

<https://helda.helsinki.fi>

---

Aerosol particles ( $0.3 - 10\frac{1}{4}\mu\text{m}$ ) inside an educational workshop : Emission rate and inhaled deposited dose

Maragkidou, Androniki

2018-08

---

Maragkidou , A , Jaghbeir , O , Hämeri , K & Hussein , T 2018 , ' Aerosol particles  
( $0.3 - 10\frac{1}{4}\mu\text{m}$ ) inside an educational workshop : Emission rate and inhaled  
deposited dose ' Building and Environment , vol. 140 , pp. 80 - 89 . <https://doi.org/10.1016/j.buildenv.2018.05.031>

---

<http://hdl.handle.net/10138/315198>

<https://doi.org/10.1016/j.buildenv.2018.05.031>

---

cc\_by\_nc\_nd

acceptedVersion

---

*Downloaded from Helda, University of Helsinki institutional repository.*

*This is an electronic reprint of the original article.*

*This reprint may differ from the original in pagination and typographic detail.*

*Please cite the original version.*

# Aerosol Particles (0.3–10 µm) inside a Workshop Area—Emission Rate and Deposited Dose

Androniki Maragkidou<sup>1</sup>, Omar Jaghbeir<sup>2</sup>, Kaarle Hämeri<sup>1</sup>, Tareq Hussein<sup>2\*</sup>

<sup>1</sup> University of Helsinki, Department of Physics, P.O. Box 64, FI-00014, Helsinki, Finland

<sup>2</sup> The University of Jordan, Department of Physics, Amman 11942, Jordan

## Abstract

The main objective of this study was to investigate the accumulation and coarse particles concentration inside an educational workshop and calculate emissions factors as well inhaled deposited dose. We measured the particle number distribution (diameter 0.3–10 µm) and focused on two particle size fractions: submicron particles in the diameter range 0.3–1 µm and coarse particles (1–10 µm). The occupants activities inside the workshop included coffee brewing, lecturing, tobacco smoking, welding, scrubbing, and sorting/drilling iron. The highest concentrations were observed during welding activities; mean  $PN_{0.3-1}$  ( $PM_{0.3-1}$ ) and  $PN_{1-10}$  ( $PM_{1-10}$ ) concentrations were about 1865.86 (54.49 µg/m<sup>3</sup>) and 6.46 cm<sup>-3</sup> (102.54 µg/m<sup>3</sup>) with most of the particles were emitted below 1 µm in diameter. 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%.

**Keywords:** Particulate matter; Indoor air quality; Emission rate; Deposited dose; Educational workshop

## 1. Introduction

---

\*Corresponding author. Tel.: +962-6-5355000; Fax: +962-6-5300253  
E-mail: [T.hussein@ju.edu.jo](mailto:T.hussein@ju.edu.jo)

The indoor air tends to be contaminated by more pollutants than the air outdoors [1–4]. 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 [5].

Particles originate from either outdoor or indoor sources or a combination of both [3,13]. Human activity such as tobacco smoking, walking, cooking, vacuuming, cleaning, using kerosene for heating and burning wood for heating or cooking are the main sources of indoor pollutants [14–15]. Moreover, re-suspension by indoor activities (i.e. active walking, cleaning, and dusting) and combustion processes such as toasting, oven roasting or baking, barbecuing are major sources of particles larger than 2.5  $\mu\text{m}$  and fine particles, respectively. [14, 16–17, 22–24]. Furthermore, He [23] reported that fine mode of particles in indoor environments was also generated by sources such as biological pollutants and sprays. Elevated concentrations of  $\text{PM}_{2.5}$  and  $\text{PM}_1$  were also observed during cooking and tobacco smoking [21]. Particles of various sizes produced by outdoor sources, can be introduced into indoor environments through infiltration processes that are linked to ventilation systems, building features and materials [3,9,13].

Indoor Air Quality (IAQ) in educational facilities is associated with ventilation mechanisms, furniture, high occupant density, type of activities and the re-suspension of particles from disturbances caused by the dynamic motion of occupiers [3, 28–30]. The performance of students and teachers, their health and well-being depend on good indoor air quality [1, 31–35].

Regarding the relationship between IAQ and workplaces such as offices, studies reported that great quantities of particles are emitted by office electronic equipment such as copiers, printers and computers [6, 36–40]. Moreover, IAQ has been associated with the efficiency of employees and health effects caused by psychosocial and environmental conditions that occurred in the work environment [13, 41–43]. Hedge et al. [44], Hodgson and Collopy [45] and Gyntelberg et al. [46] assessed airborne particulate matter and dust in non-industrial buildings and confirmed that health related issues and poor performance of workers are closely related to bad air quality. Moreover,

several studies documented eye, nose and throat irritation symptoms that were caused by coming into contact with office dust [45, 47–48].

Special attention has been paid lately to particulate matter emitted from manufacturing processes in industrial environments. For example, Chan et al. [49], Thornburg and Leith [50] and Iavicoli et al. [51] pointed out that the majority of the processes taking place in a metallurgic industry generated particles larger than 1  $\mu\text{m}$  in diameter, whereas other procedures were considered to be major sources of sub-micrometer particles, too. Moreover, operations in industrial workplaces that include welding, grinding, smelting, soldering, laser ablation, cutting, polishing, and heat treating are considered to be significant sources of ultra-fine particles [51–56]. Riediger and Möhlmann [59] reported that particle number concentrations of ultra-fine particles produced by activities such as plasma cutting, metal grinding, brazing, smelting, laser ablation, and metal inert gas and tungsten inert gas welding ranged from  $2.0 \times 10^4$  to  $4.0 \times 10^7$  particles  $\text{cm}^{-3}$ . 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 [55, 60–64].

Knowledge on occupational exposure to coarse particles inside workshops is currently very limited [51–56]. Moreover, most of the research has focused on measuring and reporting the particle mass and number concentration of the coarse and fine particles, respectively [51,56, 65–69]. The emission factors as well as the inhaled deposited dose in the respiratory system were seldom mentioned in previous research. Therefore, the main objective of this study therefore was to assess the exposure to large particles inside an educational workshop. We measured the particle number size distribution (0.3–10  $\mu\text{m}$ ) during March 31<sup>st</sup> until April 6<sup>th</sup> 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 in order to estimate the loss rate and the emission rate of aerosol particles inside the workshop area. The inhaled deposited dose was also calculated for the time period of indoor 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 ( $32 \times 10 \times 3 \text{ m}^3$ ) was located on the ground floor. 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). The workshop was occupied during 8:00–16:00 by workers and/or visitors on workdays. Sometimes, it was occupied by students training. The majority of the windows were kept open during working hours.

### *2.2. Aerosol Measurements*

The particle number size distribution (0.3–10  $\mu\text{m}$ ) was measured with an Optical Particle Sizer (TSI OPS 3330, 13 size-bins, 1 minute time resolution, 1 L/min flow rate, and dead-time correction). The instrument was calibrated by the manufacturer and 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 above the ground.

### *2.3. Data Handling*

The aerosol data were first quality checked and validated. 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 (Tables 1 and 2). Particle mass concentration (PM) was also calculated (Tables 3 and 4).

#### 2.4. Indoor aerosol modeling

The dynamic behavior of indoor aerosols can be described by the mass-balance equation [70–71]:

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

where I and O are the aerosol particle concentrations indoors and outdoors, respectively, P is the penetration factor of aerosol particles across the building shell (natural ventilation) or a standard filter installed in a mechanical ventilation system,  $\lambda$  is the ventilation rate,  $\lambda_d$  is the deposition rate of aerosol particle onto available indoor surfaces, and 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.

Although this mass-balance equation is 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,  $\lambda$ ,  $\lambda_d$  or even ER [72–73]. It was utilized it in the current study to calculate the loss rate of aerosol particles, according to the principles described by Hussein [43] and Hussein et al. [13]. Subsequently, the emission rates were estimated according to the semi-empirical approach described by Hussein et al. [73].

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 [43] and Hussein et al. [13] 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 inhaled deposited dose inside the respiratory system was evaluated according to Hussein et al. [73–74]:

$$\text{Deposited dose}_{PM} = \int_{t_1}^{t_2} \int_{D_{p1}}^{D_{p2}} V_E \cdot DF \cdot n_N^0 \cdot f \cdot d\log D_p \cdot dt \quad (2)$$

where  $V_E$  ([L/min<sup>1</sup>] or [m<sup>3</sup>/h<sup>1</sup>]) is the minute ventilation (known also as volume of air breathed per time),  $DF$  [--] is the respiratory deposition fraction of aerosol particles and  $n_N^0 = \frac{dN}{d\log(D_p)}$  [particles cm<sup>-3</sup>], where  $D_p$  is the particle diameter, is the lognormal particle number distribution. It should be noted that both  $DF$  and  $n_N^0$  are functions of  $\log(D_p)$ .  $f$  is a dose metric such as the particle surface area ( $\pi D_p^2$ ) or particle mass ( $\frac{\pi}{6} D_p^3 \rho_p$ ). In our case  $f$  is the particle mass. The integrals are evaluated during an exposure time period  $\Delta t = t_2 - t_1$  to large particles (1–10  $\mu\text{m}$ ) on any time resolution.

