CFD Letters

Journal homepage:
https://semarakilmu.com.my/journals/index.php/CFD_Letters/index
ISSN: 2180-1363

CFD Investigation of Toluene Emission in a Printing Room

Ahmad Amirul Aiman Mohd Khalid[1], Fauziah Jerai[1,*], Nor Azira Mohd Zainuddin[2], Norliana Mohd Abbas[1], Azli Abdul Razak[1]

[1] School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, 40450, Shah Alam, Selangor, Malaysia
[2] Cawangan Dasar dan Pengurusan Korporat, Jabatan Kerja Raya, 50480 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 30 January 2024
Received in revised form 25 February 2024
Accepted 21 March 2024
Available online 30 November 2024

Keywords:
CFD simulation; IAQ; VOC emission; room office; photocopiers

ABSTRACT

Volatile organic compounds (VOCs) comprise several harmful chemical such as benzene and toluene, that can cause acute and chronic health effects for individuals. One of contributors of VOC are printers, photocopiers, and fax machine that use ink that when it is heated during printing operations will emit VOC. Printing shops heavily operate these devices (machines) and often several of them at the same time and this will cause the VOC level inside the premises to be higher compared to home and offices that have similar equipment. This study estimates the VOC, particularly toluene, concentration, and distribution inside a printing room, by using Computer Fluid Dynamic (CFD) analysis approach software. The software aid in physical modelling of the emission flow based on copiers machine numbers and influence of parameters like concentration levels and anthropometric data. Despite implementing ventilation and at a minimum number of operating copiers, the study reveals that toluene emissions exceed the recommended limit, particularly among females who have higher exposure than males due to height. The quantity of copiers and the positioning influenced the dispersion of toluene in the investigated area.

1. Introduction

The awareness of indoor air quality (IAQ) among the public has been on the increase as more and more individuals are spending their time working in offices and recently in their homes due to COVID-19 lockdowns. But only a handful pay attention to this issue and decided that this issue should not be underestimated. IAQ has broad definitions in multiple forms. According to the definition by Department of Safety and Health (DOSH) Malaysia [1], indoor air is the air inside a building, including air which is within a room and air which is removed from a room by mechanical means. This term applies and not limited to offices, lecture hall, shopping complexes, homes, and hospitals. While American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) stated that the IAQ is the air in and surrounding the building, particularly the air that affects the health quality and well-being of the occupants [2].

* *Corresponding author.*
E-mail address: fauziahjerai@uitm.edu.my (Fauziah Jerai)

https://doi.org/10.37934/cfdl.17.5.90102

VOCs are one of the various chemicals that contribute to the degradation of indoor air quality (IAQ). VOC, short for volatile organic compounds, denotes organic molecules with a vapour pressure exceeding 10 Pascals (Pa) at 25 degrees Celsius (ºC), a maximum boiling point of 260 ºC at 1 atmospheric pressure (atm), and a maximum of 15 carbon atoms [3]. Printing devices, such as printers, fax machines, photocopiers, and all-in-one printing devices, are considered significant sources of VOC. They are frequently used by students, lecturers, teachers, and office workers [4-6]. VOCs are also produced by computers and notebooks, although the emission levels are relatively insignificant (ranges from 100 to 200, μgh^{-1}) [7, 8]. Additionally, laser printers emit a range of VOCs, including hazardous substances like toluene, benzene, and chloroform which can lead to chronic health problems through prolonged exposure [9, 10]. This proves that people typically inhale VOCs without realizing it in their daily routines.

The concentration of VOCs, specifically toluene, was measured during working hours at photocopy centres in Tehran [11]. According to the findings, indoor toluene levels are notably higher than outdoor levels during business hours, providing evidence that rooms with photocopiers contain increased VOC levels. As a result of this alarming information, several studies were conducted to investigate the link between VOC exposure and human health. A specific discovery has indicated that individuals employed in printing facilities are more susceptible to chronic cancer throughout their lifetime [12]. Moreover, exposure to toluene can result in memory impairment, eye irritation, increased drowsiness [11], and may even induce effects resembling alcohol consumption if the substance is misused [13]. In a separate study on toluene exposure, a group of participants were exposed to 100 parts per million (ppm) of toluene for a duration of 6 hours. As a result, the participants reported experiencing discomfort, including irritations of the eyes, nose, and throat, as well as drowsiness and fatigue [14].

One method for measuring the VOC concentration involves the utilization of a qualified individual (Hygiene Technician 1) to perform on-site air quality monitoring [15]. Although considered the most precise approach, its adoption in businesses and premises exempted from Occupational Safety and Health (USECHH) Regulations 2000 entails substantial financial implications [16]. Therefore, in order to accurately measure VOC emissions in a cost-effective manner, the utilization of Computational Fluid Dynamics (CFD) analysis is recommended [17]. There are multiple factors that contribute to the selection of CFD as an investigation method. For instance, engineers can utilize CFD to anticipate product performance without the need for physical fabrication, thereby exposing potential critical flaws that could have severe consequences in real-world scenarios [18]. Additionally, as mentioned earlier, the utilization of Computational Fluid Dynamics (CFD) can substantially decrease the financial burden of performing experiments or analyses. This is achieved by eliminating variables such as material prices, equipment setup costs, time, and other expensive procedures [19]. Moreover, Computational Fluid Dynamics (CFD) has the ability to offer valuable insights into large-scale experiments or scenarios, generating results such as eddy dissipation, mass fraction, and vorticity that may be challenging or even unattainable through experimental means [18, 20, 21].

