Building and Environment 140 (2018) 80–89

Contents lists available at ScienceDirect

Building and Environment

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

Aerosol particles (0.3–10 μm) inside an educational workshop – Emission rate and inhaled deposited dose

Androniki Maragkidou[a], Omar Jaghbeir[b], Kaarle Hämeri[a], Tareq Hussein[a,b,*]

[a] University of Helsinki, Institute for Atmospheric and Earth System Research (INAR), PL 64, FI-00014 Helsinki, Finland
[b] The University of Jordan, Department of Physics, Amman 11942, Jordan

ARTICLE INFO

Keywords:
Exposure
Indoor air quality
Particle losses
Aerosol modeling

ABSTRACT

In this study, we measured the concentrations of accumulation and coarse particles inside an educational workshop (March 31–April 6, 2015), calculated particle emission and losses rates, and estimated inhaled deposited dose. We used an Optical Particle Sizer (TSI OPS 3330) that measures the particle number size distribution (diameter 0.3–10 μm) and we converted that into particle mass size distribution (assuming spherical particles and unit density). We focused on two particle size fractions: 0.3–1 μm (referred as $PN_{0.3-1}$ and $PM_{0.3-1}$) and 1–10 μm (referred as PN_{1-10} and PM_{1-10}). The occupants' activities included coffee brewing, lecturing, tobacco smoking, welding, scrubbing, and sorting/drilling iron. The highest concentrations were observed during welding with $PN_{0.3-1}$ ($PM_{0.3-1}$) was ~1866 cm^{-3} (55 μg/m^3) and PN_{1-10} (PM_{1-10}) was ~7 cm^{-3} (103 μg/m^3). The lowest concentrations were observed during coffee brewing and metal turning with $PN_{0.3-1}$ ($PM_{0.3-1}$) was ~22 cm^{-3} (0.7 μg/m^3) and PN_{1-10} (PM_{1-10}) was ~0.5 cm^{-3} (4 μg/m^3). The emissions rate of coarse particles was 85–1010 particles/hour × cm^3 whereas that for submicron particle in the diameter range 0.3–1 μm was 5.7×10^4–9.3×10^4 particles/hour × cm^3 depending on the activity and the ventilation rate. The coarse particles losses rate was 0.35–2.1 h^{-1} and the ventilation rate was 0.24–2.1 h^{-1}. The alveolar received the majority and particles below 1 μm with a fraction of about 53% of the total inhaled deposited dose whereas the head/throat region received about 18%. This study is important for better understanding the health effects at educational workshops.

1. Introduction

The indoor air tends to be contaminated by more pollutants than the air outdoors mostly due to a vast range of indoor sources types [1–5]. It was also pointed out that energy-efficient building, increased usage of domestic personal care products and cleaners, and synthetic building materials are potential sources of indoor pollutants [6]. Therefore, we shouldn't be surprised by the fact that the some indoor pollutant concentrations have been reported to be 2–5 times higher and in some occasions even more than 100 times higher than those outdoors [4,7].

In general, indoor aerosols are either from outdoor or indoor origin [3,8–13]. Particles of various sizes produced by outdoor sources can migrate into indoor environments through indoor-outdoor air exchange processes (e.g. filtration and infiltration) that are affected by ventilation type and building features [3,8,14]. Indoor sources of aerosols are, typically, characterized by the occupants' activities and indoor environment type (i.e. household, educational buildings, offices, workshops, etc.). In general, human activities such as tobacco smoking, cooking, kerosene heaters, wood burning are the main sources of indoor fine aerosols [5,9,15]. Re-suspension by indoor activities such as walking, cleaning, and dusting is a major source of micron particles [9–12,16–20]. Inside educational buildings, the potential indoor sources of aerosols might include office electronic equipment such as copiers, printers, and computers [21–26], in addition to ventilation mechanisms, furnishing, high/low occupancy, and re-suspension processes [3,27–29]. Inside workshops and industrial environments, the activities include mechanical processes, high temperature processes, welding, grinding, smelting, soldering, laser ablation, cutting, and polishing [30–38]. These sources can produce significant amounts of both fine and coarse aerosols [32–38].

Besides imposing serious health effects, it is believed that the performance of students and teachers as well as employees' efficiency are affected by poor Indoor Air Quality (IAQ) [1,39–43]. For example, the sick building syndrome (SBS) has been reported in many types of indoor environments [44–50]. Specifically, Hedge et al. [46], Hodgson and Collopy [47] and Gyntelberg et al. [48] investigated SBS inside non-industrial buildings such as offices and town halls. Their results supported by questionnaires and reports signed by buildings' occupants

* Corresponding author. The University of Jordan, Department of Physics, Amman, 11942, Jordan.
E-mail address: t.hussein@ju.edu.jo (T. Hussein).

https://doi.org/10.1016/j.buildenv.2018.05.031
Received 30 January 2018; Received in revised form 14 May 2018; Accepted 14 May 2018
Available online 24 May 2018

showed that particulate matter and office dust in addition to building characteristics (such as ventilation, heating and air conditioning mechanisms), individual factors (i.e. gender, age), occupational factors (job type, duration, etc.) and environmental factors (i.e. lighting, temperature, etc.) had severe impacts on workers' health and performance. Analysis of symptoms such as eye, nose and throat irritation caused by coming into contact with office dust can be found in studies conducted by Hedge et al. [46], Gyntelberg et al. [48], Armstrong et al. [49] and Menzies et al. [50]. Moreover, occupational exposure to gases and particulate matter originating from welding fumes is strongly correlated to adverse health implications such as asthma, chronic bronchitis, respiratory problems, metal fume fever, pneumoconiosis and increased probability of lung cancer [36,51–55]. Therefore, it is highly recommended to develop protocols to improve the IAQ with respect to both health effects and workers performance [56–58].

