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Predicting airborne pathogen spread indoors

Whenever we exhale, we release tiny droplets which may contain pathogens. Researchers at the University of Birmingham have used ARCHER2 to model how the airborne transmission of these droplets is affected by factors such as ventilation and heating. Understanding this is key to making indoor spaces more resilient and preventing large-scale spread of diseases such as COVID-19, tuberculosis or measles.

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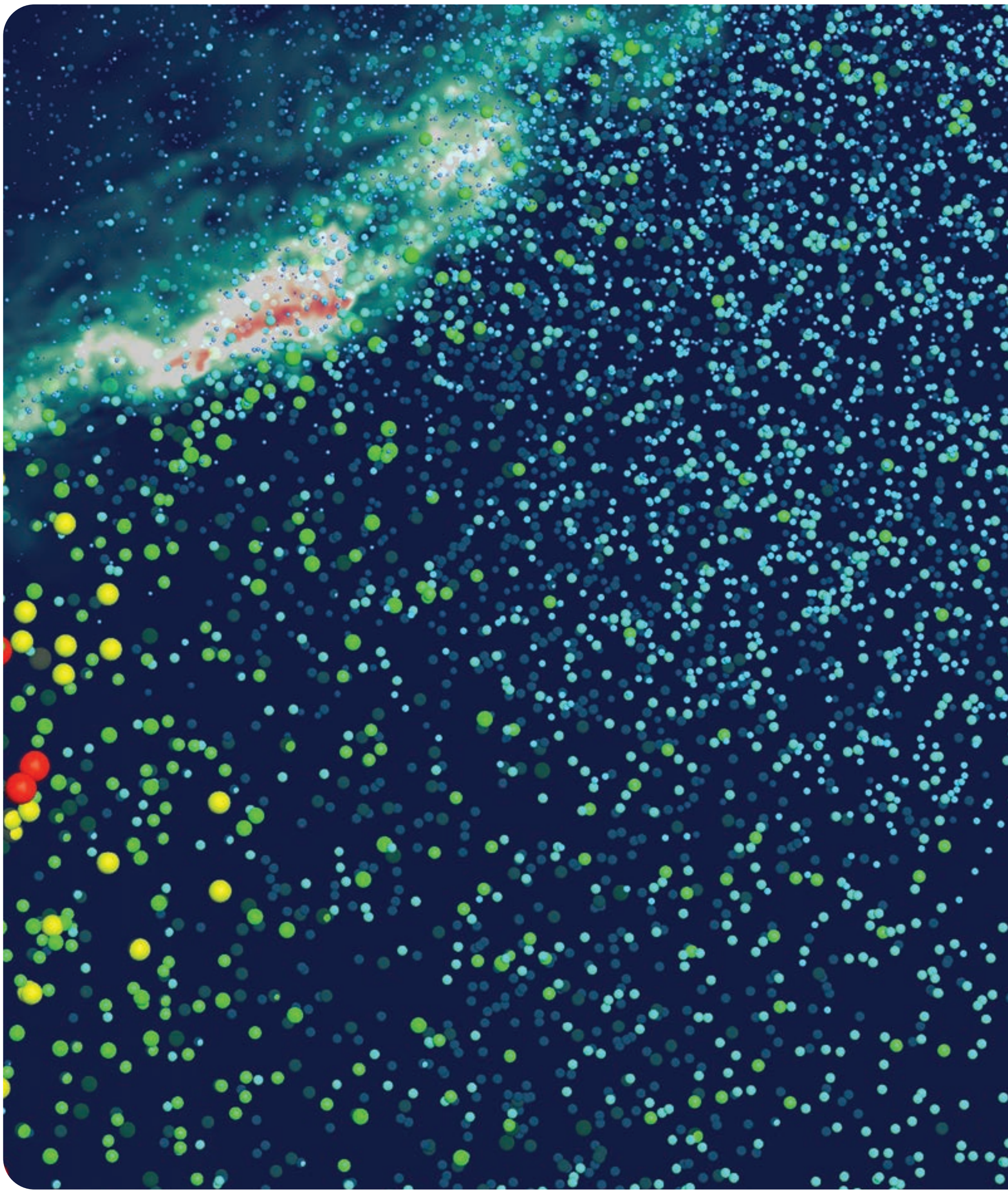