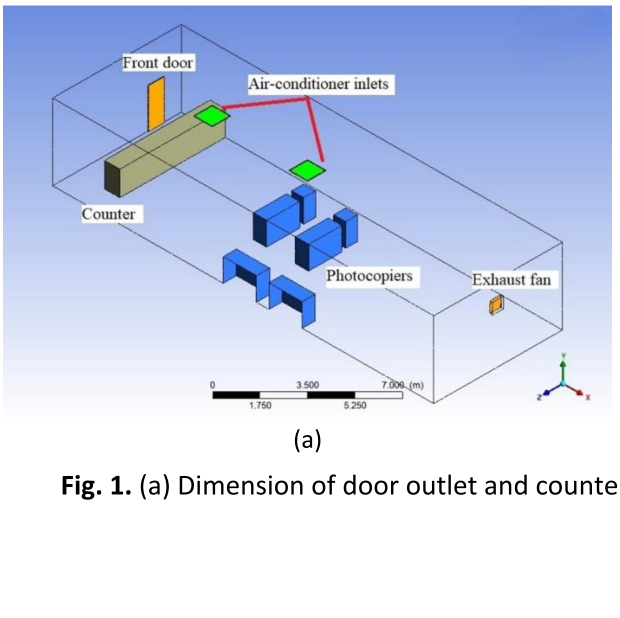
The use of CFD tools can significantly enhance indoor air quality management by accurately forecasting the impact of various factors on the concentrations of indoor toluene and other VOCs [22, 23]. The validated CFD model considers factors such as air exchange, which can decrease toluene levels by improving the adsorption performance of building materials [24]. By predicting the influence of air exchange rate, adsorptive material loading factor, and convective mass transfer rate, the CFD model provides a better understanding of toluene removal efficiency, which is crucial for optimizing indoor air quality management.

Toluene was picked as a representative for VOC emissions from photocopiers in this research because it is commonly found in toners and has been extensively studied as a volatile organic compound [25, 26]. Moreover, toluene is noteworthy compared to other VOCs because of the extensive research conducted on its properties, health effects, and emission rates, as well as the accessibility of this information [27, 28]. This makes it an appropriate selection for representation and examination. Raising awareness about the risks of toluene exposure is essential for employers and government entities to implement control measures. Therefore, it is necessary to provide monitoring and education for photocopier operators to mitigate the hazards and risks associated with photocopying. In light of this concern, the present study was undertaken to investigate the issue using a CFD analysis approach. The main objective was to investigate the dispersion of VOC, with a specific focus on toluene, and measure the concentration of toluene emitted by photocopiers. To make observations on toluene concentration, anthropometry data, specifically sitting and standing height of Malaysians, were used. The goal of this research is to establish a reference for a photocopier centre, ensuring the safety of both workers and visitors in the room or space.

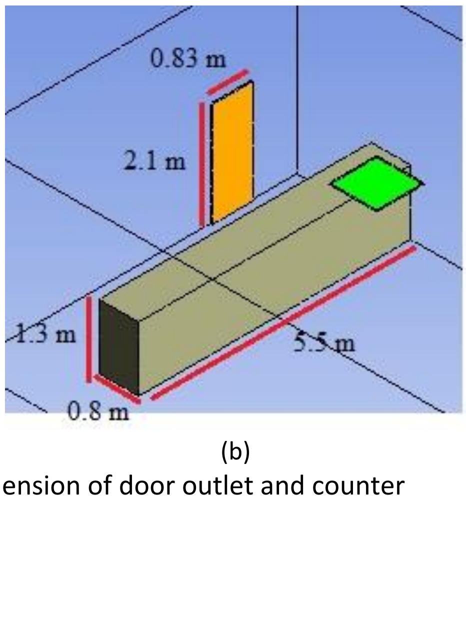
2. Methodology

2.1 Geometry and Meshing

A Kuala Lumpur-based printing shop with different numbers of operational photocopiers was chosen to showcase the variation in toluene emissions. A three-dimensional geometry was constructed based on the actual room geometry as shown in Figure 1(a) with a dimension of 19.86 m × 6.7 m × 4.0 m. As stated before, a basic photocopier was used in this simulation with a dimension of 0.617 m × 0.62 m × 1.1 m and 0.69 m × 1.731 m × 1.213 m respectively. The exhaust fan dimension was 0.24 m × 0.24 m, and the air conditioner inlet was 0.95 m × 0.95 m. The door and counter dimensions on the hand were based on assumption using similar furniture dimensions, as shown in Figure 1(b). All the item designs are constructed as basic three-dimensional rectangles to shorten the time taken to design them and to simplify number and size of the element during meshing (see Figure 2). The values obtained were grid independent. To observe the best meshing results, all three-relevance centre sizing (fine, medium and coarse) were tested. A total of 495,732 meshing was done for the fine model, while 251,322 and 150,411 meshing were done for the medium and coarse models, respectively. Based on the data presented in Table 1, it can be concluded that choosing the fine meshing model resulted in the most favourable outcomes during the simulation. The selection of the fine meshing model was based on its slightly higher density and mass fraction values, suggesting that it would yield the most favourable simulation outcomes. According to the findings in Table 1, opting for the fine meshing model yielded the most favourable results in the simulation [8].



(a)



(b)

Fig. 1. (a) Dimension of door outlet and counter (b) Dimension of door outlet and counter

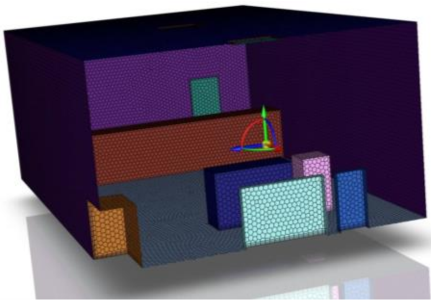


Fig. 2. Meshing geometry

Table 1
Grid independence study for male standing, two copiers at workers' area

Number of elements	Size of elements (mm)	Volume Average density [kg/m^{-3}]	Mass fraction [-]
215011	3.5	0.2647	0.2407
425232	2.5	0.2662	0.2437
594100	1.0	0.3006	0.3289

2.2 Geometrical Models and Boundary Conditions

In this study, the Turbulence k-ε model was selected as the turbulence model. The selection was made based on the measurement of copier emissions within the room fluid domain, with the assumption that both the air flow and VOC emission were positioned away from the walls. Another reason for selecting this model is that it is recommended for simulating scenarios involving flows with chemical mixture, multi-phase flow, and combustion. This model can create a rough yet accurate estimation of the flow field [29]. The boundary conditions for this simulation comprise two velocity inlets, represented by two cassette air-conditioners positioned at the ceiling of the room, with identical airflow velocities. An exhaust fan for the ventilation purpose and a door was set as an outlet. In addition, numbers of copiers have been designated as the source of mass flow inlet, contributing to the release of toluene emissions within the room. The toluene rate value was derived by referring to the study conducted by Kowalska *et al.,* [30] and supported by Destaillats *et al.,* [28]. Table 2 and Table 3 below present the specifics of the equations and boundary conditions of the toluene associated with the selected model.

