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RESEARCH ARTICLE

Numerical simulation of social distancing of preventing airborne transmission in open space with lateral wind direction, taking into account temperature of human body and floor surface

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Abstract

This paper presents the numerical results of particle propagation in open space, taking into account the temperature of the human body and the surface of the ground. And also, the settling of particles or droplets under the action of gravitational force and transport in the open air is taken into account, taking into account the temperature during the process of breathing and sneezing or coughing. The temperature of the body and the surface of the ground, different rates of particle emission from the mouth, such as breathing and coughing or sneezing, are numerically investigated. The effect of temperature, cross-inlet wind, and the velocity of particle ejection from a person's mouth on social distancing is being investigated using a numerical calculation. The variable temperature of the human body forms a thermal plume, which affects the increase in the trajectory of the particle propagation, taking into account the lateral air flow. The thermal plume affects the particles in the breathing zone and spreads the particles over long distances in the direction of the airflow. The result of this work shows that in open space, taking into account the temperature of the body and the surface of the ground, a 2-m social distance may be insufficient for the process of sneezing and social distance must be observed depending on the breathing mode.

Keywords Airborne transmission · Thermal effects from body · Particle dispersion · Indoor · Breathe · COVID-19 · Social distancing · SARS-CoV-2-laden droplets · Computational fluid dynamic (CFD)

Introduction

Over the past two decades, the third highly pathogenic representative of the coronavirus family is MERS and SARS-CoV-2 (Issakhov et al. 2021a, b). At present, due to the rapid growth of infected people around the world, there is a sharp need to combat the spread of the virus. So far, certain and effective treatments have been developed to mitigate the effects of the disease (Smieszek et al. 2019). One of them is vaccination — which has greatly improved the general population confinement in some countries by relaxing strict quarantine measures (Grimalt et al. 2022). However, there are some risks of reinfection for the vaccinated population. For this, strict precautions must be taken in public places, as public places are hotspots for the spread of the virus (Birgand et al. 2020).

In addition, COVID-19 is transmitted from asymptomatic people through the airborne route, so it is necessary to understand the spread of the virus in the environment in order to prevent the accumulation of infection (Morawska et al. 2020, Bai et al. 2020, Feng et al. 2020, Gao et al. 2021). In connection with this, many research papers have been carried out, for example, on outbreaks of infectious diseases in various enclosed spaces, such as hospitals (Takanabe et al. 2021, Xian et al. 2020; Xu et al. 2021, Chia et al. 2020, Mizukoshi et al. 2021) public places (Rencken et al. 2021, Park et al. 2021), public

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transportation (Alexei Pichardo-Orta et al. 2022), air travel (Li et al. 2016, Zee et al. 2021) and open-space office (Weissberg et al. 2020). Everyone knows that most cases of respiratory diseases are transmitted by airborne droplets or through close contact. For example, such as tuberculosis, measles, chicken pox (Busco et al. 2020; Li et al. 2020) influenza, bronchitis, and pneumonic plague (Leclair et al. 1980, Escombe et al. 2007, Roy and Milton 2004, Sattar et al. 1987, Chan et al. 2020) are transmitted by airborne droplets.

The main mechanism for the spread of viral diseases is coughing and sneezing. When simply breathing, sneezing or coughing, small droplets are formed, consisting of water and air. Consequently, these small particles have different generation rates and durations, with different effects on the environment and the human body (Hinds 1982, Zhao et al. 2005). And also, the spread of the virus by airborne droplets indoors and outdoors depends on many factors, such as, humidity, pollution, particle size, temperature, population density, ventilation rate, particle settling rate, the presence of other aerosols or volatile organic compounds (VOC), and others (Cai et al. 2020, Memarzadeh 2012, Schaffer et al. 1976, Lowen et al. 2007). Moreover, all these factors affect different infectious organisms differently and to varying degrees, and in some cases it is difficult to draw a conclusion, since different experimental methods were used during the study (Tang 2009).

Coughing and sneezing is a major source of exhaled pollutants and is also a symptom of most respiratory infections (Duguid 1945, Gupta et al. 2009). There are many scientific papers on the size of the distribution of droplets during active breathing, sneezing, and coughing and have a wide range of diameters approximately $dp < 10^{-6}$ m (Chao et al. 2009, Zhang et al. 2015, Morawska et al. 2009, Papineni and Rosenthal 1997). Therefore, the distance and settling of particles also depends on the size and speed of their propagation. And also, the number and size of the particles differ significantly, for example, when sneezing, about 40,000 drops are formed, and when coughing, about 3000 drops (Cole and Cook 1998, Wei and Li 2016). Moreover, the behavior of large and small particles in the air plays an important role in reducing the risk of SARS-CoV-2 infection. In addition, the particles spread differently from 0 to 7 m and beyond. This spread depends on the influence of various factors, such as settling, size, air flow and evaporation of droplets, etc. Another important point is that at high temperature and relative humidity, particles can evaporate and shrink, changing their propagation trajectory. The work (van Doremalen et al. 2020) showed that viable SARS-CoV-1 and SARS-CoV-2 influenza infectious particles remain in the air for about 1–3 h (Kampf et al. 2020, van Doremalen et al. 2020). Thus, droplets or particles are more likely to spread both indoors and outdoors, increasing the risk of infecting people in a certain period of time after exposure (Wang et al. 2020a, b, Zhang and Li, 2012). Xian et al. 2020; Li et al. 2020 consider the evaporation and propagation of particles in the open air. It should be noted that this kind of study is quite rare in studies, and most studies focus on ventilation assessment, vehicle pollution dispersion, various chemical reactions and particulate matter associated with outdoor ventilation (Chen et al. 2017; Zhang et al. 2020a, 2020b; He et al. 2017; Liu et al. 2015; Yang et al. 2020; Scungio et al. 2018; Tung et al. 2021; Yao et al. 2020; Bartzis et al. 2015). From those studies, it can be observed that the spread of COVID-19 in the open air is still to be studied, since the virus can be transmitted not only indoors, but also outdoors (Zhang et al. 2020c, Xu et al. 2021). There is a lot of work and WHO recommends a certain social distance, at least 1–2 m from each other in rooms, to reduce the risk of infection (WHO 2020). To determine the optimal distance to prevent the transmission of infectious diseases, there are still no solutions for physical distancing in the outdoors (Kissler et al. 2020; Gao et al. 2021). As the results of some simulation studies show, 2 m for social distancing may not be enough (Dbouk and Drikakis 2020; Feng et al. 2020, Pendar and Páscoa, 2020; Issakhov et al. 2021a, b).

Computational Fluid Dynamics (CFD) simulations are used to predict airborne spread of the virus (Holmes and Morawska 2006) because, CFD simulations are affordable and inexpensive compared to experiments. In order to get a more accurate forecast, setting the boundary conditions close to reality plays an important role, for example, flow velocity, flow direction, temperature, pollutant source area, etc. Therefore, numerical simulation makes it possible to obtain a more accurate prediction for particle propagation even taking into account particle evaporation (Li et al. 2018).

The purpose of this work is to determine the optimal distance to prevent the transmission of infectious diseases in the open air, which takes into account the distributed body temperature and ambient temperature during various breathing patterns, coughing, and sneezing. Accounting for these factors during simulation brings this calculation closer to a more realistic case. As it is knowing, the spread of infectious diseases depends on many factors, and determining a safe distance without taking into account these factors may lead to incorrect results, which may not lead to a very good result.

Mathematical model

For the correct construction of the mathematical model of the air flow, the system of Navier–Stokes equations is used, which is numerically implemented through the ANSYS Fluent. For modeling are used the incompressible Navier–Stokes equations. The continuity and momentum equations used in the model are defined as follows:

$$\frac{\partial u_j}{\partial x_j} = 0 \tag{1}$$

$$\frac{\partial u_i}{\partial t} + \frac{\partial}{\partial x_j}\left(u_i u_j\right) = f_i - \frac{1}{\rho}\frac{\partial p}{\partial x_j}\left[\mu_{eff}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial x_j}{\partial u_i}\right)\right] \tag{2}$$

where μ_{eff} – the effective viscosity, p – the pressure, $\mu_{eff} = \mu + \mu_t$, where μ_t – the turbulence viscosity. The external force of the body considered is gravity, so that $f = \rho g$, where g is the acceleration due to gravity, ρ—the density.

The kinematic relationship between the position of particles and the speed of particles is

$$\frac{dx_p}{dt} = u_p \tag{3}$$

$$m_p \frac{du_p}{dt} = F_D + F_G \tag{4}$$

where x_p, the particles location, F_G is the gravity force, F_D, the drag force, u_p, the velocity of particles, u_f, the velocity of fluids, m_p, the mass of particles and F_D calculated as follows

$$F_D = \frac{1}{2}\rho_f \frac{\pi d_p^2}{4} C_D\left(u_f - u_p\right)\left|u_f - u_p\right| \tag{5}$$

where the resistance coefficient

$$C_D = \begin{cases} \frac{24}{Re};(Re < 1) \\ \frac{24}{Re}\left(1 + 0.15Re^{0.687}\right);(1 \le Re \le 1000) \end{cases} \tag{6}$$

where ρ_f is the density of the fluid, ρ_p is the particle density and d_p is the particle diameter, $Re = \frac{\rho d_p\left|\vec{u}-\vec{u}_p\right|}{\mu}$ is the Reynolds number.

In order to close the system of equations was used SST k-ω turbulent model, which described in detail in (Spalart, 1997; Menter and Kuntz 2003; Menter 1994; Jones and Launder 1972; Issakhov and Mashenkova 2019; Issakhov and Omarova 2019; Issakhov et al. 2020a; Issakhov et al. 2020b; Issakhov, Alimbek, Zhandaulet, 2021).

These equations are approximated by using the finite volume method. The numerical model for this problem was presented using the widely used SIMPLE method (Semi-Implicit Method for Pressure-Linked Equations). This method is used in many works to solve various problems of hydrodynamics and heat transfer and served to create a whole class of numerical methods. All variables that were used in this method are completely physical. For discretization of the all equations of convective term was used Second Order Upwind scheme (Issakhov and Omarova 2021; Issakhov and Zhandaulet 2019; Issakhov and Borsikbayeva 2021; Issakhov et al. 2022a, b, c; Issakhov et al. 2022a, b, c; Issakhov, Alimbek, Abylkassymova, 2022).

Numerical simulations

Validation of the mathematical model and numerical algorithm was performed for the test problem and the obtained results were compared with experimental data, this procedure is described in more detail in the works papers (Issakhov et al. 2021a, b; Issakhov et al. 2022a, b, c). This work represents the propagation of a particle in open space, taking into account the temperature of the human body, the environment and the lateral inlet air flow, and also takes into account different speed regimes for breathing, coughing and sneezing. For implementations of numerical simulations, the problems were taken in an indoor room with a person. The size of the constructed room with a person is X × Y × Z = 8 × 3 × 3 m, and the total height of a European person is 1.8 m. To describe the process of breathing, coughing, and sneezing, the level of the mouth was used; in addition to this process, particles are ejected from the mouth. The height from the floor to the mouth inside the box is approximately 1.65 m. In the presented work, the distribution of concentration and particles was considered, taking into account the influence of the inlet wind, body temperature and the surface of the ground, provided that a person is talking, sneezing or coughing. The full size of the area under consideration is shown in Fig. 1.

