Reduced personal exposure to airborne cross-infection using wearable exhaust ventilation

Bivolarova, Mariya P.; Kierat, Wojciech; Hvidkjær, Signe; Stengade, Kathrine-Amalie; Illum, Trine ; Gad, Stine Boe; Melikov, Arsen K.

Published in:
Proceedings of 11th International Conference on Indoor Air Quality, Ventilation & Energy Conservation in Buildings

Link to article, DOI:
10.1051/e3sconf/202339602032

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Bivolarova, M. P., Kierat, W., Hvidkjær, S., Stengade, K.-A., Illum, T., Gad, S. B., & Melikov, A. K. (2023). Reduced personal exposure to airborne cross-infection using wearable exhaust ventilation. In *Proceedings of 11th International Conference on Indoor Air Quality, Ventilation & Energy Conservation in Buildings* (Vol. 396). Article 02032 EDP Sciences. https://doi.org/10.1051/e3sconf/202339602032

E3S Web of Conferences **396**, 02032 (2023) https://doi.org/10.1051/e3sconf/202339602032
IAQVEC2023

Reduced personal exposure to airborne cross-infection using wearable exhaust ventilation

Mariya P. Bivolarova[1], *Wojciech* Kierat [2], *Signe* Hvidkjær [1], *Kathrine-Amalie* Stengade[1], *Trine* Illum[1], *Stine* Boe Gad[1], and *Arsen K.* Melikov[1]

[1] International Centre for Indoor Environment and Energy, Department of Environmental and Resource Engineering, Technical University of Denmark, Kongens Lyngby, Denmark,
[2] Department of Digital Systems, Silesian University of Technology, Gliwice, Poland,

Abstract. This study aimed to explore an alternative solution for protection against cross-infection. Exposure reduction to exhaled airborne contaminants by wearing an exhaust nozzle was studied. Experiments were performed in a full-scale test room (64.8 m^3) equipped with a small section of a stadium tribune with six seats. Two breathing thermal manikins and four heated dummies were placed on the tribune. The manikins were equipped with artificial lungs simulating a realistic breathing cycle and respiratory flow. One of the breathing manikins was used to mimic a sick person having an infectious respiratory disease. The exhaled air of the "infecting person" was mixed with tracer gas to imitate pathogens. Four types of air exhaust nozzles were studied for their efficiency to reduce exposure to exhaled contaminants. The nozzle was positioned in front of the mouth of the infecting person. The test room was ventilated with mixing background ventilation. The use of the exhaust nozzle resulted in cleaner air in the room and at the breathing zone of the simulated occupants compared to only using dilution by the background ventilation. The novel device has the potential to capture exhaled air and reduce airborne cross-infection in densely occupied sitting areas.

1 Introduction

Airborne transmission of respiratory diseases such as COVID 19 poses great risk of spreading the infection in public events where many people are gathered. It is not surprising that large sport stadiums with a great number of spectators would be a hot spot for the spread of infectious viruses such as COVID-19 [1]. Several prevention strategies including increased physical distancing of at least 1 meter, avoiding crowds and close contact have been recommended by the World Health Organization [2]. However, in a crowded stadium, this and other measures for an effective social distancing are rarely met. Spectators are usually sitting and standing within centimeters from each other [1].

Face masks were the most widely applied prevention measures during the COVID-19 pandemic. Face masks can be uncomfortable to wear and long-term use may cause headache, respiratory problems, rash, and allergic reactions.

A novel approach with the potential to capture an infected exhaled air locally and thus expel pathogens by an infecting person was suggested by Bolashikov et al. [3]. The study showed that wearable headset with exhaust nozzle has high efficiency in capturing and removing infected exhaled air before it is mixed with the room air. It was also reported that the use of the exhaust headset reduced both the exposure of patients in a hospital patient room as well as the background concentration of the simulated exhaled air pollutants.

The objective of the current study was to investigate the capture efficiency of wearable exhaust ventilation for exposure reduction to airborne exhaled contaminants. The efficiency of four designs of exhaust nozzles was studied. For this purpose, spectators' exposure to exhaled airborne contaminants from an infecting spectator at a football match was studied, where the spectators were placed close together sitting on a tribune.