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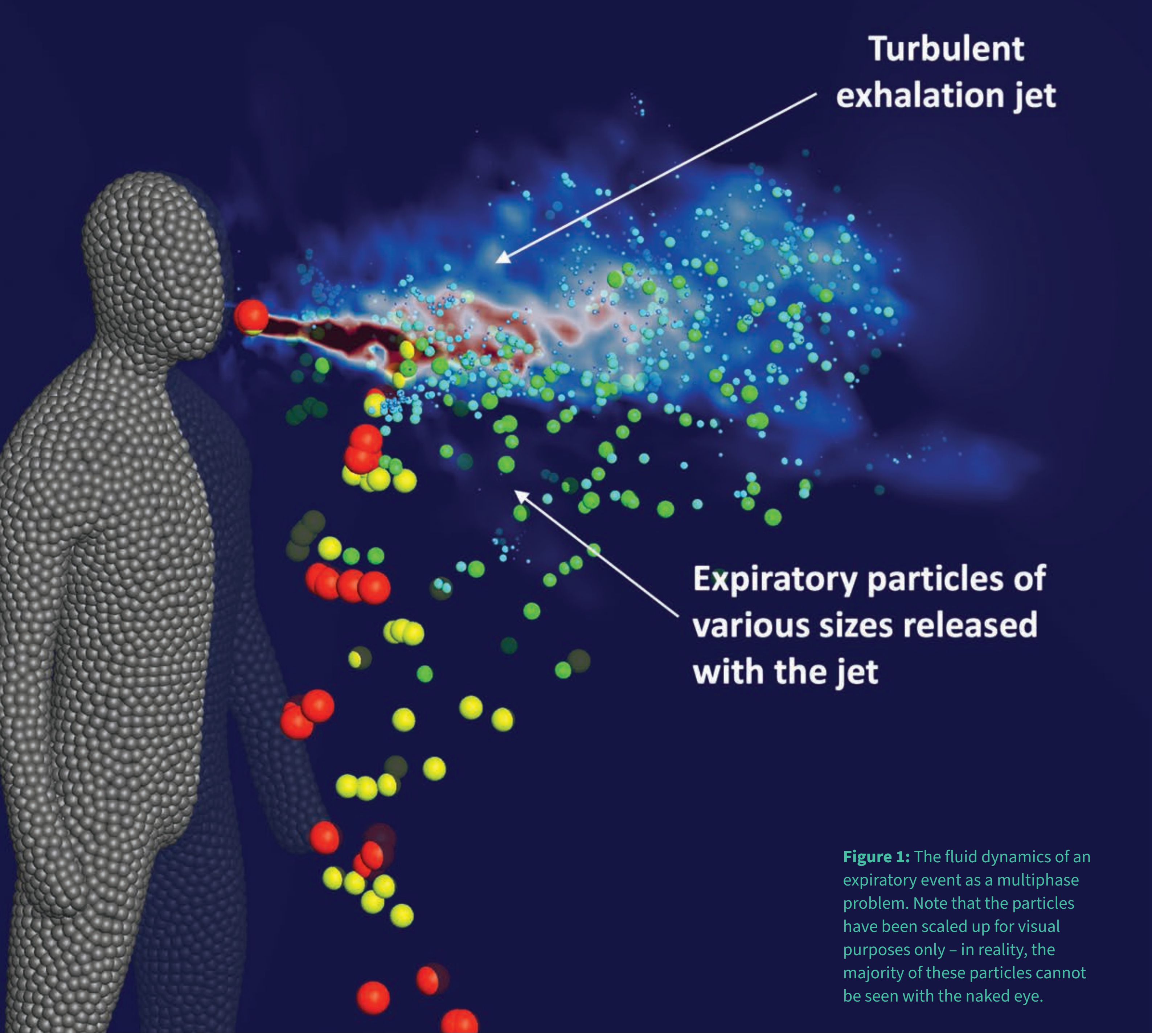

Figure 1: The fluid dynamics of an expiratory event as a multiphase problem. Note that the particles have been scaled up for visual purposes only – in reality, the majority of these particles cannot be seen with the naked eye.