The studies show that the speeds for sneezing, coughing while talking are different from each other (Verma et al. 2017, Xu et al. 2018, Hasan 2020, Redrow et al. 2011). The variation in the speed of ejected particles from the human mouth was from 1 to 20 m/s. In this study, a simpler version of sneezing and coughing was investigated, but it should be taken into account that this process of sneezing and coughing occurs once. The main factor is that many people sneeze more than once per sneeze cycle. Thus, in the problem, the rate of simple breathing is periodic, and the rate of the process of coughing or sneezing is pulsed. In addition, repeated sneezing or coughing increases the distance of the ejected particles by an even greater propagation distance.

The particle diameter is set in the range of about 10^{-6}–10^{-3} m depending on normal breathing, coughing or sneezing (Zhao et al. 2005).

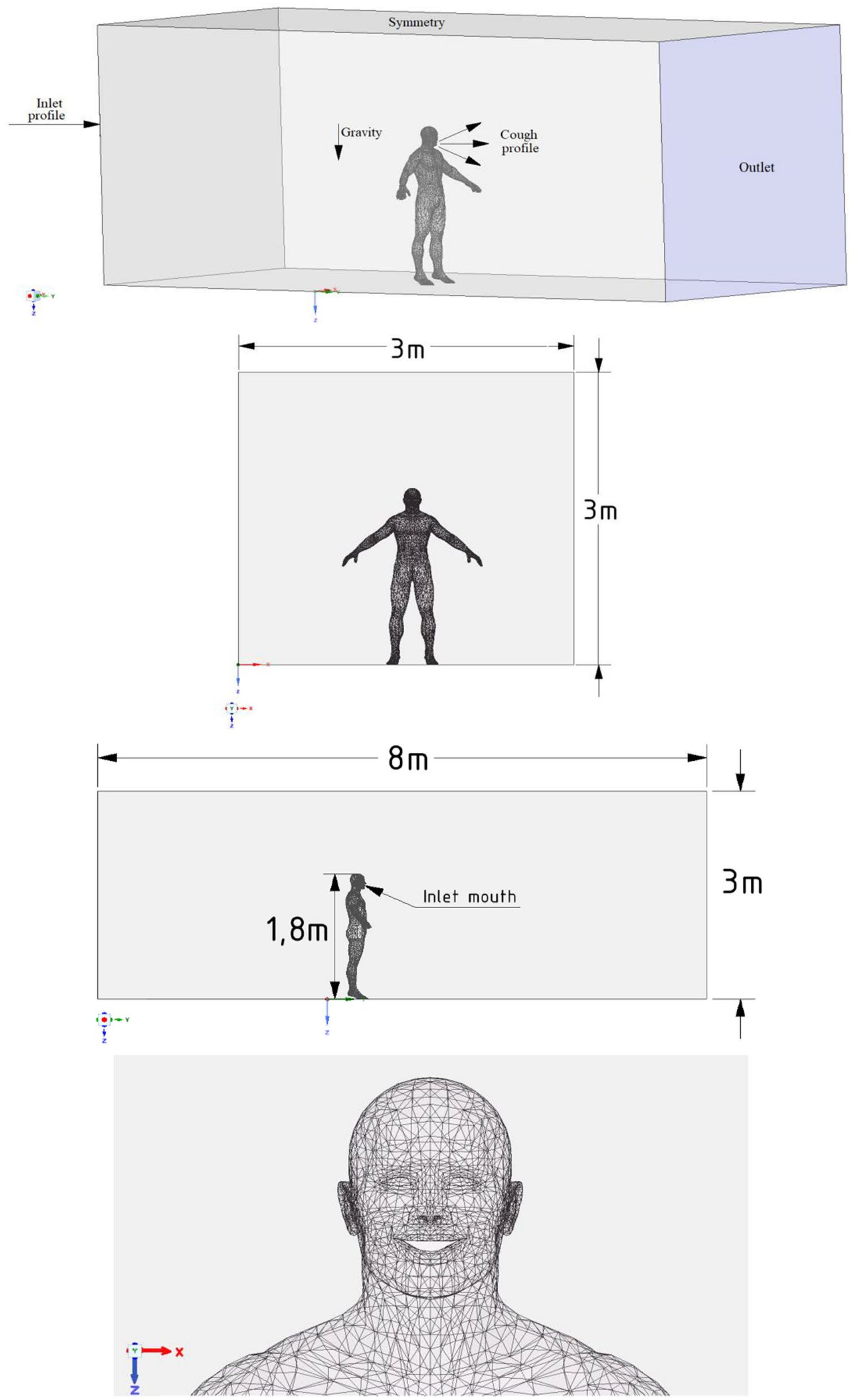


Fig. 1 Geometry of the study area

The total duration of one sneeze was approximately 0.1925s (Busco et al. 2020). The following formulas were used to describe the rate of particle ejection from the mouth

$$\begin{cases} u = V, 10.1 \leq t \leq 10.25 \\ u = Vsin(2\pi t), 10.25 \leq t \leq 10.5 \\ u = sin(2\pi t), 10.5 \leq t \end{cases}$$

Particles are droplets of a mixture consisting of water and air, based on some works for this problem, the particle density was set to 600 kg/m^3 (Zhao et al. 2005). In this paper, it was considered several scenarios with variable body and ambient temperatures in open space: (a) breathing at a speed of V = 1 m/s; (b) coughing at a speed V = 6 m/s; and (c) sneezing at a speed of V = 20 m/s. For all cases, the initial 10 s is simulated taking into account the variable temperature of a person and the surface of the ground, taking into account the lateral inlet wind (inlet), and the particles are ejected from the mouth from 10.1 to 10.3 s, and then up to 20.5 s, the process of inhalation and exhalation of a person without ejection. This sets the particle ejection temperature to 309.75 K. The floor temperature is also set to a constant value of 305 K. This procedure is given by the connection in order to approximate a more real process. All scenarios take into account the influence of variable body and floor temperatures, taking into account the inlet wind on the movement and concentration of emitted particles before the process of breathing, coughing and sneezing.

In order to obtain a more accurate result in a short period, the computational grid was refined in certain areas. For the study area, it was used clumps around the mouth (face mouth = 0.001) and around the human body (face body = 0.005) to reduce the number of cells and computational costs, since this geometry is complex. The total number of elements of the study area is 7 731 570 and nodes (nodes = 1 366 119). The three-dimensional (3D) computational grid of this area is shown in Fig. 2. The following functions were taken as the distribution profile of the incoming flow and for body temperature:

$$U_{inlet} = 0.7(1 - exp(-2(z + 3)))$$

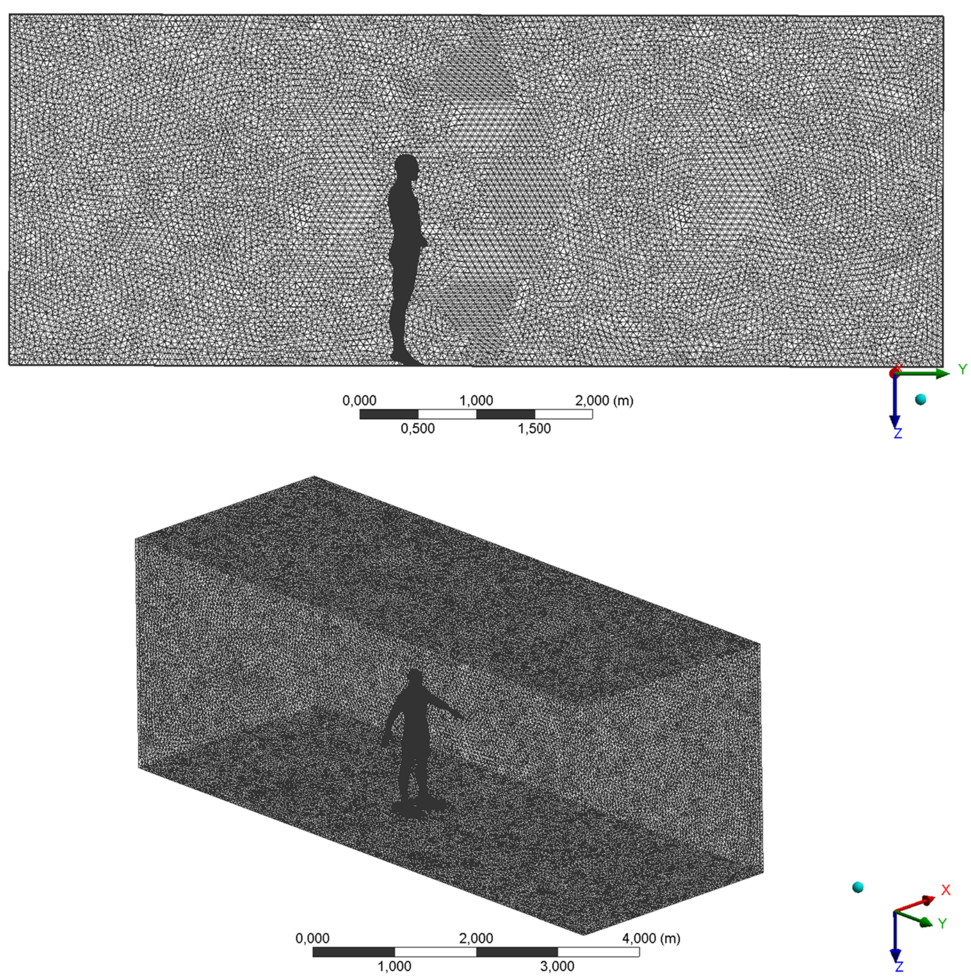


Fig. 2 Computational grid of the study area

In order to realize the initial distribution of body temperature, it was taken into account that body temperature is not evenly distributed throughout the body (Psikuta et al. 2017), since the maximum temperature is on the human head (310.75 K), and the minimum temperature is on the lower extremities (309.75 K). For this purpose, the initial approximation of body temperature is given by the following formula

$$T_{body} = 309.75 + z/1.8$$

where z varies according to the height of the person.

Numerical simulation results

Figures 3, 4 and 5 show the temperature distribution over time for various speed modes. To obtain these results, the first 10 s of the simulation was performed taking into account the variable temperature of the body and floor, but the emission of particles from the mouth is not carried out. This procedure is carried out in order to form temperature and velocity fields. After the formation of temperature and velocity fields, the particle is ejected. As it can be seen from the obtained numerical results, the influence of a variable body temperature and the presence of an air flow significantly affect the distribution of velocity and the distance of particle movement. It should be noted that, taking into account the force of friction and gravity, a thermal plume arises due to the variable body temperature and the presence of a lateral inlet air flow accelerates the transfer and diffusion of the particles. As a result, one can see a huge change in the thermal plume at different points in time for each scenario. Moreover, it should be noted that due to the thermal plume, an additional lift force is generated, which lifts up the lateral inlet air flow, which ultimately leads to the fact that the ejected particles rise up.