Table 2
Summary of mathematical equation

Equation	Mathematical equations	
Kinematic eddy viscosity, v_t	$v_t = C_\mu \frac{k^2}{\varepsilon}$	(1)
Turbulence kinetic energy (k)	$\frac{\partial k}{\partial t} + \bar{u}_j \frac{\partial k}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\frac{(v + v_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right] - \varepsilon + \tau_{ij}\frac{\partial \bar{u}_i}{\partial x_j}.$	(2)
Turbulence dissipation rate (ε)	$\frac{\partial \varepsilon}{\partial t} + \bar{u}_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\frac{(v + v_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right] - C_{\varepsilon 1}\frac{\varepsilon}{k}\tau_{ij}\frac{\partial \bar{u}_i}{\partial x_j} - C_{\varepsilon 2}\frac{\varepsilon^2}{k},$	(3)
	The Prandtl numbers used for k and ε was $\sigma_k = 1.0$ and $\sigma_\varepsilon = 1.3$ respectively. The remaining constant in this model are $C_\mu = 0.09$, $C_{\varepsilon 2} = 1.92$.	

Table 3
Boundary condition of toulene

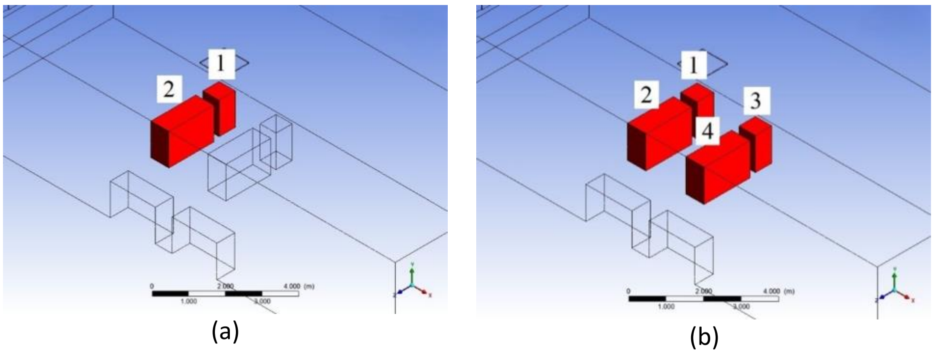
Details of Inlet Boundary Condition	Value
Chemical formula	C_7H_8
Mass flow rate [kg/s]	3.06×10^{-6}
Initial Gauge Pressure [Pa]	0
Turbulent Intensity [%]	5
Reference temperature [°C]	25

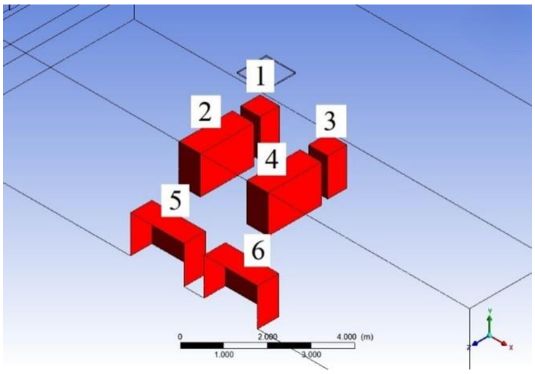
2.3 Toluene Emission Investigation

Three different cases were used in this simulation to analyze the emission of toluene from the photocopiers. Table 4 illustrates the different numbers of photocopiers used as the emission source in each of these cases. The dispersion of toluene throughout the room was determined using the path lines graphic method. Several plane surfaces were utilized on the ZX axis to visualize the contours of the mass fraction and generate a report averaging the mixture density and toluene mass fraction. The location of the plane surfaces used in the simulation is derived from a previous study on Malaysian anthropometric measurements [31], as stated in Table 5 below. Once the models were selected and the boundary conditions were established, the solution was computed using a pressure-based solver in a steady state, considering the influence of gravity acceleration along the Y-axis. By examining the mixture flow, multiple data such as molar concentration, density, and mass fraction with respect to position can be extracted.

Table 4
Description of simulation for each case

Case	Descriptions
Case 1: Two (2) operational photocopiers	Simulated the emission during a slow working day which the printing shop has less customer than usual and only uses two photocopiers, as shown in Figure 3(a).
Case 2: Four (4) operational photocopiers	Simulated the emission during a normal business operation which the printing shop has the usual number of customers and only uses four photocopiers, as shown in Figure 3(b).
Case 3: Six (6) operational photocopiers	Simulated the emission during busy season where the shop must use all the six printers to meet the demand of their customers, as shown in Figure 3(c).





(c)

Fig. 3. (a) Case 1: Two photocopiers (b) Case 2: Four photocopiers (c) Case 3: Six photocopiers

Table 5
ZX plane surfaces

Name	Y-axis (m)
Male standing height	1.679
Male sitting height	0.835
Female standing height	1.534
Female sitting height	0.779

3. Results and Discussion

The following results show the dispersion range and concentration level of the toluene vapour in the room, which were influenced by the number of operational photocopiers. Anthropometric data from Table 5 was used to measure toluene concentration at various height levels. Subsequently, the data derived from the results were compared to previous studies and the The National Institute for Occupational Safety and Health (NIOSH) Standards in the United States [32] to reveal potential health risks stemming from exposure to the harmful emission.

