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Research Paper

Computational modeling of particle transport and distribution emitted from a Laserjet printer in a ventilated room with different ventilation configurations

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HIGHLIGHTS

- The distribution of emitted particles form a laserjet printer was studied in the breathing zone.
- Effects of different ventilation configurations on the breathing zone concentration were investigated.
- Mixing ventilation system has a low mean particle concentration in the breathing zone.

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ABSTRACT

In the present research, computational modeling of particle transport and distribution emitted from a Laserjet printer was carried out in a ventilated room. A seated manikin was integrated into the study room and the manikin was evaluated in two cases: heated and unheated. Effects of different ventilation configurations of the room on the particle distribution were studied, including three displacement ventilation systems and a mixing ventilation system. The printer was located on different sides of the manikin and the particle concentrations in the breathing zone of the manikin due to the printer's particles were evaluated in all the ventilation configurations. The averaged particle concentration in the breathing zone of the manikin was calculated and validated with the experimental and numerical data available in the literature. The results of the present study showed that in case of the heated manikin, the particle concentration due to the printer pollutants is significant in the breathing zone of the manikin. The results also showed that when the printer is located on the front side of the manikin, the particle concentration in the breathing zone is quite high in most of the used ventilation configurations. Furthermore, it was found that the mixing ventilation system has a lower mean particle concentration in the breathing zone compared to the most displacement ventilation systems.

1. Introduction

Nowadays, many people are spending the majority of their day times in indoor spaces and are highly affected by the emitting particles released from copier machines and printers [1,2]. The electronics and computer engineering systems have been extensively used in the mankind life since their early development. These systems emit particles in indoor places and are known as an active source of particle generation as these systems, mostly release volatile and semi-volatile particles while they are working. These particles have different patterns and effects on the breathing zone of the human body based on the ventilation configurations and the location of a printer in rooms. These matters are very important to select the right ventilation systems and also the position of the printer in the room. The past studies [3,4] have indicated a tight relationship between the level of emitting pollutant particles and the adverse health effects such as early death and hospitalization (short term effects) plus lung cancer and cardiovascular diseases (long term effects).

Indoor air quality (IAQ) is highly dependent on the number of particles penetrating into the indoor places from outside or inside spaces. In recent years, it has been indicated that the particles emitted from printers affect the indoor air quality of offices [5,6]. General characteristics of printer's emissions like particle concentration and particle deposition rate can be experimentally

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Nomenclature

A_{in}	inlet register area (m^2)
C	particle concentration (kg/m^3)
C_0	inlet particle concentration (kg/m^3)
C_c	Cunningham coefficient
C_{va}	volume averaged concentration (kg/m^3)
C_{pa}	plane averaged particle number concentration (kg/m^3)
d	Particle diameter (μm)
G_i	Gaussian random number with zero-mean
g	gravitational acceleration (m/s^2)
k	turbulent kinetic energy (m^2/s^2)
n_j	the stochastic phenomenon of the Brownian diffusion
n	number of particles that move across the plane having an area of A
N	number of injected particles
p	the air pressure (pa)
Re_p	Reynolds number based on velocity of particles relative to air
S	ratio of particle density to fluid density
t_i	the particle residence time (s)
T_f	fluid absolute temperature (K)
T	the sampling time (s)
T_∞	ambient temperature (K)
t_p	relaxation time (s)
u, v, w	velocity components (m/s)
v_P	the particle velocity at the inlet register (s)
V	measurement volume (m^3)
x_i	particle position (m)
$v_F'^2$	squared airflow fluctuation velocity normal to the wall (m^2/s^2)

Greek symbols

ρ_f	fluid density (kg/m^3)
ε	Turbulent kinetic energy dissipation rate
μ	fluid viscosity (kg/m s)
λ	mean free path of the air molecules (μm)
υ_t	air flow turbulent viscosity (m^2/s)

Subscript

m	mean
w	wall
in	inlet
p	particle phase
f	fluid

Superscript

+	dimensionless
–	Reynolds averaging

measured in an experimental enclosed box. However, this determination of particle transportation and distribution is quite hard to achieve. This issue essences using computational fluid dynamics (CFD) as a useful tool to help understanding of the emitted pollutant particle behavior better. So far, many studies have been experimentally carried out in order to clarify the printer emission characteristics. For instance, Lee et al. investigated the emissions rate of pollutants from different types of office equipment. They showed that the emissions of ozone and VOC in laser printers are significantly higher than that of ink-jet printers [7]. Kagi et al. monitored the air contamination released from a laser printer/ink-jet printer in a room. Their results confirmed an increase of the ozone concentration and ultrafine particle numbers in the printing processes [8]. He conducted an experiment and measured particle number concentrations and $PM_{2.5}$ emissions from printers in a large open-plan office. They revealed that the particles generated by printers can significantly affect the levels of submicrometer particle number concentration in the office [9]. Hugo et al. reviewed available information on emission rates and also ambient concentrations of various pollutants which were related to office equipment use. The evaluated office equipments were computers (desktops and notebooks), printers (laser, ink-jet and all-in-one machines), and photocopier machines. They identified the toxicological substances significant in order to prepare a guide for evaluating their potential importance with respect to human exposures [5]. Morawska et al. carried out an experimental research which determined the particle composition, particle formation mechanism, and emission rate of Laserjet printers. They indicated that the emission rates of ultrafine particles of the printers are directly due to the Fuser temperature. They also showed that the particles are volatile and have a secondary nature, being formed in the air from volatile organic compounds originating from both the paper and hot toner [6]. Byeon and Kim investigated particle emissions for commercial color laser printers working under different printing speeds in an experimental chamber. They showed that the average particle number concentration is inversely proportional to the printing speed [10].

A series of studies have focused on particle transport and distribution when a manikin was present in a room. For instance, Spitzer [11] and Spitzer et al. [12] carried out some experiments to study the effect of particle motion on the breathing zone of a seated breathing manikin. They revealed that the particle's motion significantly affects the particle concentration of the breathing zone. Melikov and Kaczmarczyk [13] investigated the importance of the breathing zone of a thermal manikin when the indoor particles are inhaled. Rim and Novolselka investigated the airflow in the vicinity of a human body. They considered the effects of respiration on the breathing zone concentration of particulate and gaseous pollutants, and inhalation exposure in relation to source position and overall airflow patterns. They indicated that the overall airflow pattern influences the inhaled particle concentrations. They also revealed that highly mixed airflow in the space creates relatively uniform concentration patterns in the vicinity of the occupant. However, they also showed that the occupant thermal plume makes non-uniform concentration patterns [14]. Zukowska et al. studied several effects such as thermal insulation, the design of clothing and the chair, the blocking effect of tables on the thermal plume generated above a seated thermal manikin in a chamber [15]. Salmanzadeh et al. studied the buoyancy driven thermal plume near a sitting heated manikin. They showed that a high concentration of suspended particles in the breathing zone is seen due to the thermal plume flow created by the temperature gradient adjacent to the body [16]. Li et al. investigated effect of thermal manikin position on the characteristics of particle transport and inhalation. They revealed that the manikin orientation has a significant impact on the characteristics of particle transport and inhalation. They showed that for an occupant standing with its back towards the horizontal airflow, a little change in the leg posture can lead to an obvious variation in the source location of inhaled particles [17].

In the present study, particle transport and distribution emitted from a Laserjet printer in a ventilated room, which is scarce in the past studies, were computationally simulated using computational fluid dynamics. Combined Eulerian and Langragian methods were