The volume air breathed per time (i.e. the minute ventilation),  $V_E$ , is strongly associated with the body size [75], the activity, the age and the breathing frequency of the substance [76–77]. Values for the volume air breathed per time used in this study were adopted from Holmes [76] and Hussein et al. [74].

The respiratory deposition fraction,  $DF$ , is defined as the probability of aerosol particles to deposit in the respiratory system and it strongly depends on the gender and the activity level of the subject [78]. Moreover, the same group reported that the size range and the hygroscopicity of aerosol particles affect the  $DF$ . In particular, they pointed out the smaller the particle is the higher the  $DF$  is expected to be. Due to the fact that the relative humidity in the respiratory system and, more specifically, in the lungs is approximately 99.5% [79–80], the diffusion rate and the  $DF$  of

hygroscopic particles decrease [78]. Moreover, since the respiratory system consists of the head/throat, tracheobronchial and the pulmonary/alveolar region, the respiratory deposition fraction varies accordingly [77–78]. For our calculations, the respiratory deposition fraction values were taken from the GMD (deposition) curve of large particles (1–10  $\mu\text{m}$ ) as presented by Hussein et al. [73].

## *2.6. Scenarios of workers' activities*

The workshop was occupied from 08:00 until 16:00 during the workdays only. The indoor activities included:

- 1) iron welding and smoking,
- 2) (exhaust) fan and welding machine on, iron welding without the fan running,
- 3) (exhaust) fan on, iron welding (with exhaust fan) and sorting/drilling,
- 4) making coffee and metal turning,
- 5) metal turning and iron welding,
- 6) metal turning,
- 7) lecture and metal turning, and
- 8) three undefined events.

A more detailed description about these events is given in Table S1. During these events, 1–4 people occupied one or more sections (1, 2, 4, 5, and 6 sections see Fig. 1) of the workshop. In spite of that, the number of people in section 3 (i.e. students training section) was as many as 10 persons during practical training class (Fig. 1).

## **3. RESULTS AND DISCUSSION**

### *3.1. Mean concentrations*



During the weekend, when the workshop was unoccupied, the  $PN_{0.3-10}$  varied from 12.86–64.64  $cm^{-3}$  whereas  $PM_{0.3-10}$  ranged between 1.68–13.58  $\mu g/m^3$  (Figs. 2 and Fig. 3). In general, total  $PN_{0.3-10}$  and  $PN_{1-10}$  were increased during the occupants activities. During workdays, the  $PN_{0.3-10}$  varied between 23.13 and 4162.44  $cm^{-3}$  (Fig. 2) and the corresponding calculated  $PM_{0.3-10}$  varied between 1.15 to 596.60  $\mu g/m^3$ .

The highest mean and median particle number and mass concentrations of both submicron (0.3–1  $\mu m$ ) and micron (1–10  $\mu m$ ) particles were observed during the operation of the welding machine followed by the activity of iron welding without the use of the exhaust fan and the running of the exhaust fan afterwards (Event 2). In particular, mean and median  $PN_{0.3-1}$  ( $PM_{0.3-1}$ ) were about 1865.86 and 1958.63  $cm^{-3}$  (54.49 and 54.80  $\mu g/m^3$ ), respectively, and mean and median  $PN_{1-10}$  ( $PM_{1-10}$ ) concentrations were 6.46 and 5.80  $cm^{-3}$  (102.54 and 94.15  $\mu g/m^3$ ), respectively (Tables 1–4). This observation was during the consumption of 1 coated rutile electrode (E 6013) in combination with one tobacco smoking event that occurred inside the changing room of the workshop area (Figs. 2 and 3).

During Event 3 ((Exhaust) fan on, iron welding (with exhaust fan) & sorting/drilling), the  $PN_{1-10}$  ( $PM_{1-10}$ ) and  $PN_{0.3-1}$  ( $PM_{0.3-1}$ ) values were as high as 25.36  $cm^{-3}$  (456.28  $\mu g/m^3$ ) and 4140.17  $cm^{-3}$  (152.07  $\mu g/m^3$ ). During this event 2 coated rutile electrodes (E 6013) were used in the iron welding (Tables 2–5). The rutile electrodes were used only during Events 2 and 3, and therefore, it was assumed that their consumption might have been the reason for these high concentrations mentioned above.

It was also observed that while one person was welding iron in the metal and welding section of the workshop and another was smoking a cigarette inside the office of the workshop area (Event 1),  $PN_{0.3-1}$  and  $PN_{1-10}$  concentrations also exhibited high mean and maxima values (similar to Events 2 and 3) (Tables 1-4). More specifically, mean  $PN_{0.3-1}$  ( $PM_{0.3-1}$ ) and  $PN_{1-10}$  ( $PM_{1-10}$ ) concentrations

were equal to  $885.67 \text{ cm}^{-3}$  ( $24.95 \text{ }\mu\text{g}/\text{m}^3$ ) and  $4.46 \text{ cm}^{-3}$  ( $53.02 \text{ }\mu\text{g}/\text{m}^3$ ). Maxima values of  $\text{PN}_{0.3-1}$  ( $\text{PM}_{0.3-1}$ ) and  $\text{PN}_{1-10}$  ( $\text{PM}_{1-10}$ ) concentrations reached up to  $2316.56 \text{ cm}^{-3}$  ( $74.54 \text{ }\mu\text{g}/\text{m}^3$ ) and  $24.45 \text{ cm}^{-3}$  ( $125.35 \text{ }\mu\text{g}/\text{m}^3$ ).

Event 6 (Metal turning) was mostly associated with higher mean, median and maxima values of  $\text{PN}_{0.3-1}$ ,  $\text{PM}_{0.3-1}$  and  $\text{PN}_{1-10}$  concentrations than Events 4, 5 and 7, which included other activities in addition to metal turning (Tables 2–5). For example, during Events 4, 5, 6 and 7 mean  $\text{PN}_{0.3-1}$  ( $\text{PM}_{0.3-1}$ ) concentration were equal to 60.79, 196.95, 222.59 and  $88.05 \text{ cm}^{-3}$  (1.71, 7.10, 9.17 and  $3.16 \text{ }\mu\text{g}/\text{m}^3$ ), respectively, and  $\text{PN}_{1-10}$  ( $\text{PM}_{1-10}$ ) concentrations were 0.65, 3.78, 4.89 and  $1.97 \text{ cm}^{-3}$  (8.03, 43.67, 36.65 and  $23.53 \text{ }\mu\text{g}/\text{m}^3$ ), respectively. This observation could be attributed to the fact that Event 9 occurred right after the performance of iron welding. However, no literature review has been found to support the above speculations or provide more information concerning particle number and mass concentrations of aerosol particles during iron sorting/drilling and metal turning operations.

Sowards et al. [81] used an electrical low pressure impactor (ELPI) to characterize the fumes produced by the shielded metal arc welding (SMAW) electrodes (E6010, E308-16 and E7018) and found that 95% of the welding fumes consisted of particles smaller than  $0.3 \text{ }\mu\text{m}$  for E6010 and E7018, whereas for E308-16, 95% of the welding fumes comprised the fume particles that were smaller than  $0.6 \text{ }\mu\text{m}$ . Those same authors also discovered that larger particles generated by the three electrodes governed the particle mass distributions expressed as mass median diameters between  $0.55$  to  $0.75 \text{ }\mu\text{m}$  [82]. Additionally, Zhang et al. [55] studied the exposure of workers to nanoparticles from a gas metal arc welding (GMAW) process by using a standard solid wire electrode (ER50-6, Qingdaohu Welding Material Company of Zhejiang Province, China). The Zhang group also reported that total  $\text{PM}_{10}$  from a single GMAW event as defined by a filter-based Nano-MOUDI was equal to approximately  $700 \text{ }\mu\text{g m}^{-3}$ . This finding was similar to approximately  $800 \text{ }\mu\text{g m}^{-3}$  obtained by Elihn and Berg [83] for GMAW workplace. Zhang et al. [55] also reported that the mean particle mass concentrations of particles in the size range of  $100 \text{ nm}$  to  $1 \text{ }\mu\text{m}$  for four welding points were

approximately  $1600 \pm 1030$ ,  $2380 \pm 840$ ,  $2640 \pm 1240$  and  $3120 \pm 940 \mu\text{g}/\text{m}^3$ . Mean particle number concentrations of particles between 20 nm and 1  $\mu\text{m}$  were approximately  $(1.82 \pm 0.77) \times 10^5$ ,  $(2.29 \pm 0.56) \times 10^5$ ,  $(2.94 \pm 0.89) \times 10^5$  and  $(3.49 \pm 0.66) \times 10^5 \text{cm}^{-3}$ . Their outcomes were much higher than ours during Events 4 and 5 when rutile electrodes (E 6013) were used.