And it should also be noted that with different breathing patterns (coughing and sneezing), there is a change in the thermal plume around the body. As can be seen from Figs. 3, 4 and 5, at 12.5 s, one can notice changes in the thermal plume due to different breathing modes at the initial time, and then, due to the lateral inlet wind flow, the heat propagation characteristics are almost similar. Figures 6, 7 and 8 show the transfer of particles at different times. As can be seen from Fig. 6, the particle propagation distance, taking into account the temperature plume, in the time period from 10.2 to 10.5 s, reaches 0.12 m. From the obtained results, it can be seen that different breathing modes play an important role in particle propagation. However, it should be noted that after the process of coughing and sneezing from 12.5 s, the lifting force that is created due to the variable temperature

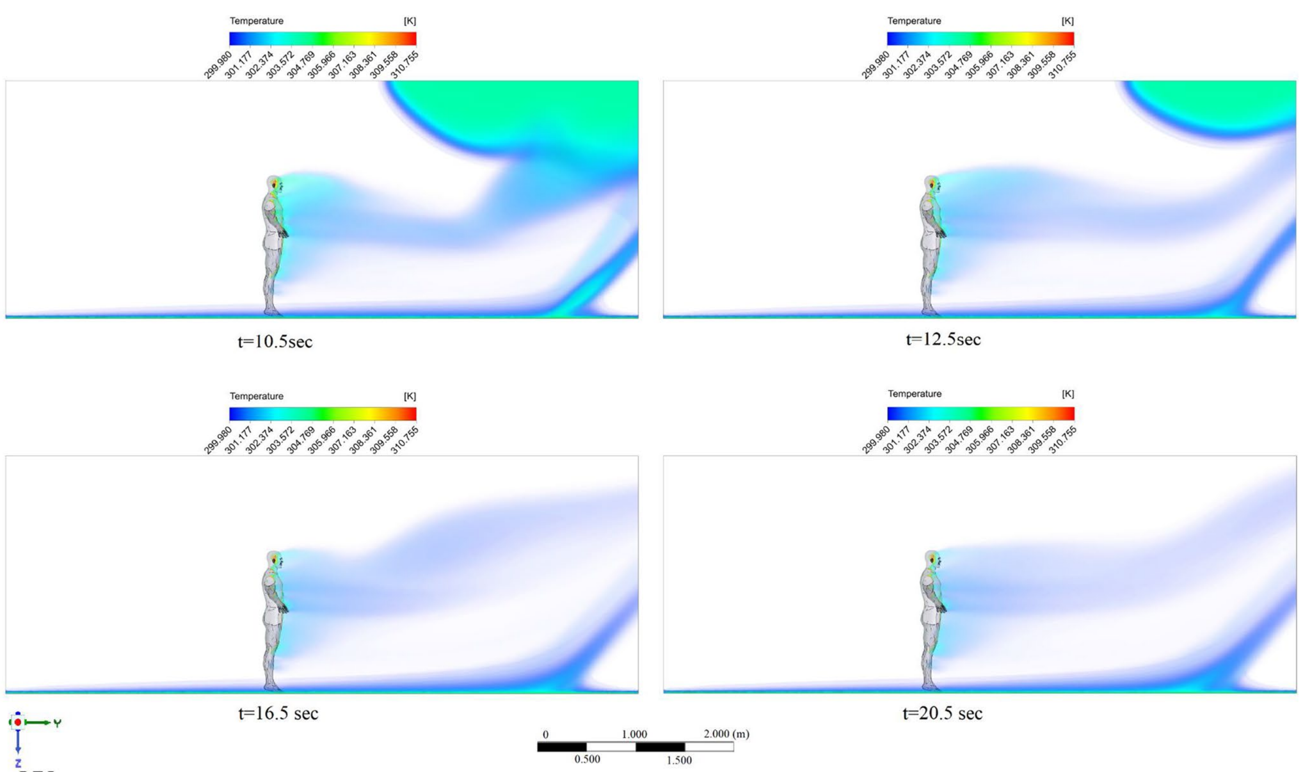


Fig. 3 Contour temperature 10.5–20.5 s cough = 1 m/s

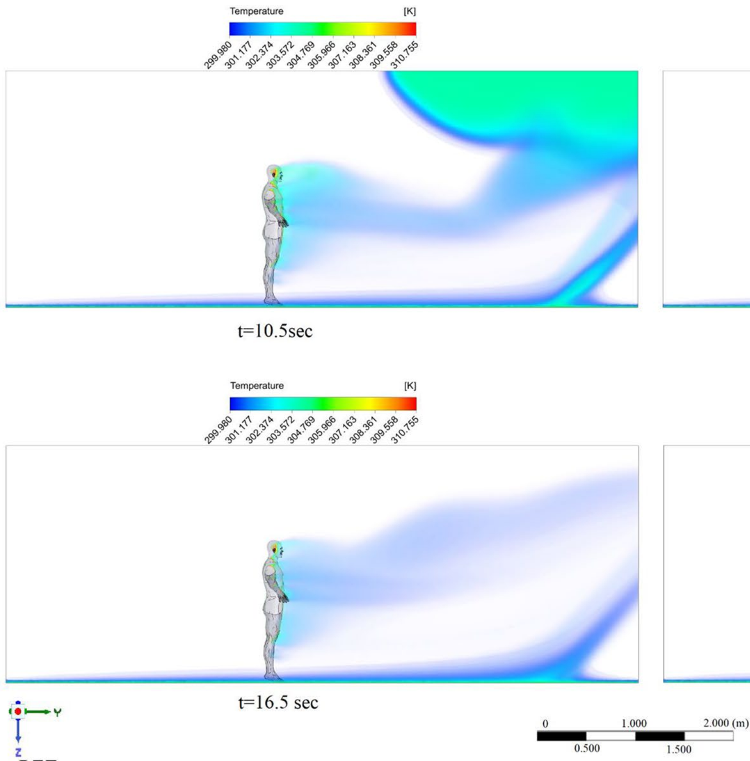


Fig. 4 Contour temperature 10.5–20.5 s cough = 6 m/s

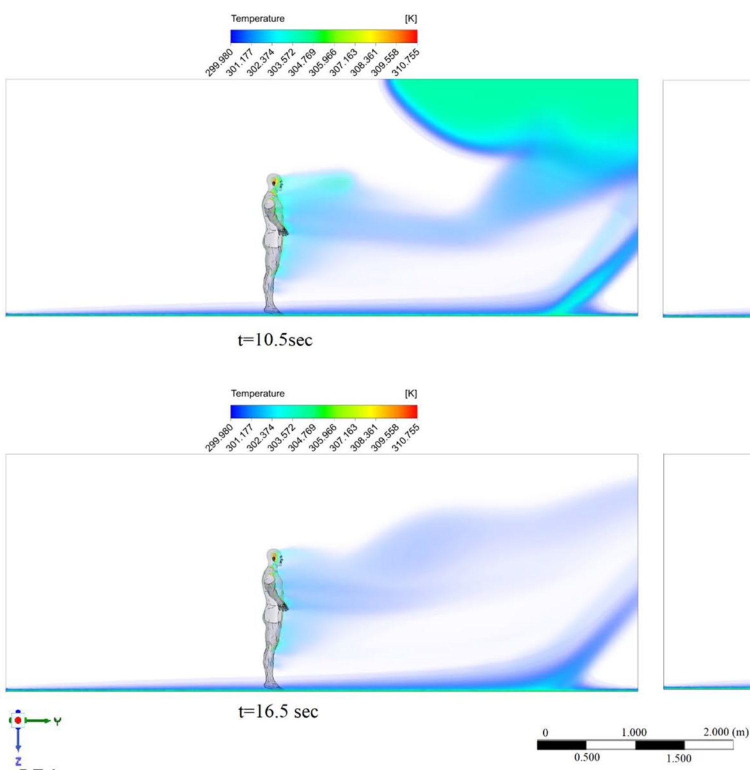
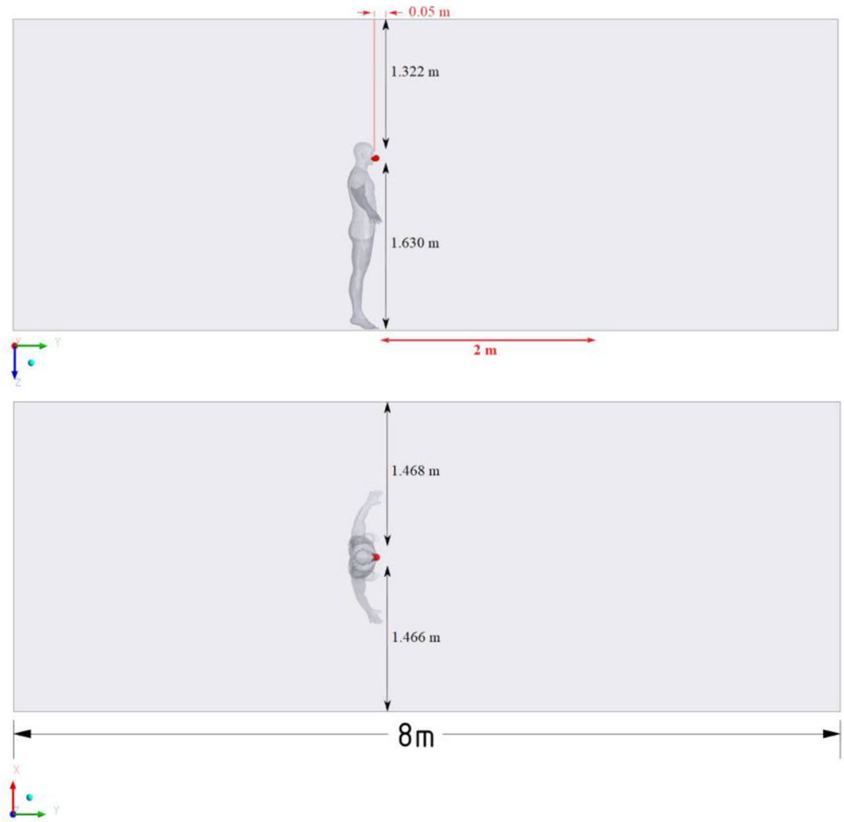
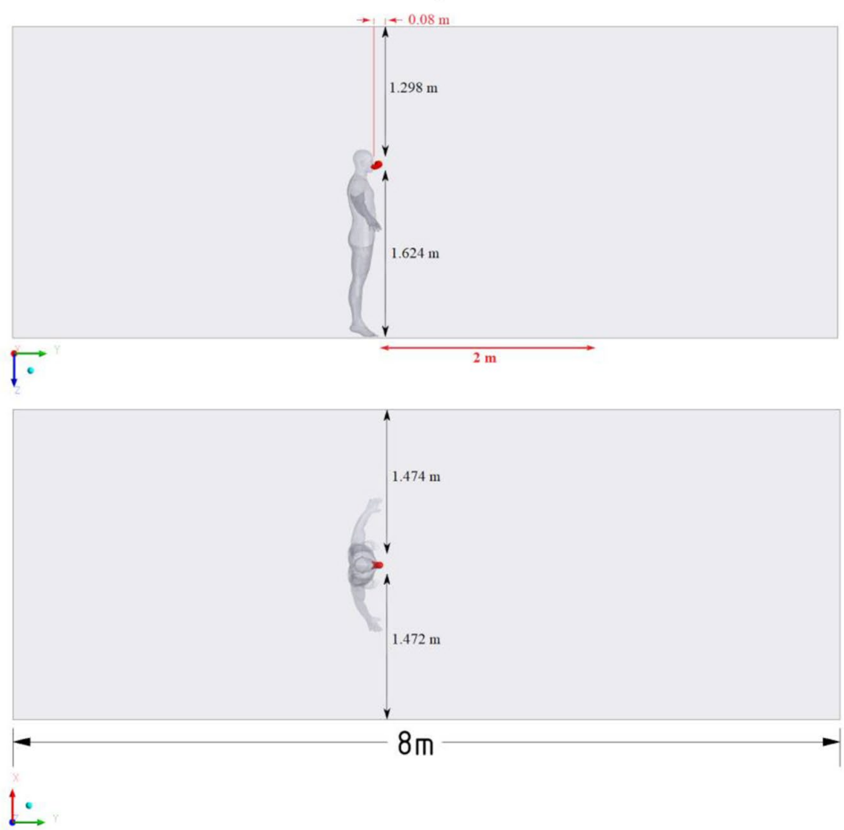