3.1 Comparison with OSHA PEL and STEL Standards

The concentration values in parts per million (PPM) were established through simulation, which determined the mass fraction and mixture density. Figure 4 to Figure 7 display the toluene concentration in cases 1, 2, and 3 respectively, along with the comparison to recommended exposure limit (REL) set by NIOSH.

In all cases, the concentration of toluene for male and female standing at the printing area is lower than the customer and worker area. The air flow transported the toluene particle from the printing area throughout the room, thus decreasing the toluene concentration in the printing area. However, it is of utmost concern to see a significant increase in the concentration of toluene when the number of operational photocopiers surpasses double the recommended exposure limit (REL) set by NIOSH. The workers and customers will probably experience SBS that includes symptoms such as headache, nausea, and runny nose [33] because of the poor IAQ caused by high toluene concentration in the air.

The data presented in Figure 4 to Figure 6 throughout Case 1, 2, and 3 reveal a noticeable increase in the average toluene concentration at standing height (ranging from 73.49 ppm to 223.53 ppm) in comparison to sitting height (ranging from 118.83 ppm to 416.7 ppm) across all genders and locations. The reason for this could be that toluene vapor, being denser than air, tends to accumulate at higher levels. Based on its location, it is consistently observed that the printing area displays the highest concentrations of toluene. The printing area exhibits the highest concentration at standing height (416.7 ppm), while comparatively lower concentrations are observed at sitting height (73.49 ppm) in comparison to other areas. One possible explanation for this could be that the source of toluene emissions in the printing area is situated at a closer proximity to a standing height level. With respect to gender, it can be inferred that there is no discernible pattern associated with toluene concentration.

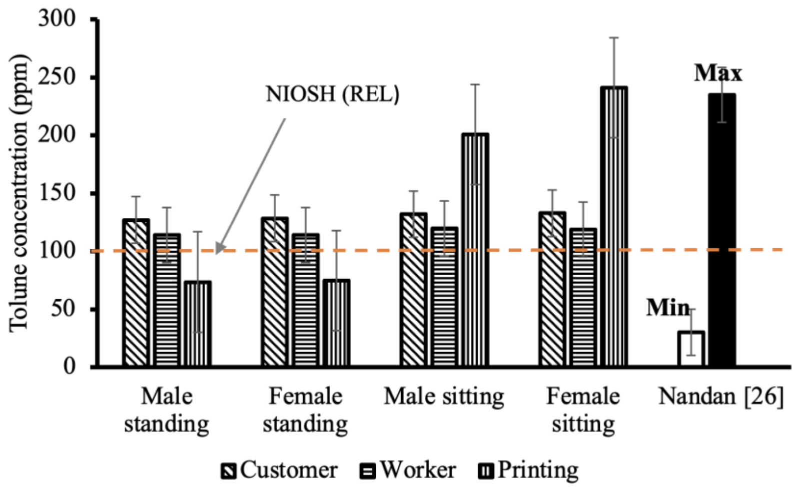


Fig. 4. Bar chart of toluene concentration during Case 1

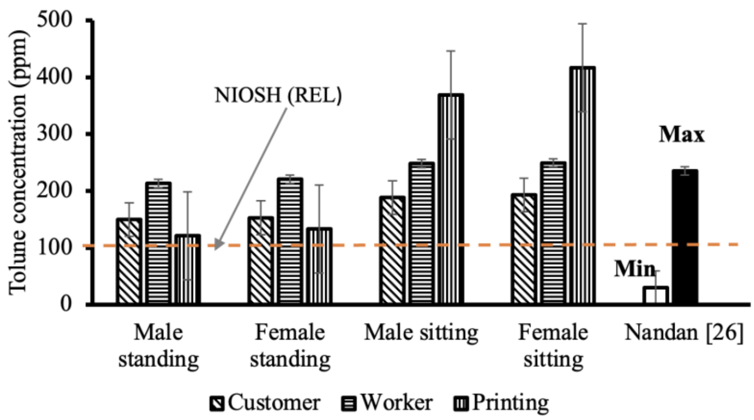


Fig. 5. Bar chart of toluene concentration during Case 2

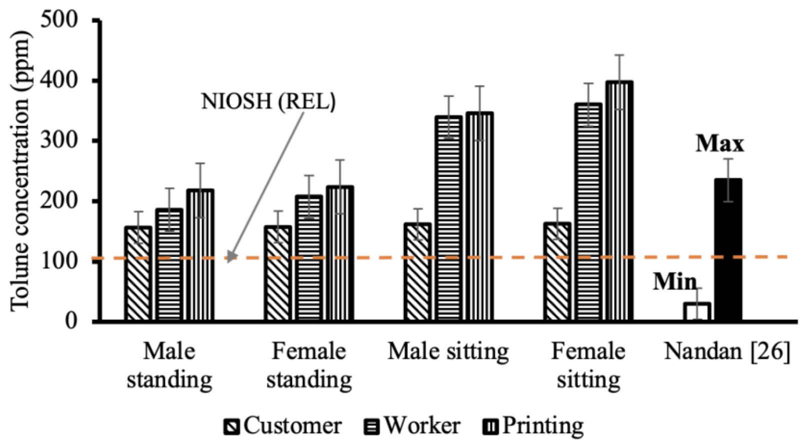


Fig. 6. Bar chart of toluene concentration during Case 3

Figure 4 until Figure 6 also utilises bars chart to illustrate the comparison of result from this study to result of a previous study conducted by a team led by A. Nandan *et al.,* [34]. The validation for this current research was based on their study, as they used toluene as the emission material and employed CFD as the simulation tool. In their study, they focused on the printing rate parameter, which was converted to toluene mass flow rate in the current simulation. Therefore, their findings serve as a suitable benchmark for assessing the impact of photocopiers on indoor air quality. Among the cases studied, Case 1 had the closest toluene concentration, while Cases 2 and 3 had higher values compared to Nandan's study due to increased toluene emissions from multiple printers. Among the cases studied, Case 1 had the closest toluene concentration, while Cases 2 and 3 had higher values compared to Nandan's study due to increased toluene emissions from multiple printers.