With respect to the literature on industrial processes research, Iavicoli et al. [51] observed that respirable particles (up to 4  $\mu\text{m}$ ) ranged from 35.4 to 192.3  $\mu\text{g}/\text{m}^3$  (mean  $\pm$  standard deviation:  $68.6 \pm 69.1 \mu\text{g}/\text{m}^3$ ) and from 97.9 to 125.4  $\mu\text{g}/\text{m}^3$  (mean  $\pm$  standard deviation:  $112.3 \pm 11.4 \mu\text{g}/\text{m}^3$ ) in the brazing station and the welding booth, respectively, of a mechanical engineering factory. Azarmi et al. [67] simulated a construction processes inside an indoor laboratory surrounding in order to investigate the release of and the exposure to coarse, fine and ultrafine particles. Their results showed that the mean  $\text{PM}_{10}$  concentration was equal to  $0.56 \times 10^3 \mu\text{g}/\text{m}^3$  and  $0.63 \times 10^3 \mu\text{g}/\text{m}^3$  when the mixing of fresh concrete with GGBS (Ground Granulated Blastfurnace Slag) and PFA (Pulverised Fuel Ash) occurred, respectively. Additionally, a mean  $\text{PM}_{10}$  value of  $0.80 \times 10^3 \mu\text{g}/\text{m}^3$  for drilling and  $0.86 \times 10^3 \mu\text{g}/\text{m}^3$  for cutting was recorded. Lin et al. [56] investigated IAQ in diverse work zones inside industrial manufacturing of fitness equipment and detected that the respirable fraction of particles fluctuated from approximately 3430–3920  $\mu\text{g}/\text{m}^3$  (mean concentration: 3690  $\mu\text{g}/\text{m}^3$ ), 170–410  $\mu\text{g}/\text{m}^3$  (mean concentration: 280  $\mu\text{g}/\text{m}^3$ ) and 220–790  $\mu\text{g}/\text{m}^3$  (mean concentration: 380  $\mu\text{g}/\text{m}^3$ ) during painting, manual welding and automatic welding, respectively. The size range of respirable particles while pouching (almost 40–110  $\mu\text{g}/\text{m}^3$ ) and cutting (approximately 60–90  $\mu\text{g}/\text{m}^3$ ) were found to be of the same order with Events 2 and 3. Nevertheless, the mean concentration during both pouching and cutting procedures were higher than the corresponding ones measured during Events 2 and 3; it was equal to 80  $\mu\text{g}/\text{m}^3$ .

All the PN concentration values from Tables 1–4 were much lower than those reported in other studies. In particular, Mølgaard et al. [84] calculated a mean particle number concentration during working hours of  $4500 \text{cm}^{-3}$  for particles between 8.5 nm to 9  $\mu\text{m}$  inside a paint shop of a workshop.

Mean working particle number concentrations inside the molding room and the gluing area were equal to  $36\,000\text{ cm}^{-3}$  and  $3300\text{ cm}^{-3}$ , respectively, for particles in the size range of 5.5 and  $31\ \mu\text{m}$ . Moreover, the mean total particle number concentration of particles between  $0.007\text{--}10\ \mu\text{m}$  was equal to  $9610 \pm 8757\text{ cm}^{-3}$  in the brazing station, whereas in the welding booth it was equal to  $64\,161 \pm 34\,554\text{ cm}^{-3}$  [51].

### *3.2. Particle loss and emission rates*

Table 5 shows the particles number loss and emission rates for submicron ( $0.3\text{--}1\ \mu\text{m}$ ) and micron ( $1\text{--}10\ \mu\text{m}$ ) particles during the events inside the workshop area. Sometimes, it was not possible to estimate particle loss rate or emissions due to data limitation.

The highest particle loss rate for particles was during Event 2; it was  $2.09 \pm 0.07\text{ h}^{-1}$  and  $2.11 \pm 0.05\text{ h}^{-1}$  for particles in the diameter ranges of  $0.3\text{--}1\ \mu\text{m}$  and  $1\text{--}10\ \mu\text{m}$ , respectively. During Event 7, the particle loss rate was the lowest;  $0.24 \pm 0.01\text{ h}^{-1}$  and  $0.35 \pm 0.01\text{ h}^{-1}$  respectively.

The emission rates were generally higher for submicron ( $0.3\text{--}1\ \mu\text{m}$ ) particles compared to the corresponding rates for micron ( $1\text{--}10\ \mu\text{m}$ ) particles (Table 5). In particular, the emission rates of particles within the diameter range of  $0.3\text{--}1\ \mu\text{m}$  were the highest at  $9.31 \times 10^4\text{ particles/h}\times\text{cm}^3$  during Event 3, and the lowest at  $5.74 \times 10^4\text{ particles/h}\times\text{cm}^3$  during Event 1. In contrast, the emission rate of micron ( $1\text{--}10\ \mu\text{m}$ ) particles were the highest during Event 1 at  $1008\text{ particles/h}\times\text{cm}^3$  and the lowest at  $75\text{ particles/h}\times\text{cm}^3$  during Event 4.

As far as the authors are aware there are no published data on particle loss rate (i.e. infiltration rate and deposition rate) inside educational, and vocational training environments. However, there are several studies that presented air exchange and deposition rates separately. For example, the median air exchange rate in 25 naturally ventilated primary schools in Brisbane, Australia, fluctuated from  $0.25$  to  $1.0\text{ h}^{-1}$  during non-school and school hours, respectively [87]. A study conducted in two

schools and one kindergarten in Kozani, Greece, found the mean air exchange rates to be  $0.99 \pm 0.64$ ,  $0.35 \pm 0.45$  and  $0.36 \pm 0.17 \text{ h}^{-1}$ , respectively during the non-heating period. The same study found the mean air exchange rates were  $0.46 \pm 0.32$ ,  $0.05 \pm 0.01$  and  $0.33 \pm 0.25 \text{ h}^{-1}$ , respectively during the heating period [88]. Guo et al. [89] found that the air exchange rate inside a primary during a 2-week measurement campaign reached the highest value of  $7.92 \text{ h}^{-1}$  when the windows were open and the air conditioning and fans were all on. The lowest exchange rate value  $0.12 \text{ h}^{-1}$  was observed when the windows were closed and both the air conditioning and the fans were off. Moreover, the air exchange rate in five classrooms of five schools located in different regions in Singapore ranged from 5.6 to  $8.1 \text{ h}^{-1}$  during occupied periods and from 5.0 to  $6.1 \text{ h}^{-1}$  during unoccupied periods [90]. Dorizas et al. [91] reported that the mean infiltration rates for nine naturally ventilated primary schools in the Mediterranean region (Athens, Greece) during spring ranged between 0.11 and  $0.82 \text{ h}^{-1}$ . However, two of these schools demonstrated high air exchange rate of approximately  $8 \text{ h}^{-1}$  due to air leakages from the older building constructions due to wind speed. Laiman et al. [87] recorded mean total particle number deposition rates for 25 primary schools in Brisbane of 102, 71 and  $105 \text{ h}^{-1}$  for grilling, printing and heating, respectively. Interestingly, the deposition rate of nano-diamonds inside a laboratory workplace fluctuated from 0.8 to  $1.9 \text{ h}^{-1}$  as a result of the air mass movement caused by the movements of the workers and the incomplete mixing of air [92]. Furthermore, Thatcher et al. [93] conducted experiments in a room of  $14.2 \text{ m}^3$  with different types of furnishing and demonstrated the influence of the amount of furnishing and the airspeed of fans indoors had upon the deposition rates. Their findings regarded the dependency of deposition rate on particle size were consistent with the observations made by He et al. [94] for residences in Brisbane.

Moreover, Hussein et al. [73] reported there is limited awareness concerning emission rates of particles generated by indoor sources. They also pointed out the need to deepen the knowledge concerning this subject as it can be very difficult to understand. Nonetheless, Laiman et al. [87] measured the particle number emission rates for two naturally ventilated teaching classrooms in each

of 25 primary schools in Brisbane. The same group discovered that the mean particle number emission rates for grilling, printing, heating and cleaning activities (i.e. vacuuming, wiping tables, chairs and windows) were respectively  $(2.51 \pm 0.25) \times 10^{11}$ ,  $(5.17 \pm 2.00) \times 10^{11}$ ,  $(8.99 \pm 6.70) \times 10^{11}$  and  $(2.09 \pm 6.30) \times 10^{11}$  particles/min. The highest particle number emission rate among three different types of printers (“low emitter”, “medium emitter” and “high emitter”) inside a chamber was equal to  $1.6 \times 10^{11}$  particles/min, whereas the mean PM<sub>2.5</sub> emission rate of one office printer was  $0.29 \pm 0.07$  µg/min [37]. Buonanno et al. [95] reported that PM<sub>2.5</sub> emission factors during exercise activities of pupils inside a school gym fluctuated from 1.5 to 8.9 mg/min. Moreover, PM<sub>10</sub> chalk dust particles were emitted at rates that ranged between 8 and 14 mg/min while wiping the blackboard in a university lecture hall [96]. Additionally, Koivisto et al. [92] recorded maximum emission rates of nanodiamonds during assignments between 09:21–11:44, 12:38–14:35, and 14:36–15:23 equal to 6.1, 12.4 and 2.2 mg/min×m<sup>3</sup>, respectively.