Fig. 5 Contour temperature 10.5–20.5 s cough = 20 m/s

Fig. 6 Particles, cough = 1 m/s open space with temperature 20.5 s. **a** Time step = 10.2 s, **b** Time step = 10.3 s, **c** Time step = 10.4 s, **d** Time step = 10.5 s, **e** Time step = 12.5 s, **f** Time step = 16.5 s, **g** Time step = 20.5 s

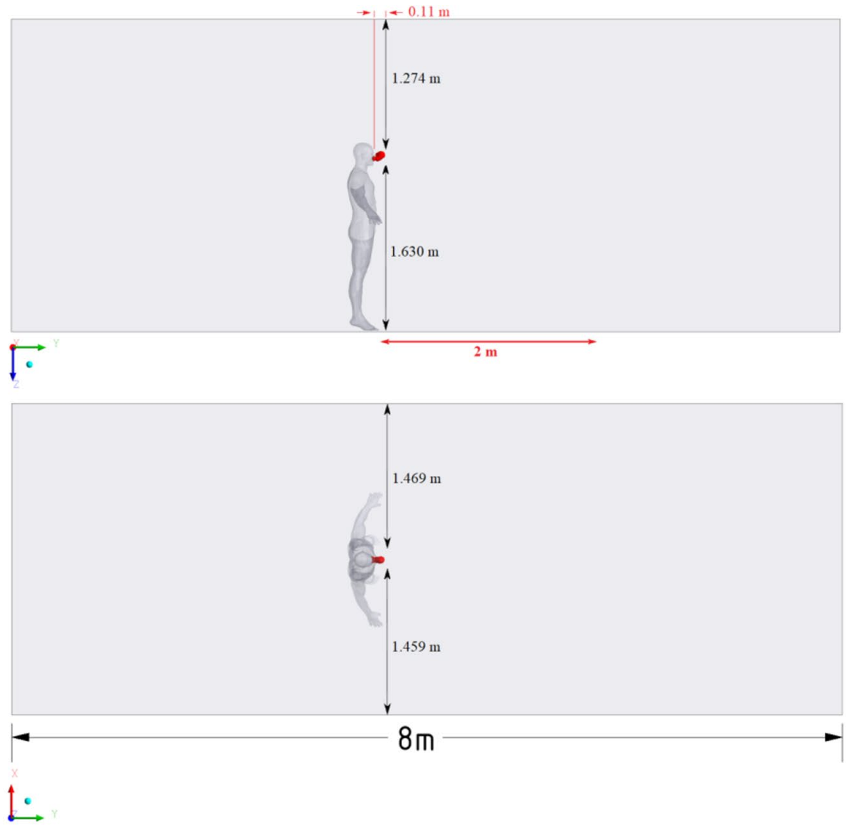


a) Time step=10.2 sec

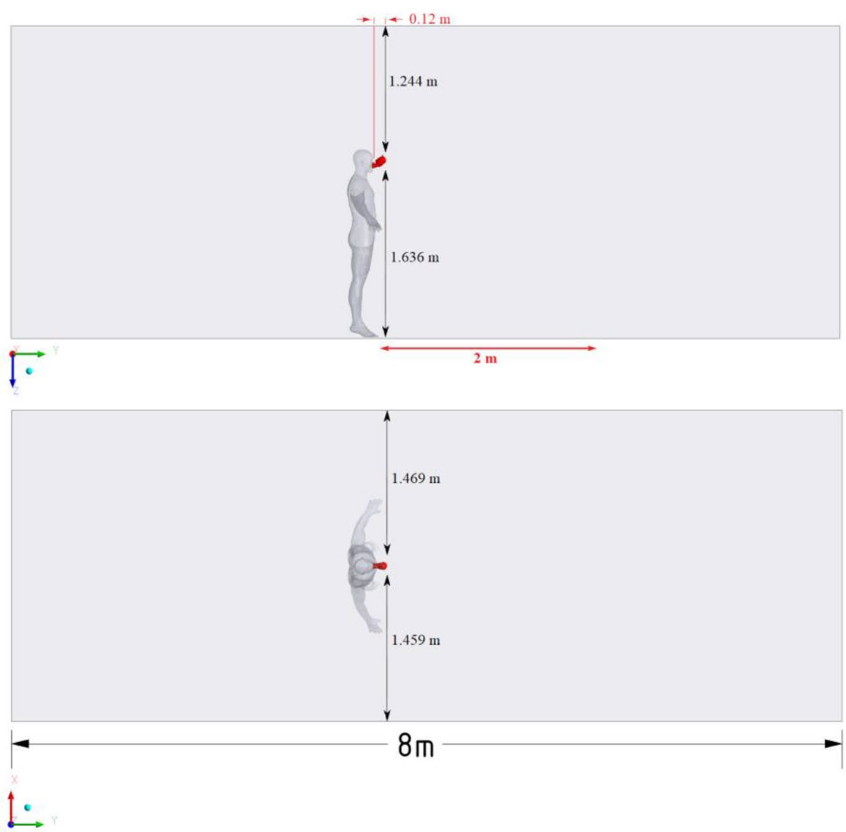


b) Time step=10.3 sec

Fig. 6 (continued)

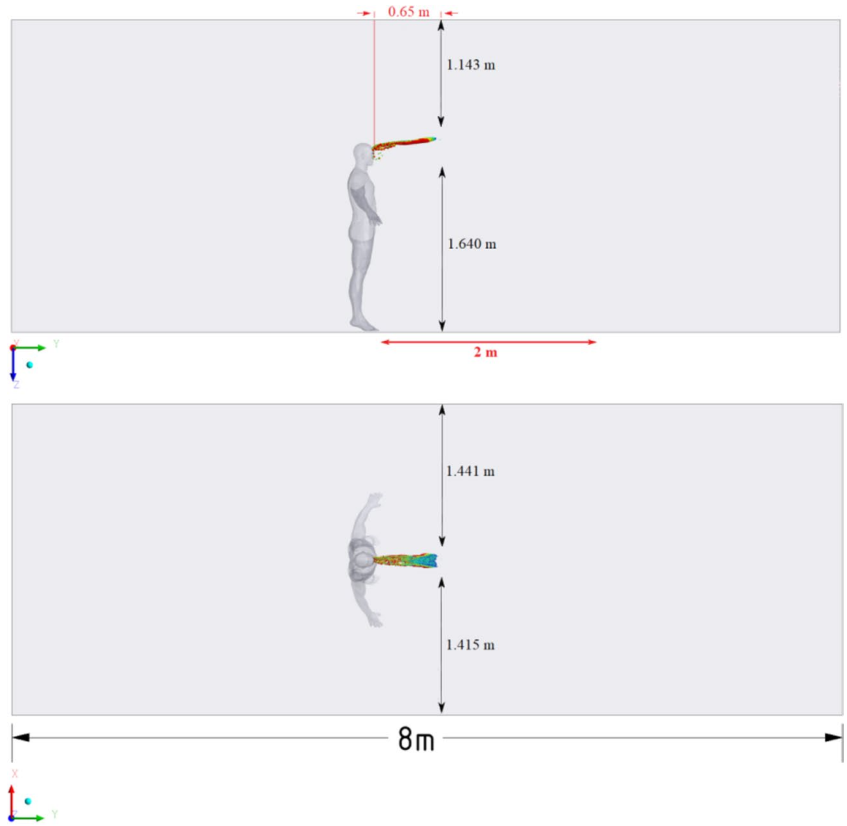


c) Time step=10.4 sec

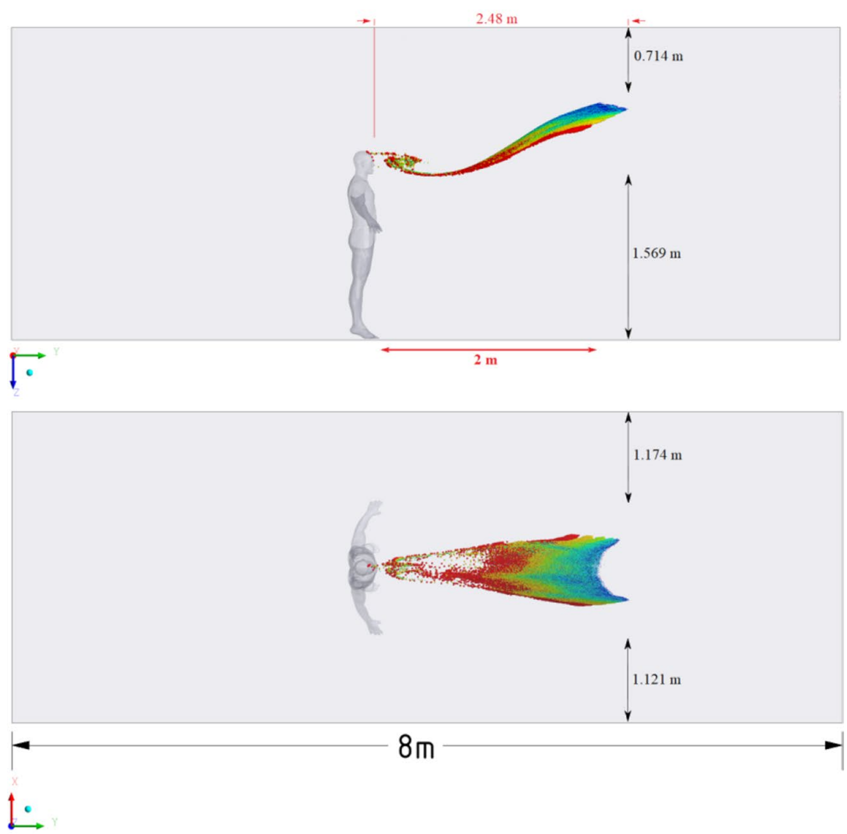


d) Time step=10.5 sec

Fig. 6 (continued)