The maximum toluene concentration value of 416 ppm can be seen in Figure 7, which displays the anticipated outcome for Case 3 where there were 6 operational copiers. This peak concentration occurs at the sitting height of females. The expected outcome of the lowest concentration of toluene is observed during Case 1 when there are 2 operational photocopiers.

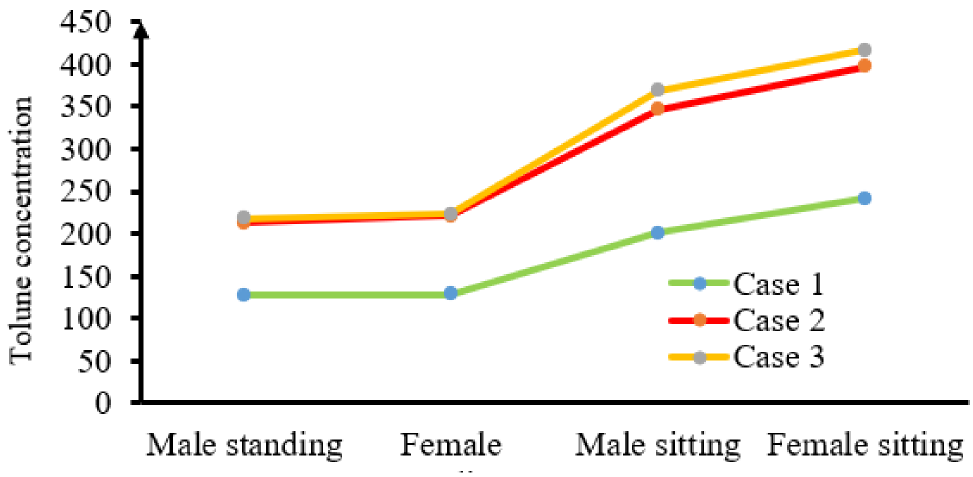


Fig. 7. Maximum concentration in all Cases

3.2 CFD Visualization
3.2.1 Case 1: Two operational photocopiers

Figure 8 and Figure 9 illustrated the emission of toluene from Case 1, two photocopiers. The dispersion of toluene emission was represented by the mass fraction path lines, and it was observed that the emission from the two photocopiers spread towards the customer area. Toluene moves mostly in the central part of the room, with little movement near the walls [22]. Due to the door serving as an outlet with a considerably sizeable area, the toluene stream flowed towards the customer area. It has been observed that the spread of toluene is minimally constrained within the customer area because of the counteracting effect serving as a barrier. In this given scenario, it can be stated that both the staff and clients were exposed to toluene emissions originating from the photocopiers. Even if the release were acceptable, the worker or staff would be exposed to occupational health hazards if there exists a situation of prolonged exposure.

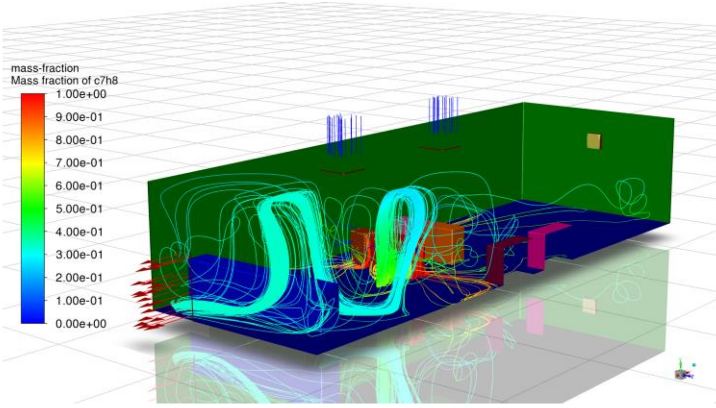


Fig. 8. Room geometry with emission spread for Case 1

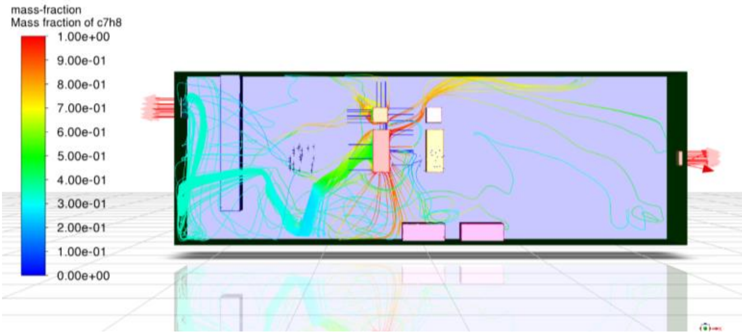


Fig. 9. Top view of Case 1

3.2.2 Case 2: Four operational photocopiers

Figure 10 and Figure 11 depict the emission of toluene in Case 2. The mass fraction path lines were utilized to illustrate the dispersion of toluene emission, showing that the emission from the 4 photocopiers extended towards both the customer area and the rear of the room. The presence of the door and exhaust fan functioned as outlets, resulting in the toluene stream being directed towards them. Staff and customers at the printing shop may exhibit symptoms of toluene exposure, including dizziness, fatigue, headache, and eye irritations. Prolonged exposure to elevated levels of toluene can cause significant health consequences, primarily affecting the central nervous system, upper respiratory tract, and mucous membranes [35].