During any expiratory event – when we exhale air from our lungs – we release warm, CO2-rich air and droplets of various sizes (Figure 1). These particles can be very small, with their diameter measuring in the order of one millionth of a metre (1 µm). Some of these particles can be as small as 1 µm or even less, while a few larger droplets may measure 100 µm or more in diameter. The COVID-19 pandemic showed the importance of understanding the modes and mechanisms of respiratory pathogen transmission and the factors affecting them, as infections occurred in many different indoor spaces and events. However, COVID-19 is not the only pathogen that can be transmitted via expiratory particles; diseases such as tuberculosis or measles have also been shown to spread through airborne transmission whereby expiratory particles are transmitted from person to person via the air. Although larger droplets can potentially carry a higher number of infective components, they can also be more easily avoided with social distancing and masks. However, very small droplets (often referred to as aerosols) have infective power too, as they linger and get trapped in air currents and can accumulate in indoor environments, in addition to being completely invisible. The fluid dynamics of such expiratory events are complex – understanding how all these factors (e.g., ventilation, heating, social distancing) affect the spread of airborne pathogens and their accumulation in different indoor scenarios is key to making these spaces more resilient and preventing large-scale spread of diseases.

To understand and explore how various parameters affect the fluid dynamics of respiratory pathogen transmission, researchers at the University of Birmingham used the computational power of ARCHER2 to run high-resolution numerical simulations of expiratory particle transport during speaking, using an in-house code, MultiFlow3D, which has been developed to include the effect of relevant physical phenomena related to transport of expiratory particles. Realistic inputs were used to model expiratory events in different indoor scenarios; the code solves the relevant equations for 3D fluid motion and tracks each individual particle in both space and time. As a result, a detailed concentration map of airborne pathogens is produced, which can be used to determine and quantify the spatiotemporal distribution of these pathogens and the infection risk under different indoor conditions. The novelty of this work lies in the ability to produce these maps while considering the turbulent mixing of particles as they spread, by using high-resolution large-eddy simulations to resolve the most relevant scales of motion in the flow field. Turbulence is an important driver of particle and pollutant dispersion, and the simulations carried out by the team can provide accurate results by capturing more of the detail representing the real-life motion of these complex events instead of relying on average flow data. This becomes even more important as the complexity of the flow problem increases. To model the spread of airborne pathogens at room scale, these high-resolution simulations require a large amount of computational power, as they need to be run for long enough to gather meaningful datasets. Having access to the large number of cores and memory provided by ARCHER2 is therefore crucial to make this work possible.

The researchers at Birmingham University first focused on the effect of temperature on the transport of exhaled droplets whilst a person speaks in a room. They investigated how these expiratory particles behave when exhaled into a room with uniform temperature, compared to a room with different strengths of thermal stratification. In reality, indoor spaces are rarely at a constant temperature, particularly in summer and winter, due to heating. Instead, the warmer air (coming from radiators, our own bodies, the kitchen, etc) moves upwards, while the heavier cold air (coming from outdoors or other sources of ventilation) sinks, creating differences in temperature that can easily surpass 1 degree per metre in the vertical direction. This is called thermal stratification. An image showing the findings from one of these simulations was selected as both the Winning Image and the Overall Winner of the ARCHER2 Image and Video Competition 2022 (Figure 2).