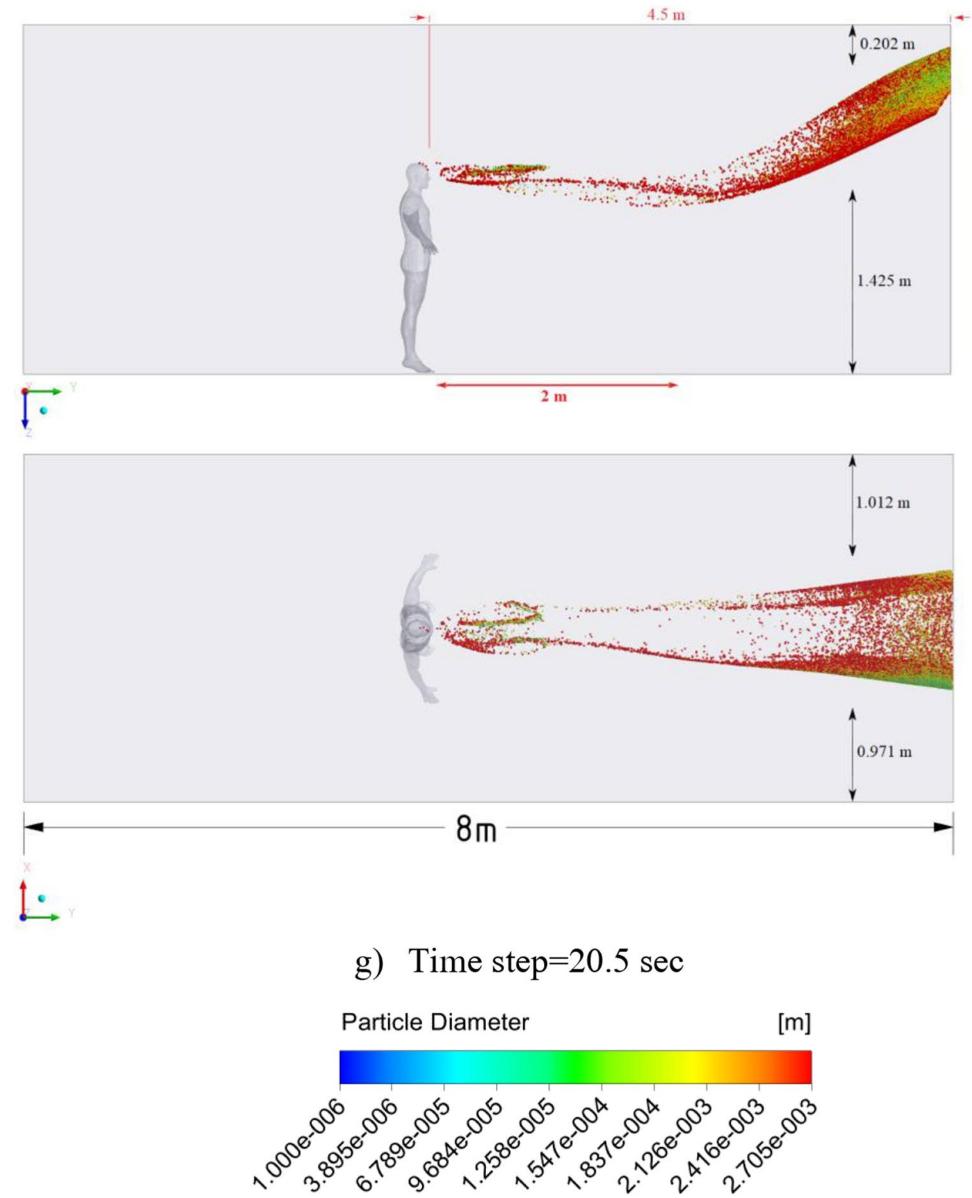


e) Time step=12.5 sec



f) Time step=16.5 sec

Fig. 6 (continued)

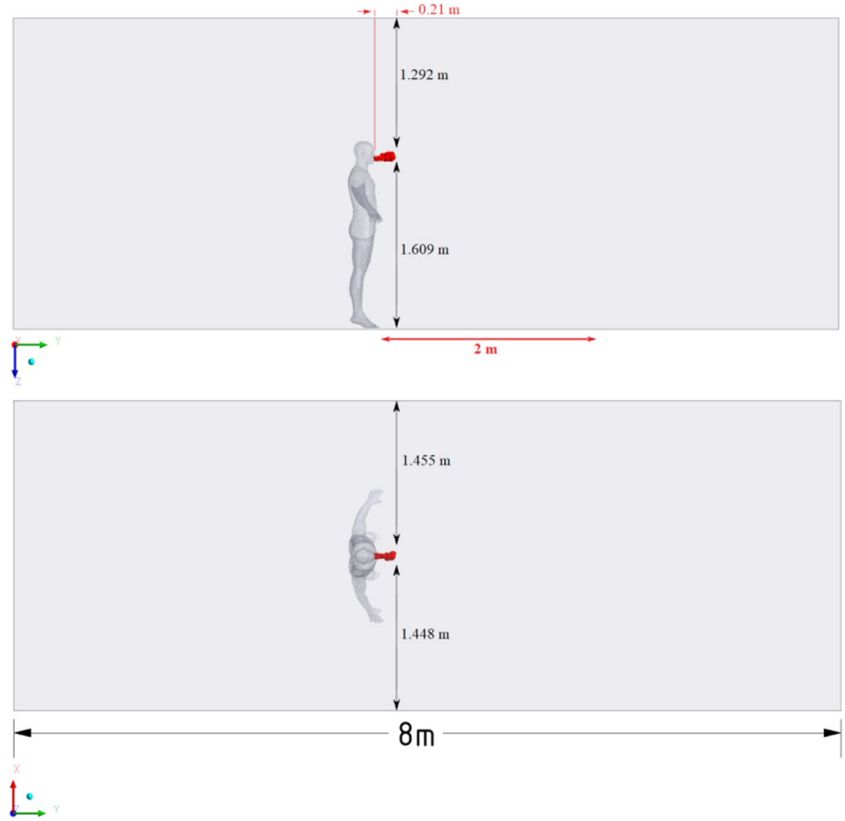


emanating from the human body significantly affects the particle propagation behavior and, despite the force of gravity, the particle rises upwards. At 16.5 s, it can be seen that around the person, due to the lateral inlet air flow and the temperature plume, small vortices are formed with particles from both sides, which move downstream. However, some particles remain in the center. After the process of coughing or sneezing during breathing, due to the high velocity value, some part of the particle remains around the person, and part of the ejected particle due to the influence of the lateral inlet air flow and the temperature plume spreads downstream.

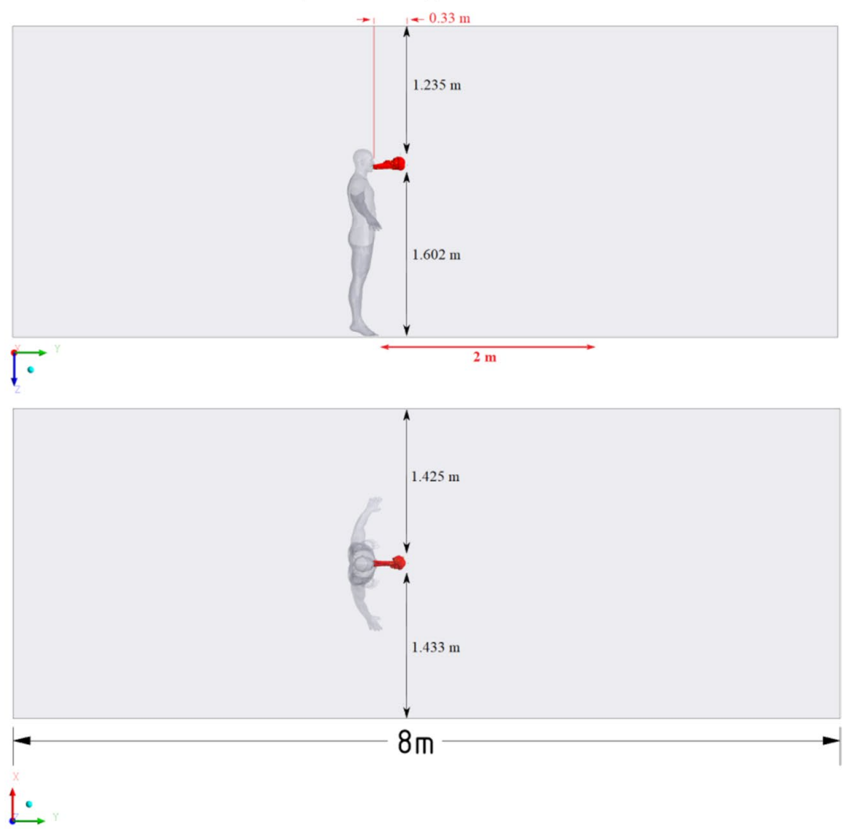
Figure 7 shows the spread of a particle during coughing, where the speed is V = 6 m/s. As the results show, due to the influence of the temperature plume, particles with small diameters are very strongly subject to lift and rise up, while slowing down and propagating the particles downstream. As a result, due to the influence of the lifting force, small particles rise up to 1.343 m.

At the same time, it should be noted that on the trajectory of the particle transfer, the lateral inlet air flow plays an important role. However, from the obtained results, it can be noted that at the initial moments of coughing and sneezing, the influence of the temperature plume and the lateral inlet air flow shows a minimal effect. However, if it compares the obtained results after the process of coughing and sneezing, one can observe changes in the distance of particle propagation. So in 10.5 s with simple breathing, the distance reaches 0.12 m, and with coughing up to 0.46 m, which is almost 4 times more.

Fig. 7 Particles, cough = 6 m/s open space with temperature 20.5 s. **a** Time step = 10.2 s, **b** Time step = 10.3 s, **c** Time step = 10.4 s, **d** Time step = 10.5 s, **e** Time step = 12.5 s, **f** Time step = 16.5 s, **g** Time step = 20.5 s

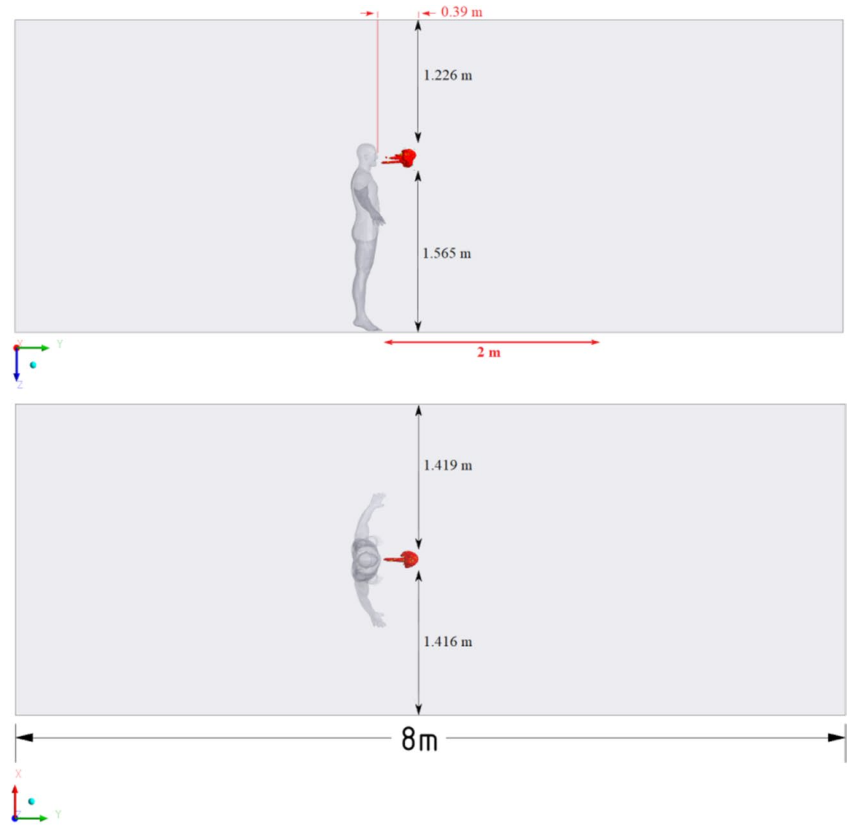


a) Time step=10.2 sec

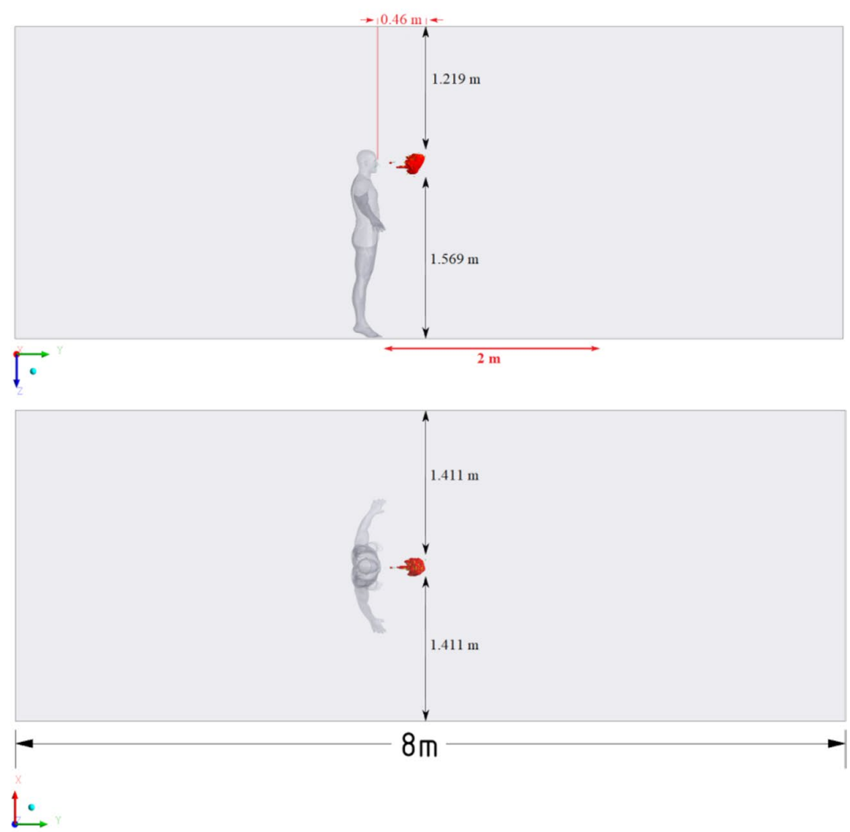


b) Time step=10.3 sec

Fig. 7 (continued)