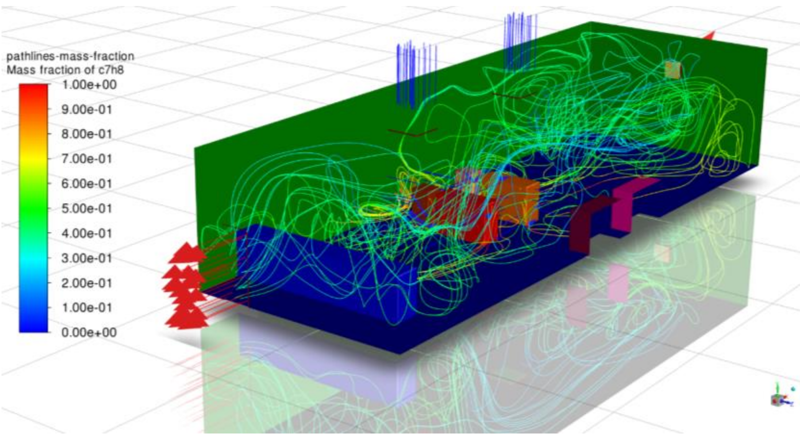


Fig. 10. Room geometry with emission spread for Case 2

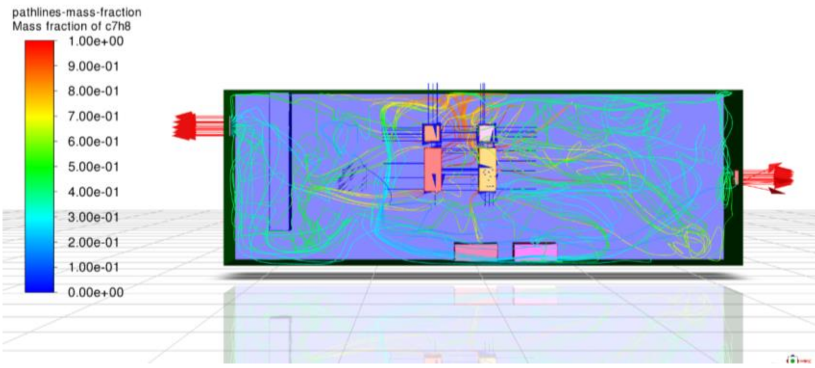


Fig. 11. Top view of Case 2

3.2.3 Case 3: Six operational photocopiers

Figure 12 and Figure 13 portray the emission of toluene for Case 3. The dispersion of toluene emissions was represented by the path lines of the mass fraction, and it was observed that the emissions from the 6 photocopiers were able to spread throughout the shop. The worker area is facing an overwhelming amount of toluene emission, leading to a serious health risk. It is strongly advised to conduct health surveillance on the staff because of their exposure to high levels of toluene emissions for approximately 8 hours daily. The staff and customers of the printing shop are at a higher risk of experiencing symptoms of toluene exposure, such as dizziness, fatigue, headache, and eye irritations, due to continued exposure to toluene emissions [35].

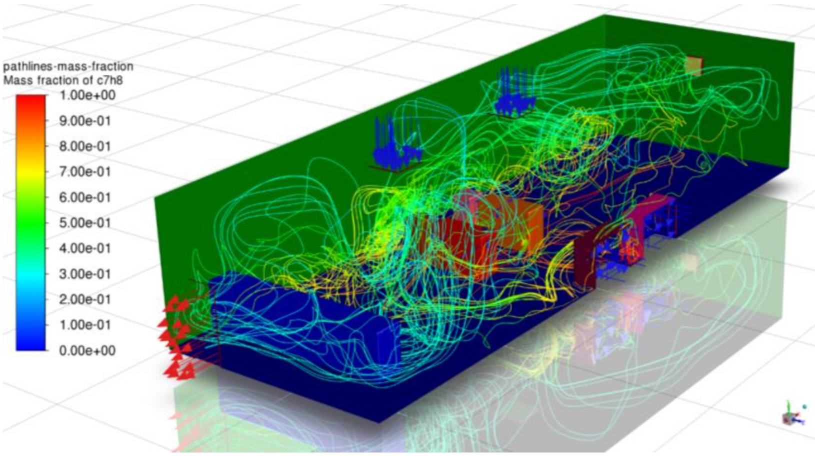


Fig. 12. Room geometry with emission spread for Case 3

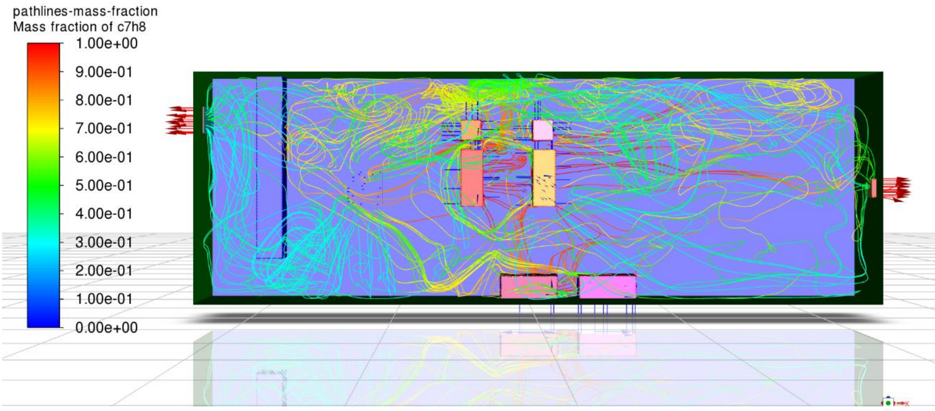


Fig. 13. Top view of Case 3

4. Conclusions

The focus of this study was to investigate the emission of volatile organic compounds, specifically toluene, from photocopiers in an office setting. Although toluene is a major volatile organic compound (VOC) emitted by photocopiers, it's important to recognize that exposure from a photocopier is not limited to toluene alone. The presence of other VOCs may further worsen the health effects connected to emissions.