### *3.3. Exposure and inhaled deposited dose scenarios*

The regional deposited dose of a male adult was calculated based on the hypothesis that during these events the workers/students performed light exercise. However, for comparison reasons regional deposited dose values during the activity of standing/resting were also reported. At this point, it needs to be pointed out that for our calculations the minute ventilation values during light exercise were adopted for the activity of walking 2.5 mph  $\approx$  4.0 km/h from Holmes [76] and Hussein et al. [74] and DF values during standing were adopted from the GMD (deposition) curve for resting from Hussein et al. [73].

Generally, as listed in Table 6, the total inhaled deposited dose of coarse particles (PM<sub>10</sub>) for a male adult was the highest during Event 3 (Total deposited dose = 204.58 µg), followed by Event 2 (Total deposited dose = 132.31 µg) and Event 7 (Total deposited dose = 42.14 µg). Even though the mean particle mass of coarse particles (PM<sub>10</sub>) during Event 3 was lower than the corresponding one

during Event 2, its duration was longer in comparison to Event 2, leading to higher total deposited dose of coarse particles (PM<sub>10</sub>). As expected, the lowest total deposited dose of coarse particles was observed when Event 4 took place (Total deposited dose = 11.71 µg).

Individually looking at the regional deposited dose of coarse particles during all the events occurred in the workshop area, we noticed that the alveolar and the head/throat region received the majority and the lowest fraction of the total deposited dose, respectively (Table 6). Particularly, the deposited dose in the alveolar region and in the head/throat region corresponded to 53.03% and 18.18% of the total deposited dose, respectively, for all the seven (defined) events. On the other hand, if it is assumed that during all the events, the workers/students were only standing instead of performing light exercise, then the deposited dose in the respiratory system of a male adult will vary significantly. In this case, the total deposited dose will decrease by approximately 39.71%. Moreover, the deposited dose in the tracheobronchial and the alveolar region will decrease by almost 86.93% and 65.84%, respectively. Surprisingly, the deposited dose in the head/throat region will receive the largest fraction of the total deposited dose as it will increase by approximately 111.20 % (Table 6).

If it is also assumed that the workers/students carried out heavier exercises or activities which produced higher concentration of particles, then the deposited dose and thus, the exposure will be even more than what was calculated here.

There is no doubt that the exposure and deposited dose would be even higher if the educational building, hence the workshop area were located close to traffic, busy streets or centers of air pollution where the concentrations are exceptionally elevated [73–74]. Therefore, the deposited dose in this research is an estimation of the minimum amount of the deposited dose in the respiratory system of a male adult during standing/resting and performing light exercise.

Another point that needs to be taken into account is that the deposited dose calculations were based on a healthy male adult. According to Anderson et al. [97], Kim and Kang [98] and Chalupa

et al. [99], the deposited dose in people with lung problems is expected to be larger than in healthy ones.

It should be kept in mind that the results obtained for the deposited dose in the respiratory system of a male adult in this study were based on estimations which took into account the particle mass of large particle (PM<sub>10</sub>) calculated for all the events (apart from the undefined), the minute ventilation, the respiratory deposition fraction and the duration of each event rather on real-time model simulations or indoor aerosol models (IAM's).

Generally, IAM's have been widely used in exposure assessments as they save time, money and efforts than measurements and real-time model simulations [73–74]. Furthermore, Hussein et al. [73–74] highlighted the importance of modeling the deposited dose in the respiratory system based on particle number, mass and active surface area as this approach could fill the gaps between exposure to and assessment of health effects of aerosol particles. For instance, the Hussein group applied a simple model in 2013 in order to calculate the total and the regional deposited dose based on particle number, mass and surface area of submicron particles in three age groups (teenagers, adults and elderly) [74]. Their results indicated that the daily total and regional deposited dose was higher in male adults than in females (based on any of the metrics). They also observed a slight difference in the values of the deposited dose in teens and elderly. Moreover, most of the deposited dose based on particle mass was accumulated in the alveolar region, whereas the tracheobronchial region received the smallest fraction of the total deposited fraction based on particle mass or surface area.

#### **4. CONCLUSIONS**

The particle number size distribution (0.3–10 µm) was measured inside an educational workshop, where conducted regular educational training and workshop tasks including iron welding and smoking, metal turning and iron welding. We focused on two different particle size fractions: (1) accumulation mode particles in the diameter range 0.3–1 µm and (2) coarse particles. Based on a



simple indoor aerosol model, we calculated the particle loss and emission rates inside the workshop during some activities. We also estimated the inhaled deposited dose in the respiratory system for a typical student or worker inside the educational workshop.

We found out that the highest concentrations were observed during welding activities. For instance, mean  $PN_{0.3-1}$  ( $PM_{0.3-1}$ ) and  $PN_{1-10}$  ( $PM_{1-10}$ ) concentrations were about 1865.86 (54.49  $\mu\text{g}/\text{m}^3$ ) and 6.46  $\text{cm}^{-3}$  (102.54  $\mu\text{g}/\text{m}^3$ ). During the same event, the highest particle loss rates for particles were documented, as well. On the other hand, maxima  $PN_{0.3-1}$  ( $PM_{0.3-1}$ ) and  $PN_{1-10}$  ( $PM_{1-10}$ ) concentrations were detected when iron welding took place, and later the operation of the exhaust fan and the activity of iron sorting/drilling occurred and they reached up to 4140.17  $\text{cm}^{-3}$  (152.07  $\mu\text{g}/\text{m}^3$ ) and 25.36  $\text{cm}^{-3}$  (456.28  $\mu\text{g}/\text{m}^3$ ). The emission rate was generally higher for submicron (0.3–1  $\mu\text{m}$ ) particles compared to micron (1–10  $\mu\text{m}$ ) particles. It is clear that the differences in the concentrations could be attributed to several factors: (1) type of activity (i.e. source specific) and (2) particle loss rate. However, further investigations are needed in order to confirm these speculations and to determine fully the physicochemical characteristics of particles measured in similar environments.

Based on our calculations for the inhaled deposited dose in the respiratory system, the alveolar received the largest fraction (~53.%) of the total deposited dose whereas the head/throat region received the lowest fraction (~18%).

## **Acknowledgements**

This study was supported by the European Commission (FP7-PEOPLE-2012-ITN) Marie Curie ITN (HEXACOMM, project no. 315760), the Deanship of Academic Research at the University of Jordan and the Academy of Finland Center of Excellence (grant no. 272041). We would like to thank the occupants of the workshop areas where we conducted the experiment; they were very cooperative. Moreover, we would like to thank the reviewer Alisdair Mclean for his valuable comments.

## References

1. **Lee, S. C., and M. Chang:** Indoor air quality investigations at five classrooms. *Indoor Air*. 9(2):134–138 (1999).
2. US EPA. (2012). “Indoor Air Quality: Tools For Schools”. Available: <https://www.epa.gov/iaq-schools> (accessed December 25, 2013).
3. **Al-Hubail, J., and A-S. Al-Temeemi:** Assessment of school building air quality in a desert climate. *Build Environ*. 94:569–579 (2015).
4. **Elbayoumi, M., N.A. Ramli, N.F.F. Md. Yusof, and W.A. Madhoun:** Seasonal variation in schools’ indoor air environments and health symptoms among students in an Eastern Mediterranean climate. *Hum. Ecol. Risk Assess*. 21:184–204 (2015).
5. **Zock, J., D. Jarvis, C. Luczynska, J. Sunyer, and P. Burney:** Housing characteristics, reported mold exposure, and asthma in the European Community Respiratory Health Survey. *J. Allergy Clin. Immunol*. 110(2):285–292 (2002).
6. **Sangiorgi, G., L. Ferrero, B.S. Ferrini, et al.:** Indoor airborne particle sources and semi-volatile partitioning effect of outdoor fine PM in offices. *Atmos. Environ*. 65:205–214 (2013).
7. **WHO, World Health Organization:** “*WHO Air Quality Guidelines Global Update 2005*”. World Health Organization: Bonn, Germany, (2005).
8. **Pope, C.A.III, and D.W. Dockery:** Health effects of fine particulate air pollution: lines that connect. *J. Air. Waste Manage. Assoc*. 56(6):709–742 (2006).
9. **Elbayoumi, M., N.A. Ramli,, N.F.F. Md. Yusof, A.S.B. Yahaya, W.A. Madhoun, and A.Z. Ul-Saufie:** Multivariate methods for indoor PM10 and PM2.5 modelling in naturally ventilated schools buildings. *Atmos. Environ*. 94:11–21 (2014).
10. **Brunekreef, B., and B. Forsberg:** Epidemiological evidence of effects of coarse airborne particles on health. *Eur. Respir. J*. 26(2):309–318 (2005).
11. **Fox, A., W. Harley, C. Feigley, et al.:** Large particles are responsible for elevated bacterial marker levels in school air upon occupation. *J. Environ. Monit*. 7(5):450–456 (2005).
12. **Aphekcom.** “*Summary Report of the Aphekcom Project 2008– 2011*”. Report prepared on the impact of air pollution on health in Europe. Available at [http://aphekcom.org/c/document\\_library/get\\_file?uuid=5532fafa-921f-4ab1-9ed9-c0148f7da36a&groupId=10347](http://aphekcom.org/c/document_library/get_file?uuid=5532fafa-921f-4ab1-9ed9-c0148f7da36a&groupId=10347) (accessed October 19, 2016).
13. **Hussein, T., L. Dada, H. Juwhari, and D. Faouri:** Characterization, fate and re-suspension of aerosol particles (0.3–10  $\mu\text{m}$ ): The effects of occupancy and carpet use. *Aerosol Air Qual. Res*. 15(6):2367–2377 (2015).
14. **He, C., L Morawska, J. Hitchins, and D. Gilbert:** Contribution from indoor sources to particle number and mass concentrations in residential houses. *Atmos. Environ*. 38(21):3405–3415 (2004).
15. **Afshari, A., U. Matson, and L.E. Ekberg:** Characterization of indoor sources of fine and ultrafine particles: A study conducted in a full-scale chamber. *Indoor Air*. 15(2):141-50 (2005).
16. **Abt, E., H.H. Suh, G. Allen, and P. Koutrakis:** Characterization of Indoor Particle Sources: A Study Conducted in the Metropolitan Boston Area. *Environ. Health Perspect*. 108(1):35–44 (2000).
17. **Lefcoe, N.M., and I.I. Inulet:** Particulates in domestic premises II. Ambient levels and indoor-outdoor relationships. *Arch. Envir. Health*. 30(12):565–570 (1975).
18. **Kamens, R., C. Lee, R. Wiener, and D. Leith:** A study to characterize indoor particle in three non-smoking homes. *Atmos. Environ. Part A. General Topics*. 25(5–6):939–948 (1991).
19. **Chao, C.Y.N., T.C.W. Tung, and J. Burnett:** Influence of different indoor activities on the indoor particulate levels in residential buildings. *Indoor Built Environ*. 7(2):110–121 (1998).
20. **Thatcher, T.L., and D.W. Layton:** Deposition, resuspension, and penetration of particles within a residence. *Atmos. Environ*. 29(13):1487–1497 (1995).