2 Methodology

2.1 Experimental Set-up

Full-scale experiments were carried out in a test room with dimensions: 5.3 m long x 4.7 m wide x 2.6 m heigh (64.8 m^3). The test room was situated in a laboratory hall with a height of 10 m. The hall was ventilated and air-conditioned by mixing ventilation and the air temperature was set to be the same as in the test room to avoid heat exchange. A small section of a stadium tribune with two rows and three seats per row was built inside the room. The tribune's rows were 2 meters long and 0.8 meter wide. The first row was 0.43 m heigh and the second one 0.86 m heigh (above the ground). There was 5 cm distance between two adjacent seats. Two breathing thermal manikins and four heated dummies with simplified human body geometries (only head, torso, and legs) were placed on the tribune to simulate spectators. Their positions are shown in Figure 1. Electrical bulbs placed inside the hollow steel construction of each dummy were used to simulate sensible heat load of 87 Watts, which is typical for a person doing light sedentary activity (1.2 metabolic rate). The thermal manikins had a realistic body size and shape of 1.7-m tall females. The manikins were dressed in a T-shirt, trousers, underwear, socks, and shoes (the total clothing insulation was 0.47 clo). The breathing of the manikins was performed by artificial lungs connected to the nose and mouth of each of them. The breathing cycle and flow rates were resembling the ones of a seated person (activity 1.2 met) that is, 10 breathing cycles/minute with pulmonary ventilation of 5.5 L/min.

The breathing mode was 2.5 s inhalation, 2.5 s exhalation and 1 s pause. The infecting manikin was exhaling through the mouth and inhaling through the nose. The opposite, exhalation nose, inhalation mouth, was simulated from the exposed manikin. The heat flux from the manikins simulated the dry heat loss from a human body in a thermally comfortable state. The heat output from the manikins was measured using a software, which controlled the transfer of necessary power to each body part of the manikins. The two manikins were simulating an infecting person and an exposed person designated as ITM and ETM, respectively. 0.5 L/min of nitrous oxide (N2O) tracer gas was dosed continuously to the exhalation flow of the infecting thermal manikin to simulate the emission of exhaled infectious particles. The concentration of the tracer gas was measured at nine points, including at the exposed thermal manikin (ETM) mouth, at head level of the dummies, in the supply and exhaust air of the room and in the room at 1.2 height (1 meter from the ITM head). During the experiments, the "infecting" manikin was wearing the headset with the exhaust nozzle.

The test room was ventilated, and air conditioned by clean outdoor air supplied via a square diffuser (Lindab LKA Ø250) which was placed in the center of the ceiling. The supply diffuser had 4-way discharge with an estimated throw length of 1.8 meter of the supply jets. The room air was exhausted through a ceiling attached LKA 250 diffuser located at the corner as shown in Fig. 1c.

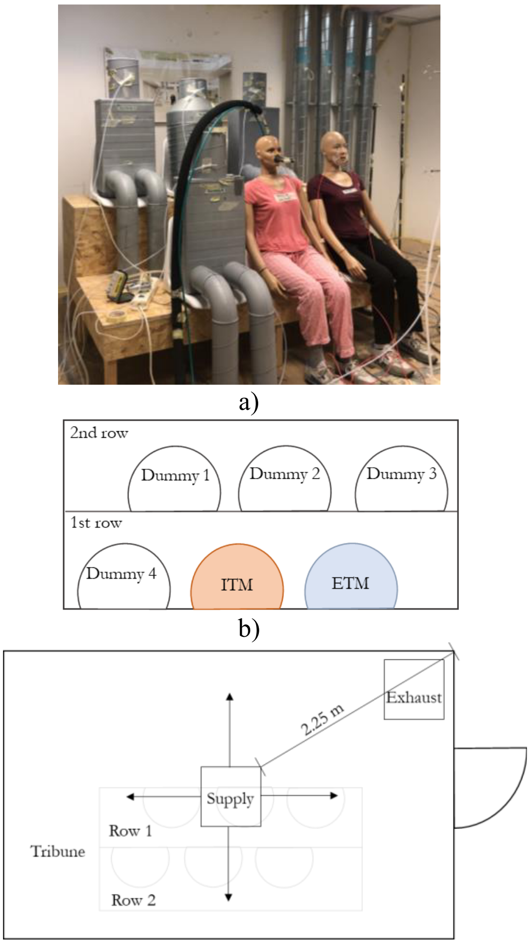
a)
b)
c)

Fig. 1. a) Experimental Set-up; b) Seating arrangement; c) Supply and exhaust diffusers set-up.