As stated earlier in the introduction, the dispersion and concentration of toluene regarding the number of operational copiers in the room were determined using a CFD analysis approach and simulation software. The study revealed that toluene emissions already exceed the prescribed limits, even with the minimum number of copiers equipped with ventilation. Most premises with photocopiers or their operators were unaware of this and unknowingly put their health at risk. It is imperative to educate and warn both the user and owner of the copier machine about the potential consequences.

According to the outcomes of this study, the quantities of copiers and the positioning of barriers are the two pivotal factors that will affect the propagation of the VOC. This is attributed to the continuous emission of toluene by all the photocopiers throughout the simulation. The concentration value of the scenario was the highest compared to the other scenarios. It can be inferred from the mass fraction field that the direction of air flow towards the room's outlet affects the dispersion of toluene. The positioning of the counter also played a significant role in impeding the dispersion of toluene in the customer area. By manipulating these factors, exposure to the harmful substance can be controlled to ensure that the occupants in the room are safe from the adverse health effect caused by the said substance. However, while these results are true for these scenarios, it cannot be generalised to other room offices and printing shop. Similar studies need to be conducted with different room geometry and photocopiers configurations to develop a comprehensive understanding VOCs emission.

Acknowledgement
This work was supported by the "Geran Dalaman Universiti – Industry Collaboration UIC 2022" [600-TNCPI 5/3/DDF (FKM) (003/2022)].

References

[1] J. Keselamatan Dan Kesihatan Pekerjaan, "INDUSTRY CODE OF PRACTICE ON INDOOR AIR QUALITY 2010 DEPARTMENT OF OCCUPATIONAL SAFETY AND HEALTH MINISTRY OF HUMAN RESOURCES, MALAYSIA JKKP DP(S) 127/379/4-39 a."

[2] R. and A.-C. E. (ASHRAE) American Society of Heating, "ANSI/ASHRAE Standard 62.1-2019: Ventilation for Acceptable Indoor Air Quality," 2019.

[3] Williams, Jonathan, and Ralf Koppmann. "Volatile organic compounds in the atmosphere: an overview." *Volatile organic compounds in the atmosphere* 1 (2007). https://doi.org/10.1002/9780470988657.ch1

[4] Li, Siwen, Yingzi Lin, Gen Liu, and Chunyan Shi. "Research status of volatile organic compound (VOC) removal technology and prospect of new strategies: a review." *Environmental Science: Processes & Impacts* 25, no. 4 (2023): 727-740. https://doi.org/10.1039/D2EM00436D

[5] Wong, Ling-tim, Kwok-wai Mui, and Tsz-wun Tsang. "Evaluation of indoor air quality screening strategies: a step-wise approach for IAQ screening." *International journal of environmental research and public health* 13, no. 12 (2016): 1240. https://doi.org/10.3390/ijerph13121240

[6] Marques, Gonçalo, and Rui Pitarma. "An indoor monitoring system for ambient assisted living based on internet of things architecture." *International journal of environmental research and public health* 13, no. 11 (2016): 1152. https://doi.org/10.3390/ijerph13111152

[7] Annesi-Maesano, Isabella, Nour Baiz, Soutrik Banerjee, Peter Rudnai, Solenne Rive, and Sinphonie Group. "Indoor air quality and sources in schools and related health effects." *Journal of Toxicology and Environmental Health, Part B* 16, no. 8 (2013): 491-550. https://doi.org/10.1080/10937404.2013.853609

[8] Bako-Biro, Zsolt, Pawel Wargocki, Charles J. Weschler, and Povl Ole Fanger. "Effects of pollution from personal computers on perceived air quality, SBS symptoms and productivity in offices." *Indoor air* 14, no. 3 (2004): 178-187. https://doi.org/10.1111/j.1600-0668.2004.00218.x

[9] Lee, Chia-Wei, and Der-Jen Hsu. "Measurements of fine and ultrafine particles formation in photocopy centers in Taiwan." *Atmospheric Environment* 41, no. 31 (2007): 6598-6609. https://doi.org/10.1016/j.atmosenv.2007.04.016

[10] Echeverria, Diana, L. Fine, G. Langolf, T. Schork, and C. Sampaio. "Acute behavioural comparisons of toluene and ethanol in human subjects." *Occupational and Environmental Medicine* 48, no. 11 (1991): 750-761. https://doi.org/10.1136/oem.48.11.750

[11] Sarkhosh, Maryam, Amir Hossein Mahvi, Mohammad Reza Zare, Yadolah Fakhri, and Hamid Reza Shamsolahi. "Indoor contaminants from hardcopy devices: characteristics of VOCs in photocopy centers." *Atmospheric environment* 63 (2012): 307-312. https://doi.org/10.1016/j.atmosenv.2012.09.058

[12] Lee, Chia-Wei, Yu-Tung Dai, Chih-Hsueh Chien, and Der-Jen Hsu. "Characteristics and health impacts of volatile organic compounds in photocopy centers." *Environmental research* 100, no. 2 (2006): 139-149. https://doi.org/10.1016/j.envres.2005.05.003

[13] Balster, Robert L. "Neural basis of inhalant abuse." *Drug and alcohol dependence* 51, no. 1-2 (1998): 207-214. https://doi.org/10.1016/S0376-8716(98)00078-7

[14] Bælum, Jesper, I. B. Andersen, Gunnar R. Lundqvist, Lars Mølhave, Ole Find Pedersen, Michael Væth, and David P. Wyon. "Response of solvent-exposed printers and unexposed controls to six-hour toluene exposure." *Scandinavian Journal of Work, Environment & Health* (1985): 271-280. https://doi.org/10.5271/sjweh.2221

[15] Caron, Florent, Romain Guichard, Laurence Robert, Marie Verriele, and Frédéric Thevenet. "Experimental assessment of modelling VOC emissions from particleboard into a ventilated chamber." *Atmospheric Environment* 320 (2024): 120341. https://doi.org/10.1016/j.atmosenv.2024.120341

[16] "LAWS OF MALAYSIA ACT 514 OCCUPATIONAL SAFETY AND HEALTH ACT 1994 PART IV-GENERAL DUTIES OF EMPLOYERS AND SELF-EMPLOYED PERSONS," 1994.