21. **Jones, N.C., C.A. Thornton, D. Mark, and R.M. Harrison:** Indoor/outdoor relationships of particulate matter in domestic homes with roadside, urban and rural locations. *Atmos. Environ.* 34(16):2603–2612 (2000).
22. **Long, C.M., H.H. Suh, and P. Koutrakis:** Characterization of indoor particle sources using continuous mass and size monitors. *J. Air & Waste Manage. Assoc.* 50(7):1236–1250 (2000).
23. **He, C.:** “Airborne Particles in Indoor Residential Environment: Source Contribution, Characteristics, Concentration, and Time Variability.” PhD diss., Queensland University of Technology, Brisbane, 2005.
24. **Braniš, M., P. Řezáčová, and M. Domasová:** The effect of outdoor air and indoor human activity on mass concentrations of PM<sub>10</sub>, PM<sub>2.5</sub>, and PM<sub>1</sub> in a classroom. *Environ. Res.* 99(2):143–149 (2005).
25. **Slezakova, K., M.C. Pereira, and M.C. Alvim-Ferraz:** Influence of tobacco smoke on the elemental composition of indoor particles of different sizes. *Atmos. Environ.* 43(3):486–493 (2009).
26. **Hussein, T., K. Hämeri, M.S.A. Heikkinen, and M. Kulmala:** Indoor and outdoor particle size characterization at a family house in Espoo- Finland. *Atmos. Environ.* 39(20):3697–3709 (2005).
27. **McAuley, T.R., R. Fisher, X. Zhou, P.A. Jaques, and A.R. Ferro:** Relationships of outdoor and indoor ultrafine particles at residences downwind of a major international border crossing in Buffalo, NY. *Indoor Air.* 20(4):298–308 (2010).
28. **Janssen, N., G. Hoek, B. Brunekreef, and H. Harssema:** Mass concentration and elemental composition of PM<sub>10</sub> in classrooms. *Occup. Environ. Med.* 56(7):482–487 (1999).
29. **Pegas, P.N., M.G. Evtyugina, C.A. Alves, et al.:** Outdoor/indoor air quality in primary schools in Lisbon: a preliminary study. *Quím Nova.* 33(5):1145–1149 (2010).
30. **Elbayoumi, M., N.A. Ramli, and N.F.F. Md. Yusof:** Spatial and temporal variations in particulate matter concentrations in twelve schools environment in urban and overpopulated camps landscape. *Build Environ.* 90:157–167 (2015b).
31. US EPA. (1996). “Indoor Air Quality Basics for Schools.” Environmental Protection Agency: Washington. DC, United States, 1996
32. **Berry M.:** *Healthy School Environment and Enhanced Educational Performance: the Case of Charles Young Elementary School.* Washington. DC, 2002.
33. **Kwok, A., and C. Chun:** Thermal comfort in Japanese schools. *Solar Energy.* 74(3):245–52 (2003).
34. **Mendell, M., and G. Heath:** Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. *Indoor Air.* 15(1):27–52 (2005).
35. **Bakó-Biró, Z., D.J. Clements-Croome, N. Kochhar, H.B. Awbi, and M.J. Williams:** Ventilation rates in schools and pupils' performance. *Build. Environ.* 48:215–223 (2012).
36. **Ren, Y., T. Cheng, and J. Chen:** Polycyclic aromatic hydrocarbons in dust from computers: one possible indoor source of human exposure. *Atmos. Environ.* 40(36):6956–6965 (2006).
37. **He, C., L. Morawska, and L. Taplin:** Particle emission characteristics of office printers. *Environ. Sci. Technol.* 41(17):6039–6045 (2007).
38. **Wensing, M., T. Schripp, E. Uhde, and T. Salthammer:** Ultra-fine particles release from hardcopy devices: Sources, real-room measurements and efficiency of filter accessories. *Sci. Total Environ.* 407(1):418–427 (2008).
39. **Koivisto, A.J., T. Hussein, R. Niemelä, T. Tuomi, and K. Hämeri:** Impact of particle emissions of new laser printers on modeled office room. *Atmos. Environ.* 44(17):2140–2146 (2010).
40. **Maragkidou, A., S. Arar, A. Al-Hunaiti, et al:** Occupational health risk assessment and exposure to floor dust PAHs inside an educational building. *Sci. Total Environ.* 579:1050–1056 (2017).

41. **Mendell, M.J. and W.J. Fisk:** Is health in office buildings related only to psychosocial factors? *Occup. Environ. Med.* 64(1):69–70 (2007).
42. **Lan, L., P. Wargocki, D.P. Wyon, and Z. Lian:** Effects of thermal discomfort in an office on perceived air quality, SBS symptoms, physiological responses, and human performance. *Indoor Air.* 21(5):376–390 (2011).
43. **Hussein, T.:** Particle size distributions inside a university office in Amman, Jordan. *Jordan J. Phys.* 7:73–83 (2014).
44. **Hedge, A., P.S. Burge, A.S. Robertson, S. Wilson, and J. Harris-Bass:** Work-related illness in offices: A proposed model of the “sick building syndrome”. *Environ. Intern.* 15(1–6):143–158 (1989).
45. **Hodgson, M.J. and, P. Collopy:** Symptoms and the micro-environment in the sick building syndrome: A pilot study. In *Proceedings of IAQ '89*, American Society of Heating, Refrigerating and Air Conditioning Engineers (eds). Atlanta, United States, 1989. pp. 8–16.
46. **Gyntelberg, F., P. Suadicani, J.W. Nielsen, et al.:** Dust and the sick building syndrome. *Indoor Air.* 4(4): 223–238 (1994).
47. **Armstrong, C.W., P.C. Sherertz, and G.C. Llewellyn:** Sick building syndrome traced to excessive total suspended particles (TSP). In *The Human equation: Health and Comfort*, J.E. Woods, D.T. Cartiniscid, N. Boschi (eds.) Proceedings of the ASHRAE Conference, San Diego, Atlanta, GA. 1989. pp 3–7.
48. **Menzies, R., R.M. Tamblyn, J. Hanley, F. Nunes, R.T. Tambyl:** Impact of exposure to multiple contaminants on symptoms of sick building syndrome. In *Proceedings of the 6th International Conference on Indoor Air Quality and Climate*, R Ilmarinen., J. Jaakkola, O. Seppänen (eds). Finland, Helsinki, 1993, Vol. 1, pp. 363–368.
49. **Chan, T.L., J.B. D’Arcy, and J. Saik:** Size characteristics of machining fluid aerosols in an industrial metalworking environment. *Appl. Occup. Environ. Hyg.* 5(3):162–163 (1990).
50. **Thornburg, J., and D. Leith:** Size distribution of mist generated during metal machining. *Appl. Occup. Environ. Hyg.* 15(8):618–628 (2000).
51. **Iavicoli, I., V. Leso, L. Fontana, D. Cottica, and A. Bergamaschi:** Characterization of inhalable, thoracic, and respirable fractions and ultrafine particle exposure during grinding, brazing, and welding activities in a mechanical engineering factory. *J Occup Environ Med.* 55(4):430–445 (2013).
52. **Banfield, J.F., and A. Navrotsky:** *Nanoparticles and the environment*. Mineralogical Society of America: Washington, DC, 2001.
53. **Zimmer, A.T., and P. Biswas:** Characterization of the aerosols resulting from arc welding processes. *J. Aerosol. Sci.* 32(8):993–1008 (2001).
54. **Ross, A.S., K. Teschke, M. Brauer, and S.M. Kennedy:** Determinants of exposure to metalworking fluid aerosol in small machine shops. *Ann. Occup. Hyg.* 48(5):383–391 (2004).
55. **Zhang, M., L. Jian, P. Bin, et al.:** Workplace exposure to nanoparticles from gas metal arc welding process. *J. Nanopart. Res.* 15(11):2016 (2013).
56. **Lin, C.C., M.R. Chen, S.L. Chang, W.H. Liao, and H.L. Chen:** Characterization of ambient particles size in workplace of manufacturing physical fitness equipments. *Ind Health.* 53(1):78–84 (2015).
57. **Wake, D., D. Mark, and C. Northage:** Ultrafine aerosols in the workplace. *Ann. Occup. Hyg.* 46(Supplement 1):235–238 (2002).
58. **Heitbrink, W.A., D.E. Evans, T.M. Peters, and T.J. Slavin:** Characterization and mapping of very fine particles in an engine machining and assembly facility. *J. Occup. Environ. Hyg.* 4(5):341–351 (2007).
59. **Riediger, G., and C. Möhlmann:** Ultrafeine aerosole an arbeitsplätzen—Konventionen und beispiele aus der praxis. [Ultrafine aerosols in workplaces – Conventions and practical examples.] *Gefahrstoffe Reinhalt.* 61(10):429–434 (2001). [German]