2.2 Wearable exhaust nozzle designs

In this study, different exhaust nozzles that would be attached to the headset were examined. Since the nozzle design was one of the most important factors to assure high effectiveness of capturing the contaminated exhaled air, the experiments were conducted by connecting the nozzle to an arm that would be in practice attached to the headset. The nozzle was positioned on a stand in front of the infecting manikin's mouth (Fig. 2a). The nozzle was placed in front of the ITM during all experiments except in the reference experiment. The nozzle's outlet was attached to a tube (d = 0.008 m) through which the air was exhausted using a pump (Fig. 2b). The exhaust air from the pump was discharged to a separate exhaust system located outside the test room.

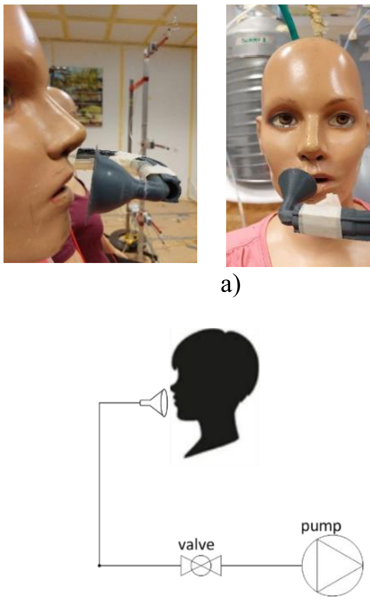
a)
b)

Fig. 2. a) Pictures of nozzle in front of the ITM; b) Setup for testing the wearable exhaust nozzle.

Four types of nozzle design were tested: flanged nozzle with throat inner Ø8 mm, flanged nozzle with throat inner Ø6 mm, circular nozzle with throat inner Ø6 mm and oval nozzle with inner Ø6 mm (Figure 3).

Fig.3 Pictures of the four nozzle designs: A. flanged nozzle with inner Ø8 mm, B. flanged nozzle with inner Ø6 mm, C. circular nozzle with inner Ø 6 mm, D. Oval nozzle with inner Ø 6 mm.

All nozzles' position was in front of the manikin's mouth but slightly skewed to the left as shown in Fig. 2a. The reason for this positioning was because it was discovered by a smoke test that the exhalation flow from the mouth was not symmetrical. The exhalation flow was directed slightly to the manikin's right side of the mouth. The distance of each nozzle from the mouth of the manikin was 1.5 cm (right) and 2.5 cm (left) (see Fig. 4).

Fig.4 Nozzle position.

The dimensions of the circular nozzle are shown in Fig.5. The corresponding dimensions of the rest of the nozzles are shown in Table 1.

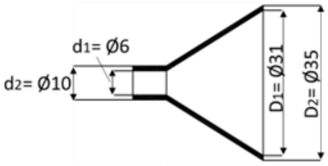

Fig.5 Dimensions of the circular nozzle in millimeters.

Table 1. Dimensions of the nozzles

Nozzle	D1, mm	D2, mm	d1, mm	d2, mm
Circular	31	35	6	10
Oval	40	44	6	10
Flanged Ø6 mm	30	45	6	10
Flanged Ø8 mm	30	45	8	10

2.3 Experimental conditions

A series of experiments were performed at supply airflow rate to the room of 60 L/s±1 L/s which was equal to 3.3 air change rate per hour (ACH). The exhaust flow rate was also 60 L/s ±1 L/s. The exhaust flow rate of the nozzles was 0.80 L/s. The room air temperature was set at 25.5 °C ± 0.2°C throughout the whole study to simulate summer conditions. The supply air temperature of the background ventilation was 18.3°C. The manikins and heated dummies were the only heat sources in the room. The heat from the six-ceiling light fixtures could be neglected since it was dissipated above the ceiling. The light fixtures were not isolated with any material from the top. The relative humidity in the room was in the range of 30 – 50%.