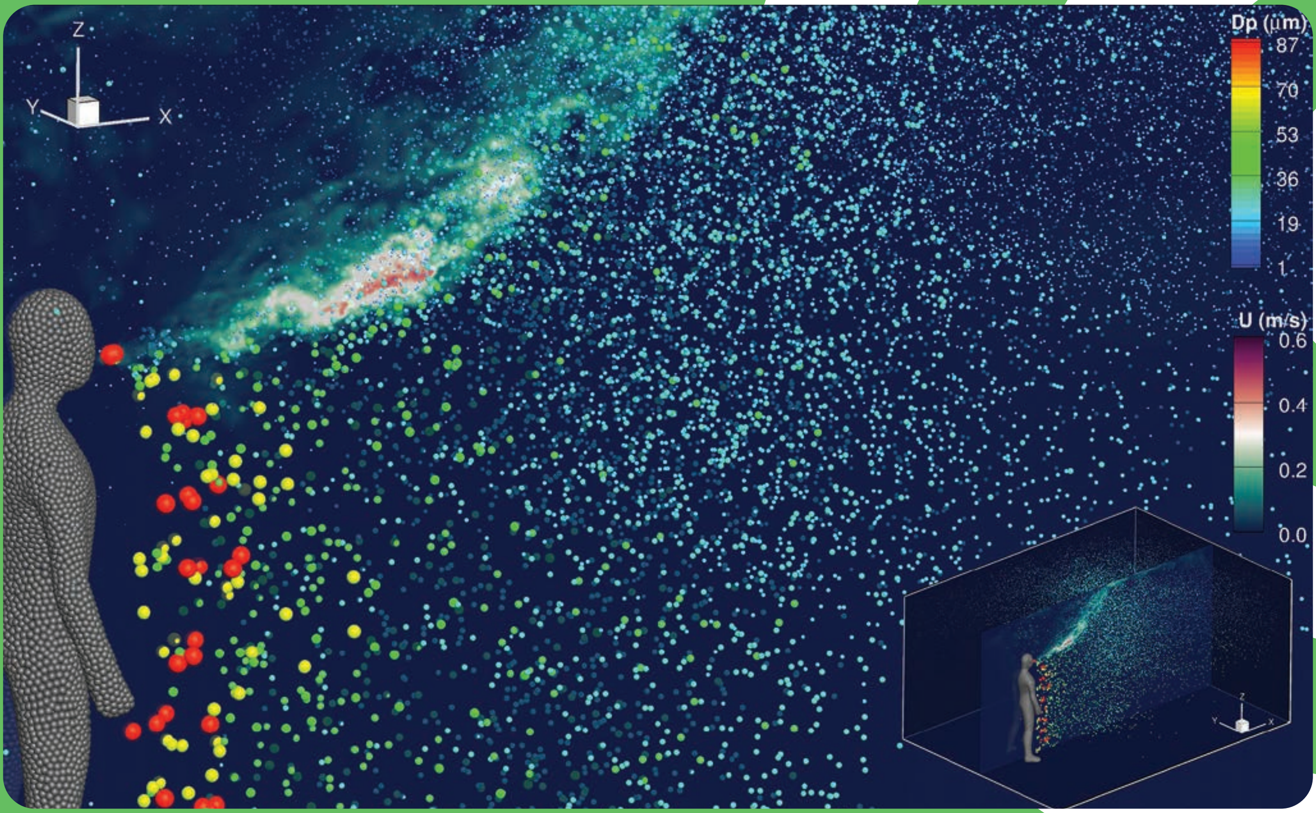

Figure 2: Close-up view of expiratory particle dispersion by turbulent exhalation jet during speaking in a room with uniform temperature of 20°C.