60. **Anseline, P.:** Zinc-Fume Fever. *Med. J. Austr.* 2(6): 316–318. (1972).
61. **Morgan, W.K.C.:** On welding, wheezing, and whimsy. *Am. Ind. Hyg. Assoc. J.* 50(2):59–69 (1989).
62. **Sferlazza, S.J., and W.S. Beckett:** The respiratory health of welders. *Am. Rev. Respir. Dis.* 143 (5 Pt 1):1134–1148 (1991).
63. **La Vecchia, G.M., and P. Maestrelli:** New welding processes and health effects of welding. *G. Ital. Med. Lav. Ergon.* 33(3):252–256 (2011).
64. **Antonini, J.M.:** Health effects of welding. *Crit. Rev. Toxicol.* 33(1):61–103 (2003).
65. **Gaidajis, G., and K. Angelakoglou:** Indoor air quality in university classrooms and relative environment in terms of mass concentrations of particulate matter. *J. Environ. Sci. Health. Part A.* 44(12):1227–1232 (2009).
66. **Tran, D.T., L.Y. Alleman, P. Coddeville, and J.C. Galloo:** Elemental characterization and source identification of size resolved atmospheric particles in French classrooms. *Atmos. Environ.* 54:250–259 (2012).
67. **Azarmi, F., P. Kumar, and M. Mulheron:** The exposure to coarse, fine and ultrafine particle emissions from concrete mixing, drilling and cutting activities. *J. Hazard. Mater.* 279:268–279 (2014).
68. **Voliotis, A., S. Bezantakos, M. Giamarelou, M. Valenti, P. Kumar, and, G. Biskos:** Nanoparticle emissions from traditional pottery manufacturing. *Environ. Sci. Process Impacts.* 16(6):1489–1494 (2014).
69. **Slezakova, K., C. Texeira, S. Morais, and M.do C. Pereira:** Children’s indoor exposures to (ultra) fine particles in an urban area: Comparison between school and home environments. *J. Toxicol. Environ. Health. Part A.* 78(13-14):886–896 (2015).
70. **Nazaroff, W.W.:** Indoor particle dynamics. *Indoor Air.* 14(Suppl 7):175–183. (2004).
71. **Hussein, T., and M. Kulmala:** Indoor aerosol modeling: Basic principles and practical applications. *Water Air Soil Pollut: Focus.* 8(1):23–34 (2008).
72. **Mølgaard, B., A.J. Koivisto, T. Hussein, and K. Hämeri:** A new clean air delivery rate test applied to five portable indoor air cleaners. *Aerosol Sci Technol.* 48(4):409–417 (2014).
73. **Hussein, T., A. Wierzbicka, J. Löndahl, M. Lazaridis, and O. Hänninen:** Indoor aerosol modeling for assessment of exposure and respiratory tract deposited dose. *Atmos. Environ.* 106:402–411 (2015).
74. **Hussein, T., J. Löndahl, P. Paasonen, et al.:** Modeling regional deposited dose of submicron aerosol particles. *Sci.Total Environ.* 458–460:140–149 (2013).
75. **Bennett, W.D., and K.L. Zeman:** Effect of body size on breathing pattern and fine-particle deposition in children. *J Appl Physiol.* 97:821–826 (2004).
76. **Holmes, J.R.:** *How much air do we breathe?* California Environmental Protection Agency, Research Note 94-11, California, USA, 1994.
77. **ICRP (International Commission on Radiological Protection):** *Human Respiratory Tract Model for Radiological Protection.* ICRP Publication 66, Pergamon Press, Oxford, England, 1994.
78. **Löndahl, J., A. Massling, J. Pagels, E. Swietlicki, E. Vaclavik, and S. Loft:** Size-resolved respiratory-tract deposition of fine and ultrafine hydrophobic and hygroscopic aerosol particles during rest and exercise. *Inhal. Toxicol.* 19(2):109–116 (2007).
79. **Ferron, G.A., B. Haider, and W.G. Kreyling:** Inhalation of salt aerosol particles-I. Estimation of the temperature and relative humidity of the air in the human upper airways. *J. Aerosol Sci.* 19(3):343–363 (1988).
80. **Anselm, A., T. Heibel, J. Gebhart, and G. Ferron:** “In vivo” studies of growth factors of sodium chloride particles in the human respiratory tract. *J. Aerosol Sci.* 21:S427–S430 (1990).
81. **Sowards, J.W., J.C. Lippold, D.W. Dickinson, and A.J. Ramirez:** Characterization of welding fume from SMAW electrodes—Part I. *Welding Journal.* 87(4):106–112 (2008).

82. **Sowards, J.W., A.J. Ramirez, D.W. Dickinson, and J.C. Lippold:** Characterization of welding Fume from SMAW electrodes — Part II. *Welding Journal*. 89(4):82–90 (2010).
83. **Elihn, K. and P. Berg:** Ultrafine particle characteristics in seven industrial plants. *Ann. Occup. Hyg.* 53(5):475–484 (2009).
84. **Mølgaard, B., A.K. Viitanen, A. Kangas, et al.:** Exposure to airborne particles and volatile organic compounds from polyurethane molding, spray painting, lacquering, and gluing in a workshop. *Int. J. Environ. Res. Public Health*. 12(4):3756–3773 (2015).
85. **Hussein, T., T. Glytsos, J. Ondráček, et al.:** Particle size characterization and emission rates during indoor activities in a house. *Atmos. Environ.* 40(23):4285–4307 (2006).
86. **Morawska, L., C. He, J. Hitchins, K. Mengersen, and D. Gilbert:** Characteristics of particle number and mass concentrations in residential houses in Brisbane, Australia. *Atmos. Environ.* 37(30):4195–4203 (2003).
87. **Laiman, R., C. He, M. Mazaheri, et al.:** Characteristics of ultrafine particle sources and deposition rates in primary school classrooms. *Atmos. Environ.* 94:28–35 (2014).
88. **Kalimeri, K.K., D.E. Saraga, and V.D. Lazaridis, et al.:** Indoor air quality investigation of the school environment and estimated health risks: Two-season measurements in primary schools in Kozani, Greece. *Atmos. Pollut. Res.* 7(6):1128–1142 (2016).
89. **Guo, H., L. Morawskaa, C. Hea, and D. Gilbert:** Impact of ventilation scenario on air exchange rates and on indoor particle number concentrations in an air-conditioned classroom. *Atmos. Environ.* 42(4):757–768. (2008).
90. **Chen, A., E.T. Gall, and V.W. Chang:** Indoor and outdoor particulate matter in primary school classrooms with fan-assisted natural ventilation in Singapore. *Environ. Sci. Pollut. Res. Int.* 23(17):17613–17624 (2016).
91. **Dorizas, P.V., M-N. Assimakopoulos, C. Helmis, and M. Santamouris:** An integrated evaluation study of the ventilation rate, the exposure and the indoor air quality in naturally ventilated classrooms in the Mediterranean region during spring. *Sci. Total Environ.* 502:557–570 (2015).
92. **Koivisto, A.J., J.E. Palomäki, A.K. Viitanen, et al.:** Range-finding risk assessment of inhalation exposure to nanodiamonds in a laboratory environment. *Int. J. Environ. Res. Public Health*. 11(5):5382–5402 (2014).
93. **Thatcher, T.L., A.C.K Lai, R. Moreno-Jackson, R.G. Sextro, and W.W. Nazaroff:** Effects of room furnishings and air speed on particle deposition rates indoors. *Atmos. Environ.* 36(1):1811–1819 (2002).
94. **He, C., L. Morawska, and D. Gilbert:** Particle deposition rates in residential houses. *Atmos. Environ.* 39(21):3891–3899 (2005).
95. **Buonanno, G., F.C. Fuoco, S. Marini, and L. Stabile:** Particle resuspension in school gyms during physical activities. *Aerosol Air Qual. Resear.* 12:803–813 (2012).
96. **Salma, I., K. Dosztály, T. Borsós, et al.:** Physical properties, chemical composition, sources, spatial of indoor aerosol particles in a university lecture hall. *Atmos. Environ.* 64:219–228 (2013).
97. **Anderson, P.J., J.D. Wilson, and F.C. Hiller:** Respiratory tract deposition of ultrafine particles disease in subjects with obstructive or restrictive lung. *Chest*. 97(5):1115–1120 (1990).
98. **Kim, C.S., and T.C. Kang:** Comparative measurement of lung deposition of inhaled fine particles in normal subjects and patients with obstructive airway disease. *Am J Respir Crit Care Med*. 155(3):899–905 (1997).
99. **Chalupa, D.C., P.E. Morrow, G. Oberdörster, M.J. Utell, and M.W. Frampton:** Ultrafine particle deposition in subjects with asthma. *Environ Health Perspect.* 112(8):879–882 (2004).