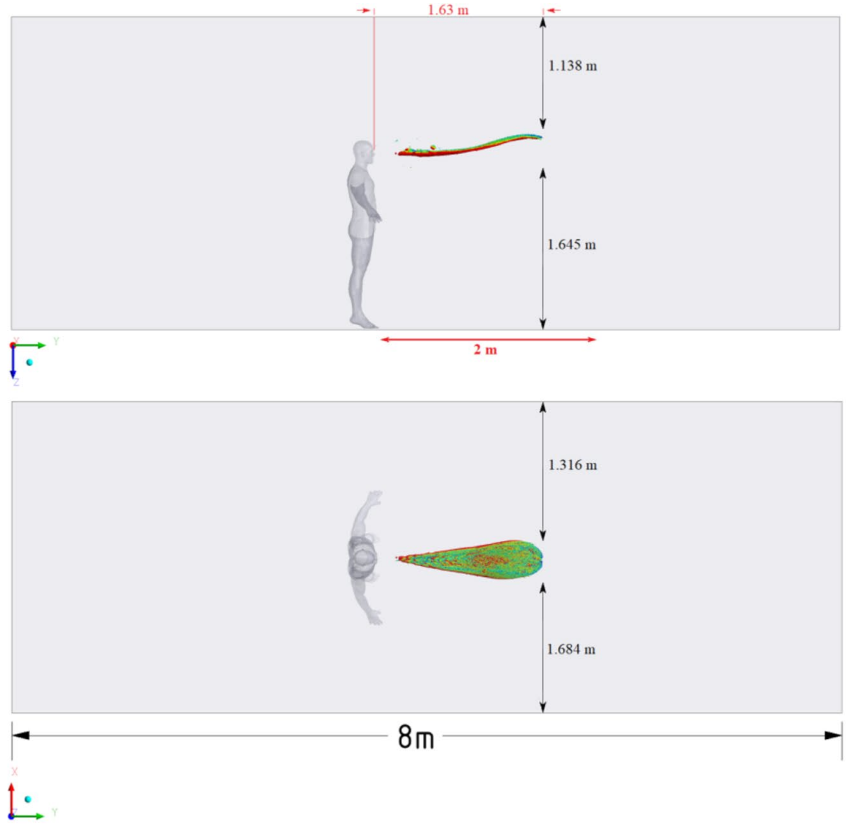


c) Time step=10.4 sec

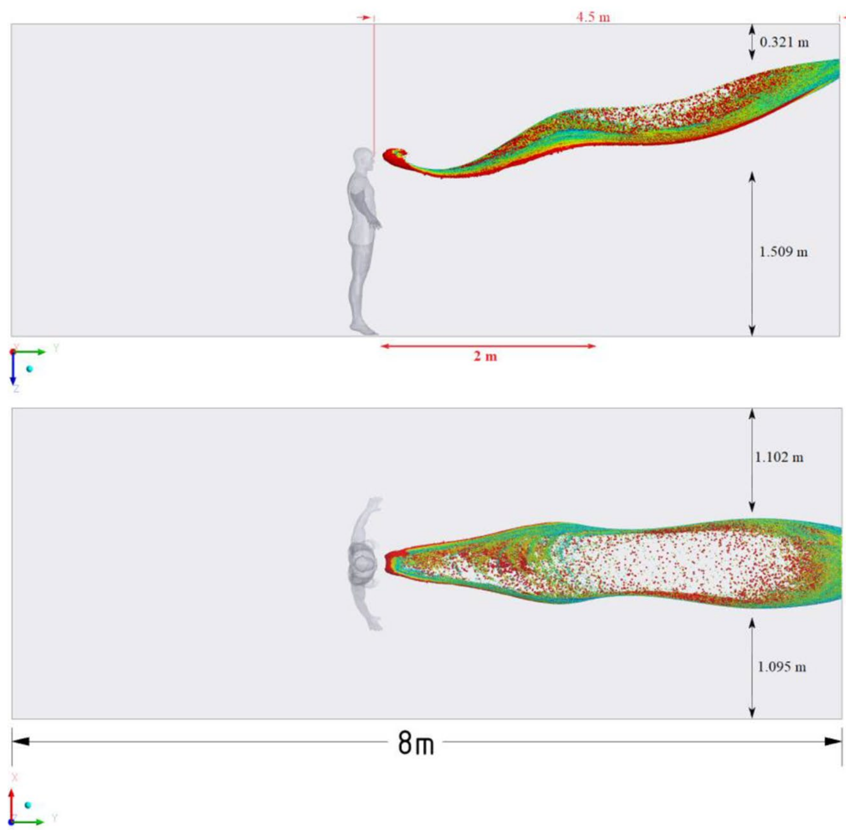


d) Time step=10.5 sec

Fig. 7 (continued)



e) Time step=12.5 sec



f) Time step=16.5 sec

Fig. 7 (continued)

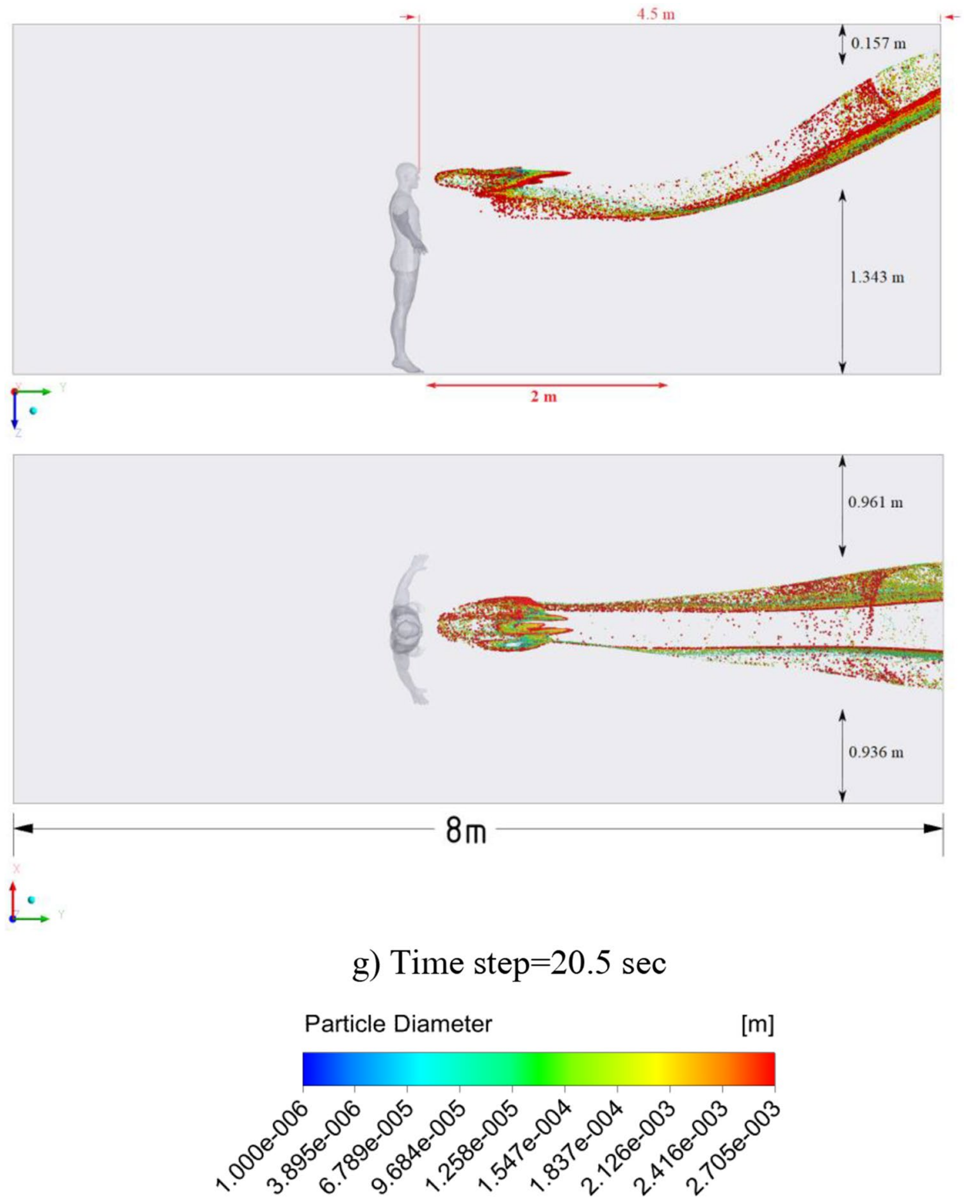


Figure 8 presents the results of particle propagation for the sneezing process at a speed of 20 m/s. The distance from a person during the propagation of a particle at 10.5 s reaches 0.99 m. At the same time, at the last moment, due to the lateral inlet air flow, it transports the particles much further. As can be seen from the obtained data, in the initial process of breathing, coughing, and sneezing, the influence of the crosswind and temperature plume has a minimal effect, while after this process, the further distribution of particles is very much dependent on the crosswind and temperature plume. It is also possible to note the spread of particles along the width depending on the lateral velocity and the presence of a temperature plume.

In all calculation scenarios, it can be seen that a large number of small droplets disperse along the jet air flow, while some small droplets diffuse upward easily depending on the temperature plume. The difference is noticed only when the emission of particles occurs for the process of respiration and larger particles after the release largely settle to the ground due to gravity.