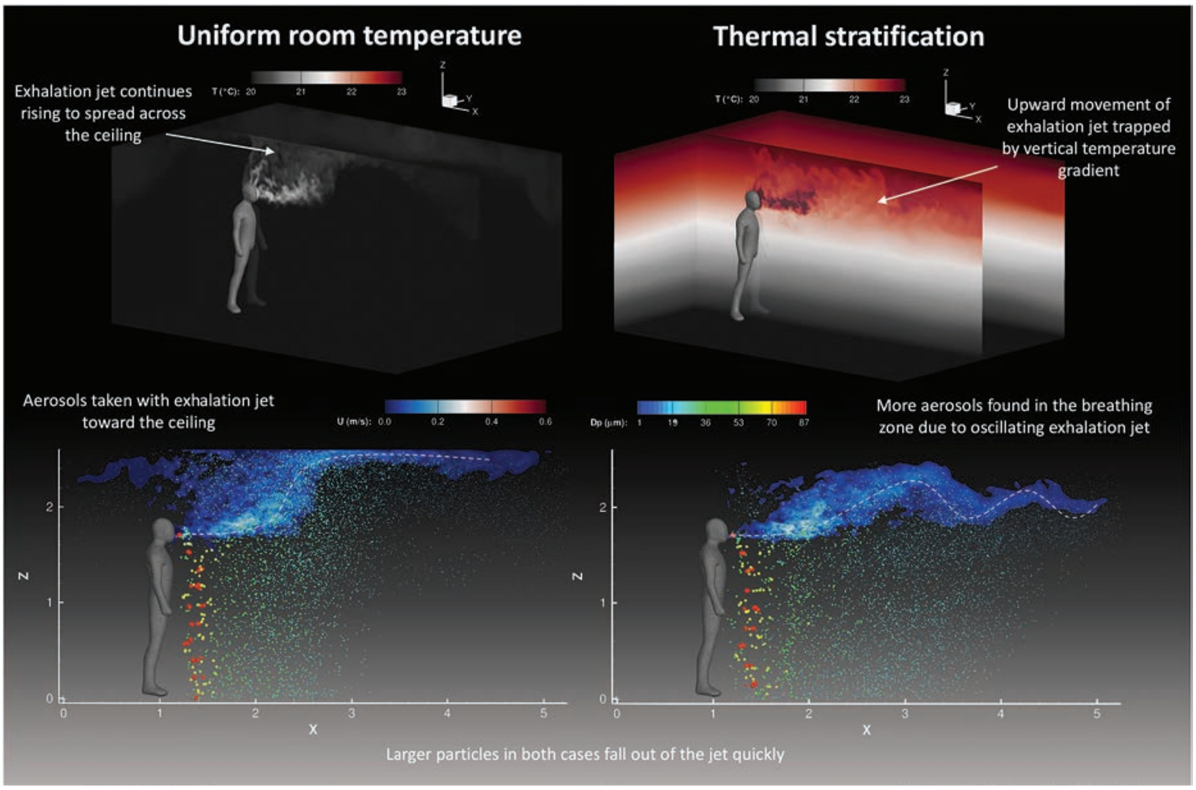

Figure 3: Influence of changes in room temperature on transport of expiratory particles via the exhalation jet. Left panel shows a room with uniform temperature and right panel shows a room with a vertical temperature gradient of 1°C/m.

The results of this research show that larger expiratory particles are unaffected by changes to room temperature, while the dynamics of smaller particles are noticeably different, as thermal stratification leads to an increased concentration of aerosols in the breathing zone (Figure 3).

The findings from these simulations will contribute to addressing the current gap in the knowledge on how airborne pathogens spread in different indoor scenarios, and how to best mitigate this with targeted evidence-based solutions for a particular indoor scenario to reduce risk of infection. Furthermore, the outcomes of this research could also be applied beyond COVID-19 to the spread and tracking of other indoor air pollutants.

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Reference:
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About ARCHER2

Archer2 is the UK's National Supercomputing Service, a world class advanced computing resource for UK researchers. ARCHER2 is provided by UKRI, EPCC, HPE and the University of Edinburgh. ARCHER2 is the latest in a series of National Supercomputing Services provided to UK researchers.