**Table 1.** Particle number concentrations [ $\text{cm}^{-3}$ ] of submicron particles ( $\text{PN}_{0.3-1}$ ).

Events	Description of events	Mean	Std. deviation	5%	25%	75%	90%	Min	Median	Max
<b>Weekend</b>	Unoccupied	31.49	12.01	14.46	20.91	40.86	48.29	12.51	30.59	64.08
<b>Event 1</b>	Iron welding & smoking	885.67	414.47	81.68	684.43	1145.23	1256.34	38.84	842.28	2316.56
<b>Event 2</b>	(Exhaust) fan & machine on, welding iron without (exhaust) fan running	1865.86	935.64	538.83	992.90	2613.33	3161.11	316.81	1958.63	3567.26
<b>Event 3</b>	(Exhaust) fan on, iron welding (with exhaust fan) & sorting/drilling	1494.77	938.23	471.58	625.50	2438.23	2709.96	443.92	1162.76	4140.17
<b>Event 4</b>	Making coffee & metal turning	60.79	37.56	22.52	29.01	83.43	120.15	21.54	50.69	158.02
<b>Event 5</b>	Metal turning & iron welding	196.95	45.94	131.17	171.06	233.10	261.37	117.54	181.12	296.98
<b>Event 6</b>	Metal turning	222.59	65.68	143.00	170.55	279.31	317.18	137.17	195.72	371.39
<b>Event 7</b>	Lecture & metal turning	88.05	10.01	71.48	81.16	94.33	100.15	67.26	89.74	109.41
<b>Event 8</b>	Undefined event	104.11	3.75	99.01	101.66	106.38	109.76	95.77	103.76	110.89
<b>Event 9</b>	Undefined event	152.39	27.29	99.84	150.12	160.79	169.91	86.44	155.95	244.38
<b>Event 10</b>	Undefined event	220.13	100.84	137.37	155.39	293.27	349.89	127.11	171.65	680.19



**Table 2.** Particle number concentrations [ $\text{cm}^{-3}$ ] of micron particles ( $\text{PN}_{1-10}$ ).

Events	Description of events	Mean	Std. deviation	5%	25%	75%	90%	Min	Median	Max
<b>Weekend</b>	Unoccupied	0.46	0.09	0.35	0.39	0.52	0.59	0.28	0.44	0.82
<b>Event 1</b>	Iron welding & smoking	4.46	3.57	2.20	2.91	4.48	7.39	2.03	3.49	24.45
<b>Event 2</b>	(Exhaust) fan & machine on, welding iron without (exhaust) fan running	6.46	4.33	1.53	2.68	9.28	13.12	1.14	5.80	16.92
<b>Event 3</b>	(Exhaust) fan on, iron welding (with exhaust fan) & sorting/drilling	4.96	4.32	1.17	1.67	7.82	10.16	1.01	2.93	25.36
<b>Event 4</b>	Making coffee & metal turning	0.65	0.16	0.49	0.55	0.71	0.86	0.46	0.61	1.36
<b>Event 5</b>	Metal turning & iron welding	3.78	1.14	1.51	3.45	4.44	5.00	0.78	3.54	6.26
<b>Event 6</b>	Metal turning	4.89	1.68	3.13	3.51	6.49	7.53	2.97	4.25	8.51
<b>Event 7</b>	Lecture & metal turning	1.97	0.44	1.27	1.59	2.24	2.57	1.16	2.05	2.94
<b>Event 8</b>	Undefined event	1.26	0.13	1.11	1.19	1.32	1.36	1.09	1.26	1.83
<b>Event 9</b>	Undefined event	1.95	0.21	1.64	1.80	2.07	2.17	1.45	1.98	2.59
<b>Event 10</b>	Undefined event	2.23	0.24	1.88	2.08	2.43	2.49	1.71	2.21	2.78

**Table 3.** Calculated particle mass concentrations [ $\mu\text{g}/\text{m}^3$ ] of submicron particles ( $\text{PM}_{0.3-1}$ ).

Events	Description of events	Mean	Std. deviation	5%	25%	75%	90%	Min	Median	Max
<b>Weekend</b>	Unoccupied	0.96	0.33	0.50	0.70	1.18	1.33	0.43	0.93	2.27
<b>Event 1</b>	Iron welding & smoking	24.95	13.83	3.25	17.95	31.49	34.60	1.64	22.52	74.54
<b>Event 2</b>	(Exhaust)fan & machine on, welding iron without (exhaust) fan running	54.49	30.76	13.73	26.01	77.43	98.79	8.21	54.80	116.75
<b>Event 3</b>	(Exhaust) fan on, iron welding (with exhaust fan) & sorting/drilling	44.16	31.32	12.15	16.25	73.47	84.33	11.41	31.11	152.07
<b>Event 4</b>	Making coffee & metal turning	1.71	0.98	0.74	0.88	2.28	3.24	0.71	1.42	4.32
<b>Event 5</b>	Metal turning & iron welding	7.10	1.98	3.92	6.07	8.72	9.77	3.17	6.50	11.20
<b>Event 6</b>	Metal turning	9.17	3.16	5.27	6.75	11.87	13.81	5.00	7.97	16.40
<b>Event 7</b>	Lecture & metal turning	3.16	0.39	2.49	2.84	3.50	3.63	2.43	3.21	4.00
<b>Event 8</b>	Undefined event	3.11	0.11	2.96	3.04	3.19	3.24	2.91	3.10	3.37
<b>Event 9</b>	Undefined event	4.45	0.71	3.02	4.41	4.74	4.89	2.69	4.62	6.65
<b>Event 10</b>	Undefined event	6.05	2.62	3.94	4.34	7.91	9.41	3.58	4.82	18.21

**Table 4.** Calculated particle mass concentrations [ $\mu\text{g}/\text{m}^3$ ] of micron particles ( $\text{PM}_{1-10}$ ).

Events	Description of events	Mean	Std. deviation	5%	25%	75%	90%	Min	Median	Max
Weekend	Unoccupied	3.97	1.70	1.94	2.73	4.77	6.26	1.09	3.62	12.77
Event 1	Iron welding & smoking	53.02	22.76	18.73	41.31	58.47	86.08	11.40	49.56	125.35
Event 2	(Exhaust) fan & machine on, welding iron without (exhaust) fan running	102.54	62.33	26.02	42.93	141.97	198.47	15.74	94.15	238.74
Event 3	(Exhaust) fan on, iron welding (with exhaust fan) & sorting/drilling	92.95	78.95	20.39	31.37	142.39	182.27	16.58	63.00	456.28
Event 4	Making coffee & metal turning	8.03	2.80	4.94	6.14	9.49	11.68	4.22	7.27	18.44
Event 5	Metal turning & iron welding	43.67	13.85	14.43	39.96	49.75	57.30	8.17	43.75	76.08
Event 6	Metal turning	36.65	10.25	23.38	27.09	46.72	50.81	19.76	34.80	55.09
Event 7	Lecture & metal turning	23.53	8.71	10.90	16.15	29.19	34.33	8.48	23.64	48.41
Event 8	Undefined event	16.80	3.22	12.47	15.00	18.17	19.49	10.67	16.68	28.66
Event 9	Undefined event	31.63	4.81	24.78	28.69	35.04	38.22	20.28	30.89	43.84
Event 10	Undefined event	36.15	6.69	24.93	31.13	41.12	42.90	22.72	36.23	52.85

**Table 5.** Particles loss rates [ $\text{h}^{-1}$ ] and emission rates [ $\text{particles}/\text{hour}\times\text{cm}^3$ ].