Thus, from the obtained data, it can be concluded that most of the larger particles begin to settle due to gravitational forces, while small particles are transported over a long distance, which, in terms of airborne disease transmission from a person, poses a greater danger or risk. As a result, in the presence of a lateral inlet wind, the risk of

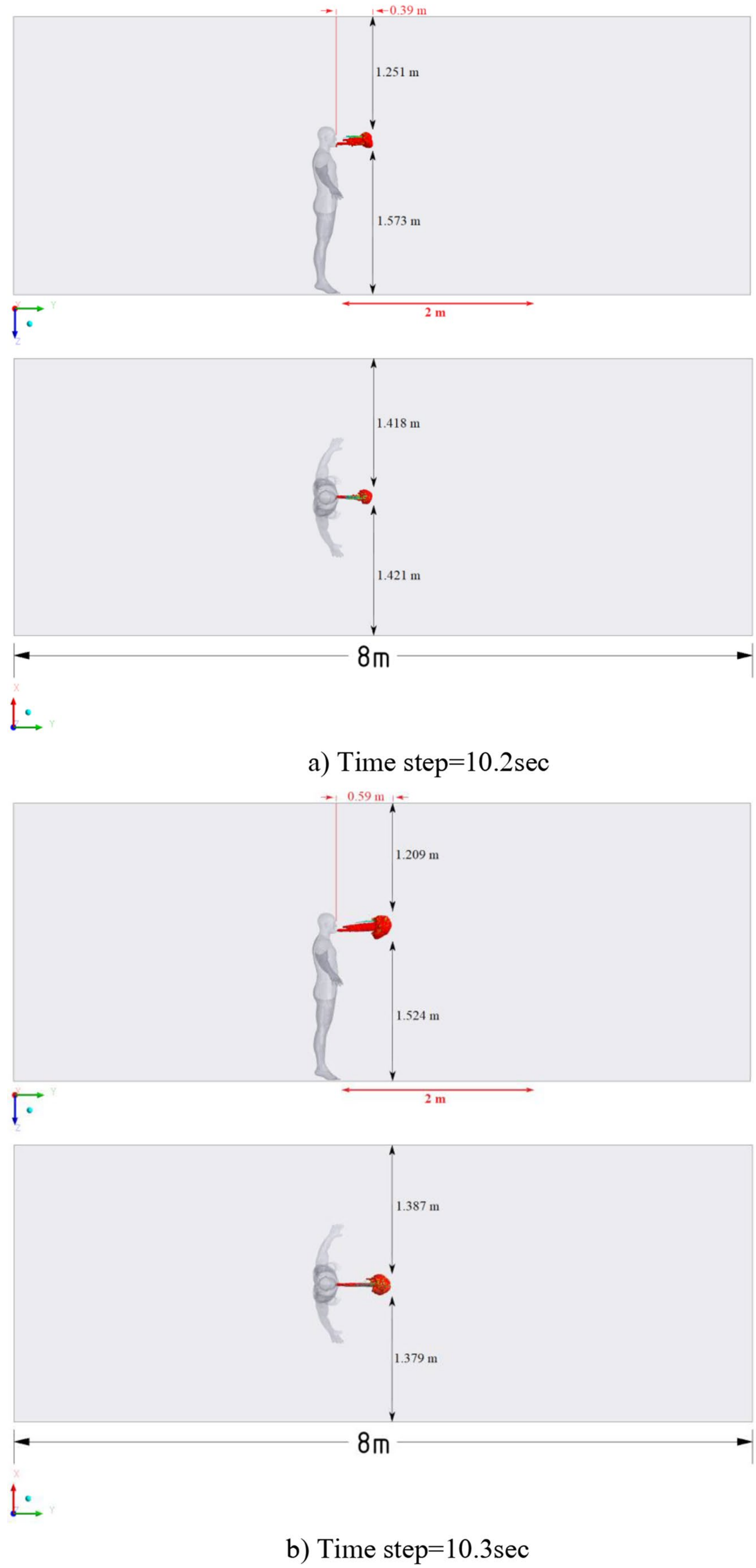
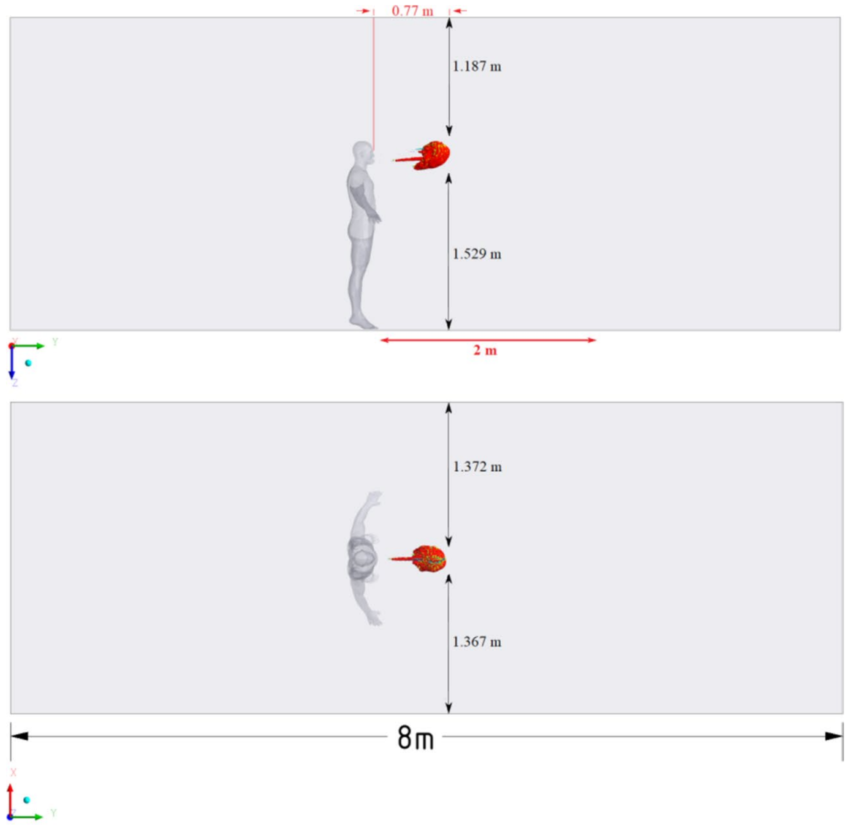
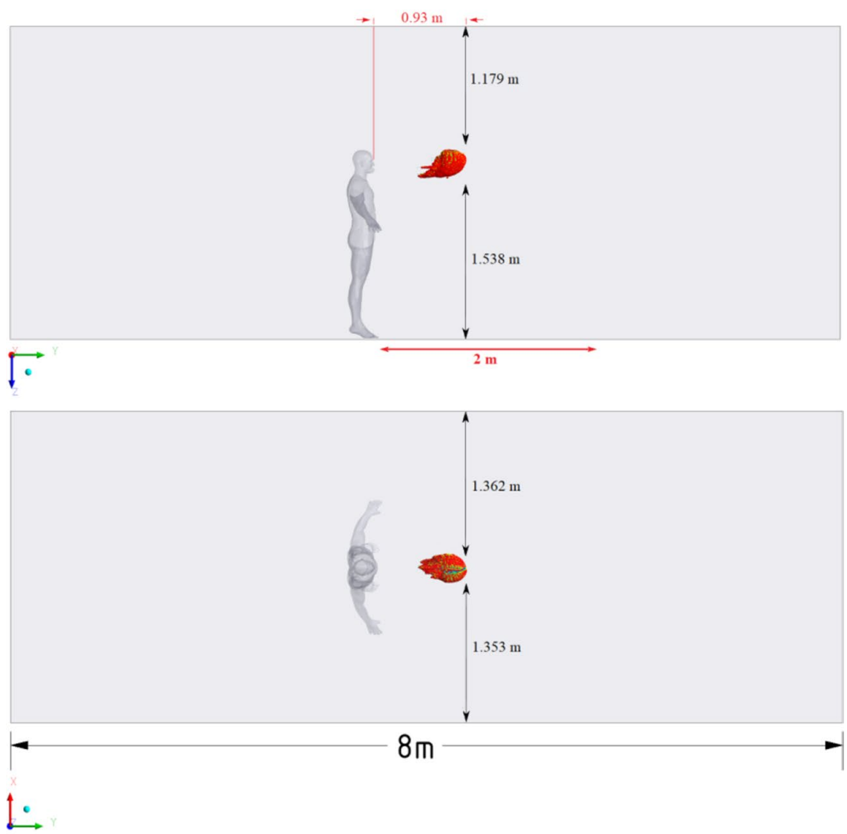


Fig. 8 Particles, cough = 20 m/s open space with temperature 20.5 s. **a** Time step = 10.2 s, **b** Time step = 10.3 s, **c** Time step = 10.4 s, **d** Time step = 10.5 s, **e** Time step = 12.5 s, **f** Time step = 16.5 s, **g** Time step = 20.5 s

Fig. 8 (continued)

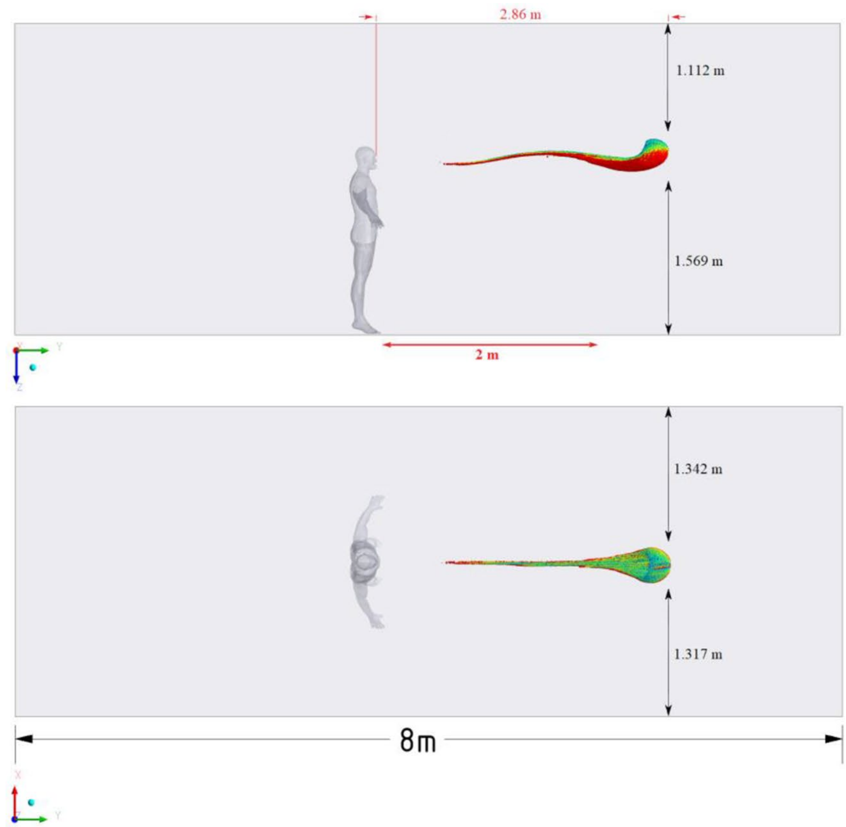


c) Time step=10.4sec

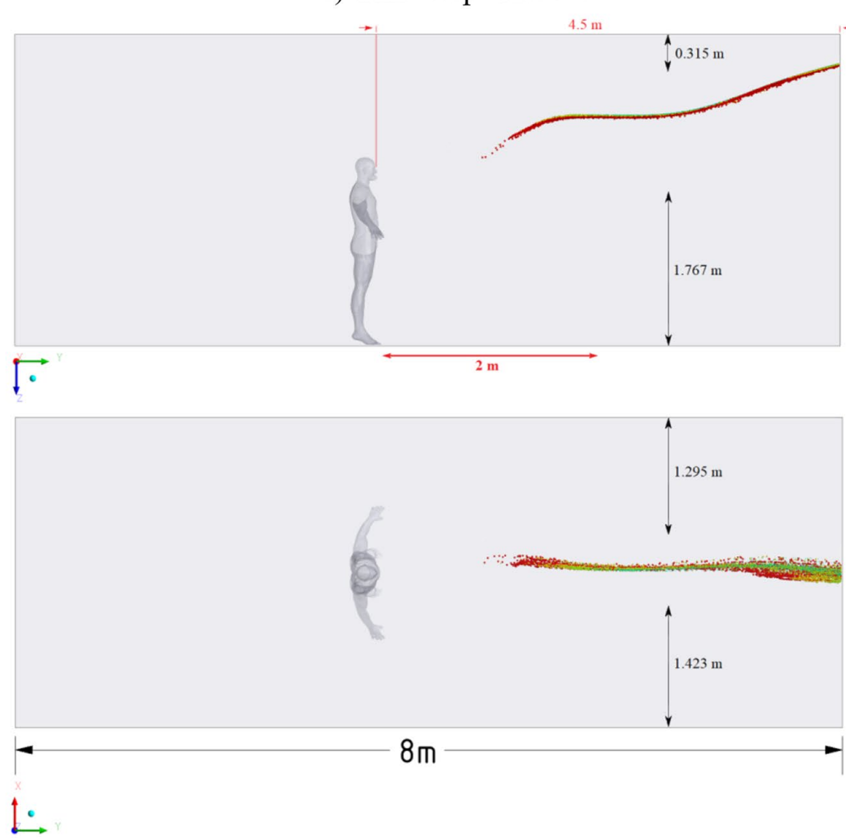


d) Time step=10.5sec

Fig. 8 (continued)

