall daily particle dose received by population (Buonanno et al., 2011, 2012, 2014).

1.4. Aim of the work

The still open questions on the exposure to biomass-generated particles in indoor environments summarized above represent a great opportunity for engineers and air quality experts involved in particle characterization. To this end, the present paper aims to evaluate the exposure in indoor microenvironments to airborne particles emitted from biomass-burning systems employed in dwellings for heating purposes including open fireplaces, closed fireplaces and pellet stoves with automatic feeder. The dose of both sub-micron and super-micron particles received by exposed population living in such dwellings was also evaluated. Moreover, the resulting lung cancer risk was estimated using an *ad-hoc* model able to take into account the contribution of both sub-micron and super-micron particles. To this end the mass fraction of carcinogenic compounds (heavy metals and polycyclic aromatic hydrocarbons, PAHs) on PM_{10} emitted by biomass-burning devices under investigation were also measured.

2. Materials and methods

2.1. Experimental campaigns

Two different experimental analyses were performed in the present study:

a) the evaluation of the typical exposure of people to particle number, lung deposited surface area and PM_{10} concentrations in indoor microenvironments where heating systems are in operation;
b) the evaluation of the mass fraction of carcinogenic compounds on PM_{10} emitted by wood and pellet combustion.

2.1.1. Experimental apparatus

In order to evaluate the typical exposure of people to the different aerosol metrics in indoor microenvironments the following instruments were used:

- a diffusion charger particle counter (DiscMini, Matter Aerosol AG), which is a compact hand-held particle counter based on diffusion charging technique able to measure particle number concentration (N), lung-deposited particle surface area concentration (sum of the alveolar- and tracheobronchial-deposited particle surface area concentrations, hereinafter referred as S_{Alv+TB}), and average diameter of particles ranging in size from 10 to 700 vvnm;
- a hand-held laser photometer (DustTrak Model 8534, TSI Inc.) able to measure PM_1, $PM_{2.5}$, PM_{10} and total PM mass concentration fractions.

The evaluation of the chemical composition of PM_{10} emitted by wood and pellet combustion phenomena was performed through the following equipment:

- a gravimetric sampler made up of a volumetric rotating pump Zambelli 6000 Plus (equipped with temperature and atmospheric pressure sensors to measure normalized sampling volume) and a Zambelli PM_{10} impactor (working at a nominal fixed flow rate of 2.3 vvm^3 vvh^{-1} according to the EN 12341 (European Committee for Standardization, 2001)) to collect particulate matter on a quartz filter for post-hoc chemical analysis and PM_{10} mass concentration evaluation;
- an Ultra Trace™ gas chromatograph coupled with a TSQ™ mass spectrometer (Thermo Fischer Scientific™, St Peters,