	PN <sub>1-10</sub>		PN <sub>0.3-1</sub>	
	$\lambda+\lambda_d$ [ $\text{h}^{-1}$ ]	ER [ $\text{particles}/\text{hour}\times\text{cm}^3$ ]	$\lambda+\lambda_d$ [ $\text{h}^{-1}$ ]	ER [ $\text{particles}/\text{hour}\times\text{cm}^3$ ]
<b>Event 1</b>	1.31±0.08	1008	1.36±0.03	5.74E+04
<b>Event 2</b>	2.11±0.09	407	2.09±0.07	8.61E+04
<b>Event 3</b>	1.08±0.06	735	1.08±0.05	9.31E+04
<b>Event 4</b>	-	75	-	-
<b>Event 6</b>	0.64±0.01	135	-	-
<b>Event 7</b>	0.35±0.01	85	0.24±0.01	6.498E+04

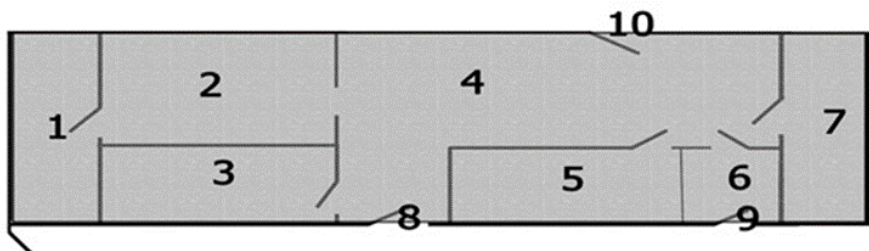
**Table 6.** Deposited dose [ $\mu\text{g}$ ] of large particles ( $\text{PM}_{10}$ ) based on particle mass calculated for an adult male during all events (apart from undefined events).

Event 1 (Iron welding & smoking)		Event 2 ((Exhaust) fan and machine on, welding iron without (exhaust) fan running)		Event 3 (Exhaust) fan on, iron welding (with exhaust fan) & sorting/drilling		Event 4 (Making coffee & metal scrubbing)		Event 5 (Metal scrubbing & iron welding)		Event 6 (Metal turning)		Event 7 (Metal sc
Activities		Activities		Activities		Activities		Activities		Activities		Activi
Standing/ Resting*	Light exercise	Standing/ Resting*	Light exercise	Standing/ Resting*	Light exercise	Standing/ Resting*	Light exercise	Standing/ Resting*	Light exercise	Standing/ Resting*	Light exercise	Standing/ Resting*
(13.91)	6.59	(50.82)	24.06	(78.57)	37.20	4.50)	2.13	(10.03)	4.75	(11.11)	5.26	(16.18(
(1.36)	10.43	(4.99)	38.09	(7.71)	58.90	(0.44)	3.37	(0.98)	7.52	(1.09)	8.33	(1.59)
(6.56)	19.21	(23.97)	70.16	(37.06)	108.49	(2.12)	6.21	(4.73)	13.84	(5.24)	15.34	(7.63)
(21.84)	36.22	(79.77)	132.31	(123.34)	204.58	(7.06)	11.71	(15.74)	26.11	(17.44)	28.93	(25.41)

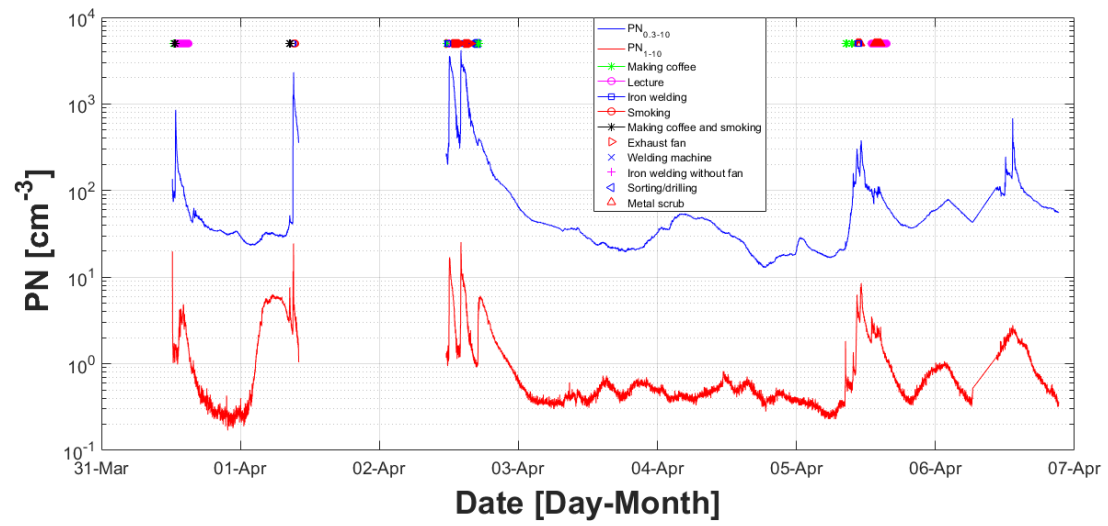
(\*)The values indicated inside parentheses () of these activities will be only mentioned for comparison reasons.

■ Workshop Section

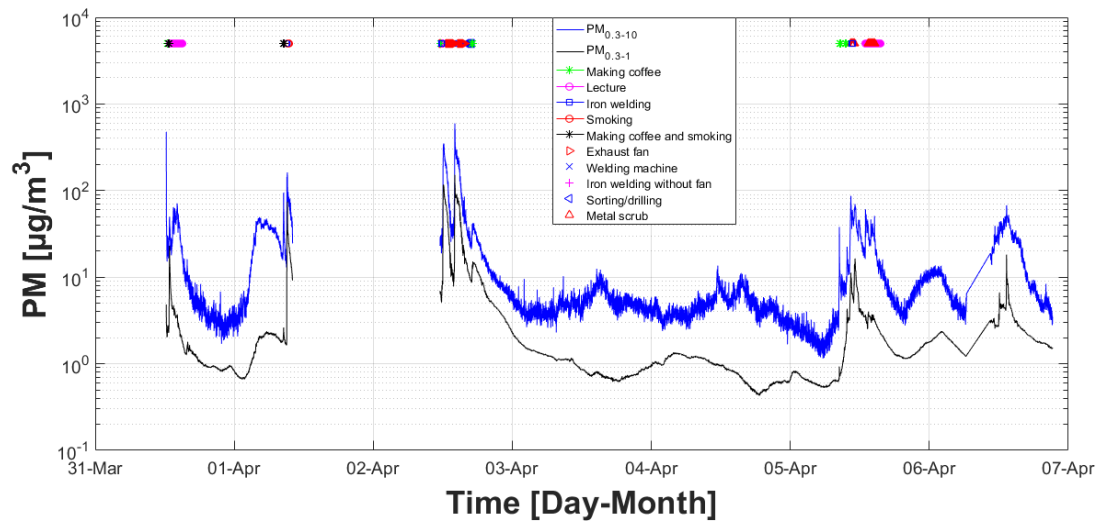
- 1 Wood workshop
- 2 Metal workshop and welding
- 3 Students training workshop
- 4 Main workshop and turnery
- 5 Office
- 6 Clothes changing room
- 7 Storage
- 8 Internal main door
- 9 Internal secondary door
- 10 External door



**Fig. 1.** A schematic chart of the workshop area of the Department of Physics.



**Figure 2.** Particle number concentrations (Time series based on a 1-minute resolution).



**Figure 3.** Particle mass concentrations (Time series based on a 1-minute resolution).



## Supplementary information

**Table S1.** Description of each event and its duration during the weekend and the workdays.

<b>Events</b>	<b>Description of events</b>	<b>Start</b>	<b>Stop</b>	<b>Duration (min)</b>
<b>Weekend</b>	Unoccupied	3.4.2015 0:00	4.4.2015 23:59	2879
<b>Event 1</b>	Making coffee, smoking & having a lecture	31.3.2015 12:42	31.3.2015 14:38	116
<b>Event 2</b>	Making coffee & smoking	1.4.2015 8:29	1.4.2015 8:39	10
<b>Event 3</b>	Iron welding & smoking	1.4.2015 9:01	1.4.2015 9:46	45
<b>Event 4</b>	(Exhaust) fan & machine on, welding iron without (exhaust) fan running	2.4.2015 11:59	2.4.2015 13:24	85
<b>Event 5</b>	(Exhaust) fan on, iron welding (with exhaust fan) & sorting/drilling	2.4.2015 13:58	2.4.2015 16:23	145
<b>Event 6</b>	Making coffee	2.4.2015 17:00	2.4.2015 17:40	40
<b>Event 7</b>	Making coffee & metal turning	5.4.2015 8:30	5.4.2015 10:06	96
<b>Event 8</b>	Metal turning & iron welding	5.4.2015 10:11	5.4.2015 10:51	39.38
<b>Event 9</b>	Metal turning	5.4.2015 10:56	5.4.2015 11:48	52
<b>Event 10</b>	Lecture & metal turning	5.4.2015 13:20	5.4.2015 15:18	118
<b>Event 11</b>	Undefined event	6.4.2015 10:36	6.4.2015 11:13	37
<b>Event 12</b>	Undefined event	6.4.2015 11:55	6.4.2015 12:53	58
<b>Event 13</b>	Undefined event	6.4.2015 13:11	6.4.2015 14:21	70