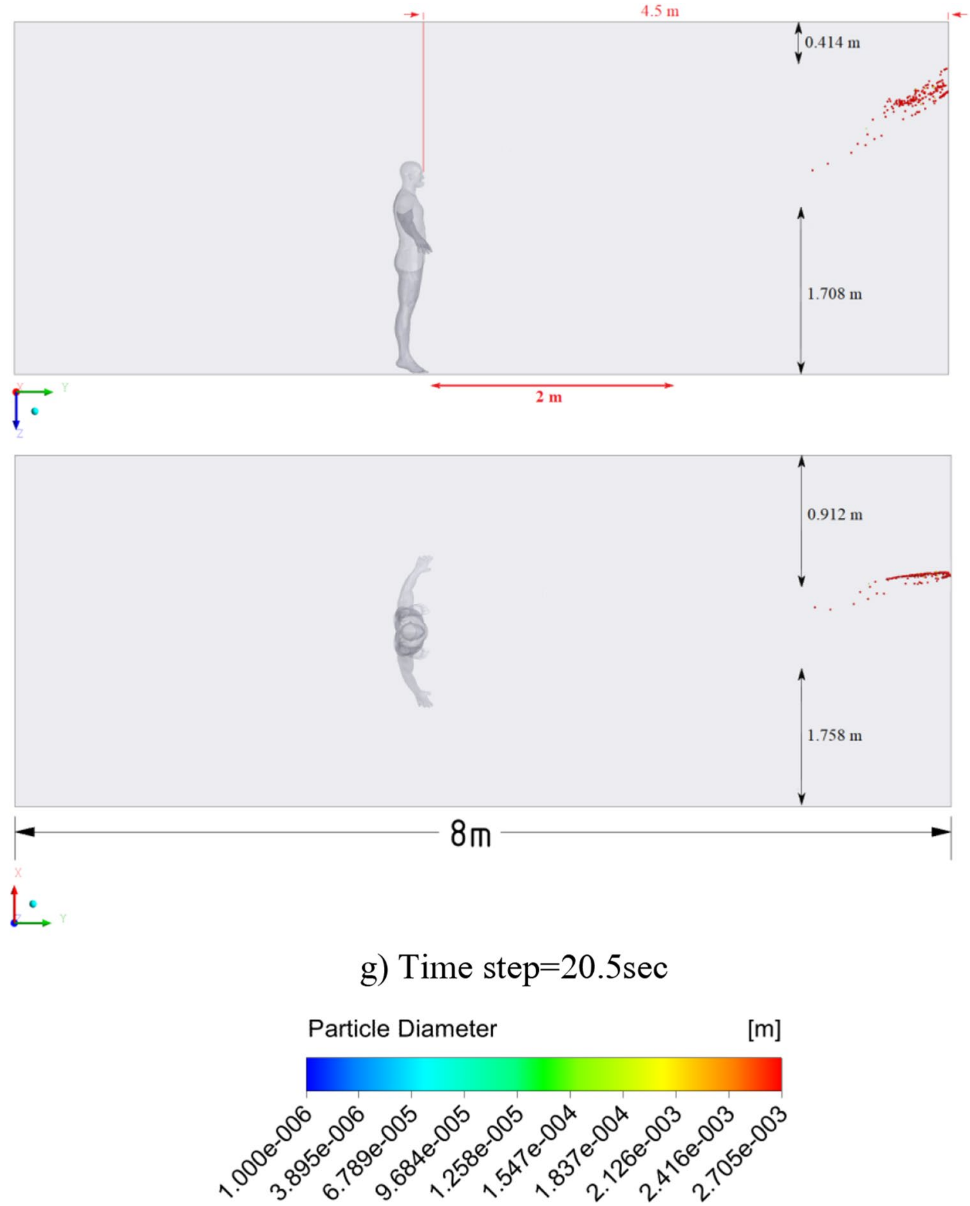


e) Time step=12.5sec



f) Time step=16.5sec

Fig. 8 (continued)



infection increases, since the particle transfer distance increases several times compared to without a wind event.

Figure 9 shows the range of particle propagation in open space, taking into account the temperature of the body and the floor surface. As the results show, under different modes of particle ejection, it significantly affects the transport of particles along the height. In the mode of particle ejection with a speed of 20 m/s and 1 m/s (case 1) in the last 20.5 s, the propagation trajectory is the same, the difference is only at the level h (height). It should be noted that due to the speed of breathing or coughing, the settling of particles, taking into account the temperature, is approximately the same, except for the sneezing option.

From the results, it can be seen that due to the lateral air flow, small vortices are formed behind the human body, which led the particles to a non-standard movement. These small vortices are formed due to the fact that the lateral air flows around the human body, while forming vortex movements behind the human body. It must be taken into account that a process of dissipation occurs, which leads to random motion. It can also be observed that due to the vortex motion in the central region behind the human body, reduced velocities are observed. In this case, the particles due to the vortex motion are brought into the external flow of motion. After these particles begin to move downstream, so that these particles are almost indicators of air flow. However, it should be noted that inertial particles are mainly collected in areas with low vorticity. At the same time, particles with greater inertia have relatively little effect on vortex movements and are mainly subject to mainly the direction of movement of the

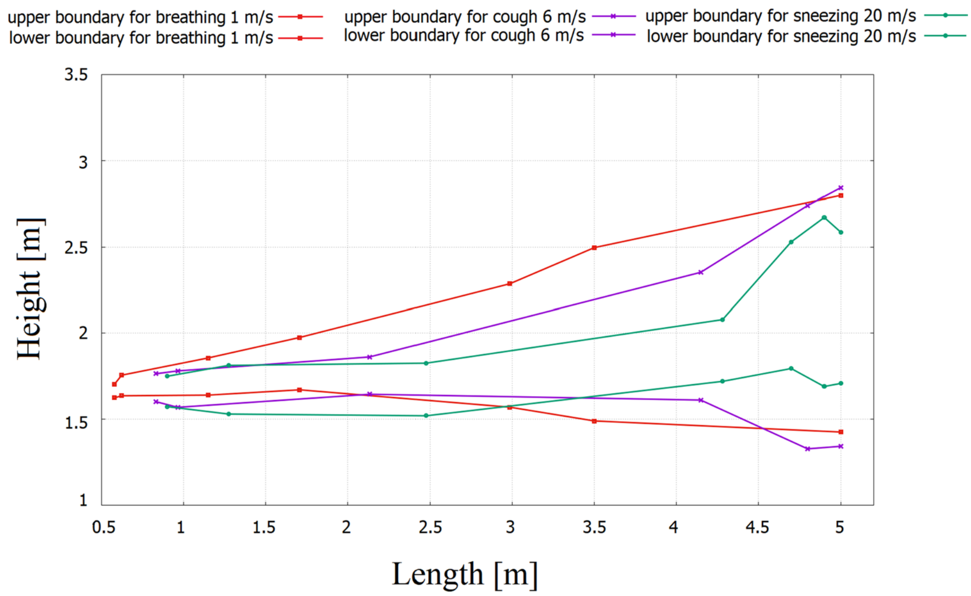


Fig. 9 Particle propagation range (scenarios 1–3)

air side flow. It should also be noted that the particles move along a circular path with an almost equal radius. However, this process will not last for a long time, since an actively dissipative process takes place behind the human body. Due to this downstream phenomenon, vortex motions are generally not observed and particles move along the air flow.

According to the obtained data, it can be concluded that when taking into account the temperature of the human body and the temperature of the ground surface in the outdoor, by sneezing or coughing, particles can be transported to a much greater distance compared to not taking into account the temperature effect. To reduce the risk of infection, it is recommended not to stand or talk to people face to face in the direction of the wind, as particles spread much faster. Taking into account the temperature of the human body and the temperature of the ground surface in the outdoor, as well as taking into account the direction of the wind, which is directed along the distribution of particles, during the process of coughing or sneezing, particles can spread in 2 s in different ways, so for breathing 0.65 m, for coughing 1.63 m, for sneezing 2.86 m. It should be noted that in order to reduce the risk of infection, not only these factors play a much role, but also the time period of influence in which a person is located.

Conclusion

In this work, computational fluid dynamics was used to investigate the effect of body temperature and the heating of the earth's surface from sunlight on the transport and dispersion of particles produced by coughing or sneezing in open space. Computational calculations have been made of the emission of particles during normal human breathing, sneezing, and coughing. The verification of the model for test problem is in good agreement with the experimental data, which was described in details in the papers (Issakhov et al. 2021a, b; Issakhov et al. 2022a, b, c) and it can be said that the entire mechanism is effectively simulated.

Based on the results of a numerical calculation on the transfer and distribution of particles or droplets formed during normal breathing, sneezing, or coughing in open space, taking into account the temperature of the human body and the floor surface, the following conclusions were made: during a normal breathing process, particles or droplets can be transferred only for short distances, when sneezing or coughing, the particles are carried almost the same distance, the difference is only in the range. Also, the presence of body temperature and the floor surface strongly influences the propagation of the particles and the thermal plume is completely destroyed due to the speed of the incoming wind. However, the presence of temperature at high ejection velocities transport particles over a much greater distance.

It can be seen, even with simple breathing and taking into account the body temperature, there is a risk of infection. Thus, concluding it was vital to keep a distance between people in the open air in order to reduce the risk of infection. According to the results of the study, it is recommended not to stand or talk to people face to face in the area in the direction of the wind in order to reduce the risk of infection, to comply with quarantine measures and at the same time maintain social distance. At the initial time, the distance of particle propagation depends on the mode of breathing, since after the process of coughing or sneezing in 2 s, the particles can spread in different ways, so the distance for simple breathing can be noted 0.65 m, the distance for coughing is

1.63 m, the distance for sneezing is 2.86 m. As can be seen by taking into account the effect of temperature of human and the heating of the ground surface from the sun's rays in an open space for the process of sneezing, a 2-m social distance may not be sufficient. It should be added that the obtained results do not take into account some influencing factors, such as humidity, evaporation of droplets, etc. Despite this study considered complex phenomena, such as the transfer of a particle in open space, taking into account the temperature of the body and the surface of the ground prevent the transmission of infectious diseases more realistic conditions.

Author contribution Alibek Issakhov has made the conception, designs of the study, writing the manuscript and interpretation of data. Perizat Omarova and Aizhan Abylkassyova have made simulation, visualization, analysis, and interpretation of data.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Consent to participate Not applicable.

Consent for publication All authors agree to publish.

Conflict of interest The authors declare no competing interests.

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