There have been many studies characterized the dynamic behavior of aerosols inside houses. However, workshops and industrial environments have not been given enough attention. In fact, most of the research regarding industrial workplaces has been focused on measuring and reporting the particle mass or number concentrations of coarse and/or fine particles [32,37,59–63]. The emission factors as well as the inhaled deposited dose in the respiratory system were seldom mentioned in previous research.

The main objective of this study was to assess the exposure inside an educational workshop. We measured the particle number size distribution (0.3–10 μm) during March 31st until April 6th, 2015. We focused on investigating the effects of some indoor activities (such as lecturing, smoking, coffee brewing, iron welding, turning and sorting/drilling) on the particle concentrations. In addition, a simple indoor aerosol model was used to estimate the particle losses and emission rates. We also estimated the regional inhaled deposited dose during the occupants' activities.

2. Materials and methods

2.1. Measurement location

The measurement campaign (March 31 – April 6, 2015) took place inside an educational workshop at the Department of Physics, University of Jordan. The Department of Physics is a three-floor construction (naturally ventilated) located at the middle of the campus. The workshop itself ($32 \times 10 \times 3\ m^3$) was located on the ground floor and it was naturally ventilated. It consisted of student training workshop, office, storage room, changing room, wood workshop room, metal workshop room (equipped with welding machinery), and a main workshop area (equipped with turnery/metal-work machinery) (Fig. 1). Workers and/or visitors occupied the workshop during 8:00–16:00 on workdays. Sometimes, it was occupied by students, who were trained to use turnery/metal-work machinery during a lecture. The majority of the windows were kept open during working hours.

2.2. Aerosol measurements

The particle number size distribution (0.3–10 μm) was measured with an Optical Particle Sizer (OPS, TSI 3330, 13 size-bins, 1 min time resolution, 1 L/min flow rate, and dead-time correction). The instrument was calibrated by the manufacturer. It was located in the metal and welding section of the workshop (Fig. 1). The distance between the OPS and the windows was 2.5 m. The sampling was performed directly without additional tubing at a height of about 1.6 m above the ground, which represented the breathing zone.

2.3. Data handling

The aerosol data were first quality checked and validated by reviewing the data against unexpected instrument malfunctions. We calculated the size-fractionated particle number (PN) concentration and calculated mean, maxima, minima and median values at different percentiles (5%, 25%, 75% and 90%) for different events. Particle mass concentration (PM) was also calculated by assuming spherical particles with unit density.

2.4. Indoor aerosol modeling

The dynamic behavior of indoor aerosols can be described by the mass-balance equation [64,65]:

$$\frac{dI}{dt} = \lambda PO - (\lambda + \lambda_d)I + ER \tag{1}$$

where:

I is the aerosol particle concentrations indoors,
O is the aerosol particle concentrations outdoors,
P is the penetration factor of aerosol particles across the building shell (natural ventilation) or a standard filter installed in a mechanical ventilation system,
λ is the ventilation rate,
λ_d is the deposition rate of aerosol particle onto available indoor surfaces, and ER is the emission rate of aerosol particles indoors,
ER is the emission rate of aerosol particles indoors.

This mass-balance equation describes a certain particle size-fraction where aerosol particles have rather similar physical properties and behavior. Although this mass-balance equation was primarily used to simulate and predict the indoor aerosol particles and their behavior, it can be used in inverse modeling to estimate some parameters such as P, λ, λ_d or even ER [66,67]. It was utilized it in the current study to calculate the loss rate of aerosol particles, according to the principles described by Hussein [58] and Hussein et al. [8]. Subsequently, the emission rates were estimated according to the semi-empirical approach described by Hussein et al. [67].

In general, the particle losses ($\lambda + \lambda_d$) include indoor-outdoor air exchange, which was natural ventilation in this case, and dry deposition onto indoor surfaces. Hussein [58] and Hussein et al. [8] emphasized that particle losses can be estimated by analyzing occasions where large amounts of indoor aerosol particles are produced during indoor activities. Such cases cause higher indoor aerosol concentrations compared to outdoor concentrations. When the indoor sources are stopped, the decline of indoor aerosol concentrations is observed.

2.5. Exposure and deposited dose estimation

The regional inhaled deposited dose in the respiratory system was evaluated according to Hussein et al. [67,68]:

$$Deposited\ dose_{PM} = \int_{t1}^{t2} \int_{D_{p1}}^{D_{p2}} V_E \times DF \times n_N^0 \times f \times dlogD_p \times dt \tag{2}$$

where.

V_E ([L/min] or [m^3/h]) is the minute ventilation (known also as volume of air breathed per time)
DF [–] is the respiratory deposition fraction of aerosol particles,
$n_N^0 = \frac{dN}{dlog(D_p)}$ [particles/ cm^3] is the lognormal particle number distribution
D_p is the particle diameter
f is a dose metric such as the particle surface area or mass

In our calculations, we considered the Geometric Mean Diameter (GMD) of coarse particles as 2.5 μm. It should be noticed that both DF and n_N^0 are functions of log(D_p). The regional inhaled deposited dose was calculated for coarse particles during a specific event exposure time