Five experimental conditions were studied to investigate the performance of each nozzle type. The conditions included a reference case in which the exhaust nozzle was not used and there was only background ventilation (3.3 ACH). During the experiments with the exhaust nozzle ventilation, the background ventilation in the room was kept at 3.3 ACH.

2.4 Measurement equipment and procedure

A calibrated photoacoustic gas analyser, Gasera One (Gasera Ltd., Finland), coupled with a Gasera multipoint sampler was used to measure the N2O gas concentration with an accuracy of 2% of the reading. A photoacoustic Innova 1412 gas analyser coupled with a six-channel Innova 1302 sampler was also used to measure the N2O concentration. Prior to the experiments, the two analysers were intercalibrated. A linear correlation ($R^2 = 0.9996$) between Innova and Gasera One analyser was obtained. The obtained data with the Innova analyser were corrected using the linear equation.

The room air temperature, relative humidity (RH) and air speed were also measured. The air temperature and relative humidity were measured using digital sensors Sensirion STH31 with accuracy 0.2°C and 3%, respectively. The air speed was measured using a multichannel low velocity thermal anemometer AirSpeed 5000, which uses transducers. The transducers were equipped with a probe that consist of omnidirectional air speed and temperature sensors. The range of air speed measurement by the sensors was 0.05 m/s to 3 m/s with an accuracy of ±0.02 m/s ± 1%.

The experiments were conducted under steady-state room air temperature and tracer gas concentration. To collect at least 30 tracer gases samples under steady state at each measuring point, one experiment lasted five to six hours.

2.5 Data analyses

The data from the tracer gas measurement were first analysed by calculating the average and standard deviation of the N2O concentrations obtained during the steady-state period of the experiments. The standard uncertainties due to accuracy and resolution of the gas analysers, and due to repeatability of the measured concentrations were estimated in accordance with the ISO/IEC Guide for the expression of uncertainty [4]. Finally, the expanded combined uncertainty was calculated with a level of confidence of 95% (coverage factor of 2).

3 Results

The measured air temperature in the room varied in the range of 25.5 - 26°C during all experiments. The air speed measured close to the tribune and in the room was in the range of 0.05 m/s - 0.13 m/s. The standard uncertainty of the tracer gas measurements was maximum 2 ppm.

Fig. 6 shows the average concentration of N2O (ppm) measured at the mouth of the exposed thermal manikin and in exhaust air of the room during the reference case and during operation of the four nozzle types. The results show that the lowest concentrations were achieved when the flanged nozzles were used. The slightly larger size of the flanged nozzle with Ø8 mm did not reduce further the simulated exhaled contaminants measured at the mouth of the manikin and in room exhaust air. The circular nozzle had the lowest efficiency followed by the oval nozzle.

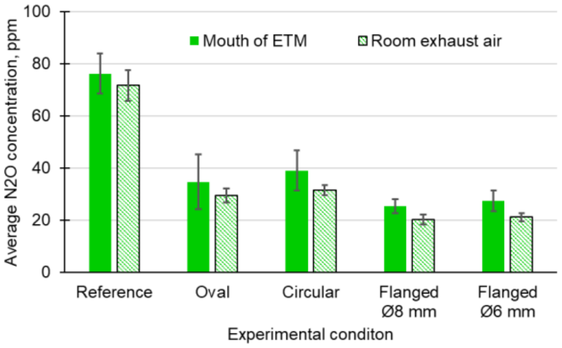

Fig. 6 Average N2O concentration measured at the mouth of the exposed TM and in exhaust air of the room during all experimental conditions. The error bars show the standard deviations.