[17] Bhaskaran, Rajesh, and Lance Collins. "Introduction to CFD basics." *Cornell University-Sibley School of Mechanical and Aerospace Engineering* (2002): 1-21.

[18] Wang, Liangzhu Leon, W. Stuart Dols, and Qingyan Chen. "An Introduction to the CFD Capabilities in CONTAM 3.0." *Proceedings of SimBuild* 4, no. 1 (2010): 490-496.

[19] Anton Schroer, Ionatan, Janice da Silva, Bethania Brochier, Paulo Ricardo Santos da Silva, Suse Botelho da Silva, and Éverton Hansen. "Study of ozone misting for sanitization of hospital facilities: A CFD approach." *Ozone: Science & Engineering* 45, no. 3 (2023): 305-319. https://doi.org/10.1080/01919512.2022.2091512

[20] Kumar, Vasa Vijaya, Mamidi Narsimha Raja Shekar, and Shankar Goud Bejawada. "Heat and Mass Transfer Significance on MHD Flow over a Vertical Porous Plate in the Presence of Chemical Reaction and Heat Generation." *CFD Letters* 16, no. 5 (2024): 9-20. https://doi.org/10.37934/cfdl.16.5.920

[21] Kamaltdinov, Marat, Peter Valentinovich Trusov, and Nina Vladimirovna Zaitseva. "Investigation of Digestion Processes in the Stomach and Duodenum using Computational Fluid Dynamics Model." *CFD Letters* 16, no. 3 (2024): 82-95. https://doi.org/10.37934/cfdl.16.3.8295

[22] D'Amico, Alessandro, Agnese Pini, Simone Zazzini, Daniela D'Alessandro, Giovanni Leuzzi, and Edoardo Currà. "Modelling VOC emissions from building materials for healthy building design." *Sustainability* 13, no. 1 (2020): 184. https://doi.org/10.3390/su13010184

[23] Shuzo Murakami, Shinsuke Kato, Yasushi Kondo, Kazuhide Ito, and Akira Yamamoto[1]. "VOC distribution in a room based on CFD simulation coupled with emission/sorption analysis." *Air Distribution in Rooms: Ventilation for Health and Sustainable Environment* 1 (2000): 473.

[24] Seo, J., S. Kato, Y. Ataka, and S. Nagao. "Measurement and CFD analysis on decreasing the effect of toluene concentration in rooms with adsorptive building materials." In *Proceedings Healthy Buildings*, vol. 5, pp. 101-106. 2006.

[25] Hong, SeungCheol, DurgaBhavani Konga, YoonShin Kim, and Somin Lee. "Effects of Printer Emissions in Mice With Preexisting Allergic Airway Responses." *Epidemiology* 22, no. 1 (2011): S168-S169. https://doi.org/10.1097/01.ede.0000392191.19287.c1

[26] Betha, Raghu, Valliappan Selvam, Donald R. Blake, and Rajasekhar Balasubramanian. "Emission characteristics of ultrafine particles and volatile organic compounds in a commercial printing center." *Journal of the Air & Waste Management Association* 61, no. 11 (2011): 1093-1101. https://doi.org/10.1080/10473289.2011.604549

[27] Lee, S. C., Sanches Lam, and Ho Kin Fai. "Characterization of VOCs, ozone, and PM10 emissions from office equipment in an environmental chamber." *Building and Environment* 36, no. 7 (2001): 837-842. https://doi.org/10.1016/S0360-1323(01)00009-9

[28] Destaillats, Hugo, Randy L. Maddalena, Brett C. Singer, Alfred T. Hodgson, and Thomas E. McKone. "Indoor pollutants emitted by office equipment: A review of reported data and information needs." *Atmospheric Environment* 42, no. 7 (2008): 1371-1388. https://doi.org/10.1016/j.atmosenv.2007.10.080

[29] Argyropoulos, Christos D., and N. C. Markatos. "Recent advances on the numerical modelling of turbulent flows." *Applied Mathematical Modelling* 39, no. 2 (2015): 693-732. https://doi.org/10.1016/j.apm.2014.07.001

[30] Kowalska, Joanna, Małgorzata Szewczyńska, and Małgorzata Pośniak. "Measurements of chlorinated volatile organic compounds emitted from office printers and photocopiers." *Environmental Science and Pollution Research* 22 (2015): 5241-5252. https://doi.org/10.1007/s11356-014-3672-3

[31] Abd Rahman, Nurul Izzah, Siti Zawiah Md Dawal, Nukman Yusoff, and Nabilla Sofia Mohd Kamil. "Anthropometric measurements among four Asian countries in designing sitting and standing workstations." *Sādhanā* 43 (2018): 1-9. https://doi.org/10.1007/s12046-017-0768-8

[32] "1988 OSHA PEL Project - Toluene _ NIOSH _ CDC"

[33] Bako-Biro, Zsolt, Pawel Wargocki, Charles J. Weschler, and Povl Ole Fanger. "Effects of pollution from personal computers on perceived air quality, SBS symptoms and productivity in offices." *Indoor air* 14, no. 3 (2004): 178-187. https://doi.org/10.1111/j.1600-0668.2004.00218.x

[34] Nandan, Abhishek, Nihal Anwar Siddiqui, and Pankaj Kumar. "Estimation of indoor air pollutant during photocopy/printing operation: a computational fluid dynamics (CFD)-based study." *Environmental geochemistry and health* 42, no. 11 (2020): 3543-3573. https://doi.org/10.1007/s10653-020-00589-0

[35] J. Taylor, F. Mike, L.W. Robert, B.W. Sharon, "Toxicological Profile for Toluene," 2017.