To compare the efficiency of each nozzle to the reference condition the N2O concentrations were normalized according to the following equation (1):

$$\varepsilon = (C_i - C_n)/C_i \qquad (1)$$

where ε is normalized concentration (capturing efficiency), C_i is the average N2O gas concentration (ppm) acquired at one of the measuring points during the reference condition and C_n is the average N2O gas concentration (ppm) acquired at the same measuring points when using one of the exhaust nozzles. A value of 1 means that the capturing efficiency was like the dilution provided by mixing ventilation operated at 3.3 ACH. The higher the value, the better the performance of the studied exhaust nozzle with respect to pollutant removal is. The capturing efficiency of the exhaust nozzles is shown in Table 2 for the various measuring locations. The results in Table 2 show that the capturing efficiencies obtained for the different measuring location were approximately the same during the studied condition. This suggests that there was good mixing in the room. Slightly higher efficiency was obtained in the room exhaust air compared to the efficiency in the breathing zones of the simulated spectators at all conditions. This is due to the proximity of the spectators with the infecting "person". The results show that the flanged nozzles had the highest capturing efficiency of about 62% - 72%.

Tabe 2 Capturing efficiency of the exhaust nozzles in percentages.

Nozzle / Location	Oval	Circular	Flanged Ø 8 mm	Flanged Ø 6 mm
Mouth of ETM	55%	49%	67%	64%
Room exhaust air	59%	56%	72%	70%
Dummy 1	54%	49%	66%	64%
Dummy 2	54%	49%	65%	63%
Dummy 3	53%	46%	64%	62%
Dummy 4	55%	49%	65%	64%

4 Discussion

The present research shows that headset with an air exhaust nozzle has a potential to lower a person's exposure to infectious particles up to 66%. This would potentially lower the risk of a disease spreading significantly at large gatherings in the case of an epidemic such as COVID-19. It could be useful also when a person is in contact with an infected patients or vulnerable patients who must be protected from getting infecting.

The results show that the highest capturing efficiency have the flanged nozzles. Similar finding was reported by Bolashikov et al. [3] in which it was also studied the potential of different exhaust nozzles to capture exhaled pollutants. They explained that the reason a flanged nozzle to perform better than a circular one is the shape. In the current study, the flanged nozzles had flanges at 45◦ around the exhaust opening of the nozzle. This design facilitated the exhaust velocities at the side of the nozzle to decrease. As a result, the exhaust velocity increased in the center of the nozzles where the exhaled air pollutants are concentrated.

It is important that the headset with incorporated nozzle is not only efficient but also that people would be willing to wear it, for instance, instead of face masks. During the Covid-19 pandemic, many countries forced people to wear face masks in large gatherings. But many people found face masks inconvenient. It has been reported that face masks can even cause headache, respiratory problems, rash and allergic reactions in long-term use [5]. Therefore, the headset could be a good alternative to the face mask. To make this realistic it is though important that it is comfortable and easy to wear. To investigate this, a prototype of the headset with integrated nozzle would have to be designed so that human subjects could evaluate the comfort of the headset.

5 Conclusions

The present study shows that the use of a wearable exhaust nozzle by an infected person can reduce nearby persons' exposure to airborne contaminants. The flanged nozzles are the most effective in this study with an average pollution capture efficiency of 66%.

Refereces

1. A. Hassanzadeh-Rad, F. Halabchi, Stadiums as Possible Hot Spots for COVID-19 Spread, AsJSM J. **e103178** (2020)
2. World Health organization, Advice for the public: Coronavirus disease (COVID-19), (2022), https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public (accessed Nov. 2022)
3. Bolashikov, Z., Melikov A, and Barova M., Wearable exhaust ventilation: Improved indoor air quality and reduced exposure to air exhaled from a

sick doctor. Science and Technology for the Built Environment 21:8, pp. **385–399** (2015)

4. ISO/IEC Guide 98-3:2008. Uncertainty of measurements – Part 3: Guide to the expression of uncertainty in measurement (GUM: 1995). JCGM **100** (2008)
5. Sundhedsstyrelsen (2021). “Brug af mundbind i det offentlige rum”. In Danish, In: Dokumentation og sundhedsfaglige anbefalinger – 24.november 2021.url:https://www.sst.dk/da/corona/forebygsmitte/generelle-raad