Engineering CFD Predicts Effects of Ventilation and Aerosol Droplet Size on Associated Virus Spread

by

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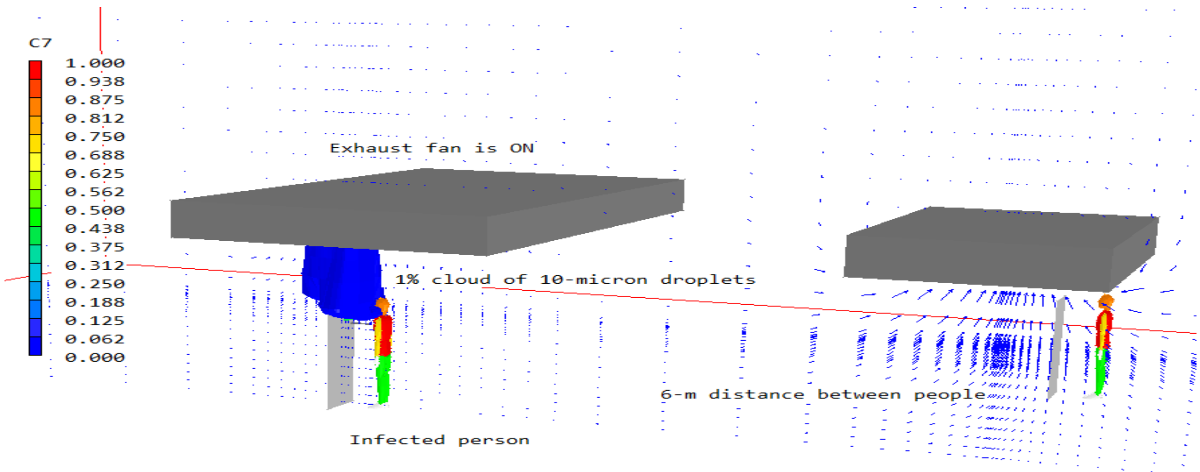
By extending PHOENICS/FLAIR, a special-purpose engineering software for Heating, Ventilation and Air Conditioning (HVAC) systems , Applied Computational Fluid Dynamics Analysis (ACFDA) has been able to make an important step towards the development of Computational Fluid Dynamics (CFD) computer model for specialized human environments with special emphasis on predicting the virus spread by aerosol clouds emerging from their occupants. Employing this model, a detailed multiphase flow and aerosol particle distributions can be economically predicted by engineers with little or no special training. This will permit the computational assessment of epidemiological safety of built occupied environments prior to construction of HVAC systems, support the design decisions for changing the existing and to-be-constructed projects and reduce the cost and time-scales of testing and appropriate equipment procurement for workplaces and public spaces. It will enable governmental agencies to develop proper health and safety mitigation measures aimed at reducing a possible virus spread after relaxing the lockdown restrictions.

A major concern with current COVID-19 dynamics is that a widely accepted 2-m separation distance could be insufficient. Also, relaxing the lockdown restrictions might cause increases in infections. Moreover, the existing HVAC systems need to be evaluated to be adequate for preventing the virus spread in public spaces.

The purpose of this article is to provide the reader with information about reasonably simple yet realistic and comprehensive approach by which he or she may mathematically predict the spread of infected aerosol in built occupied environment with account for the effects of ventilation and sizes of aerosol particles. It is proposed here to apply a CFD technique, in its engineering multi-physics mode, to model the spread of virus by aerosol clouds emerging from human occupants. A detailed CFD modeling of workplaces and public spaces with a specified HVAC system, barriers, safety screens and people's locations would be helpful in decision making for developing and implementing the proper health and safety mitigation measures.

The aerosol model employed in the demonstration case below allows to simulate movement and locations of multiphase clouds (air with liquid droplets) based on industry-standard and well established CFD technique for prediction of flow distributions. Additionally, the conservation equations for mass fractions of various droplet size groups are made size dependent with an account of liquid-air mixing, evaporation and condensation. Basic details of model theory and its validation can be found elsewhere.

The model has been applied to CFD predictions of aerosol-attached virus spread in a typical workplace occupied by two persons depicted on **Fig. 1-3** below in red and green working clothes. The workplace is a rectangular room ventilated by two exhaust fans shown as grey boxes. It is assumed that the 10-micron and 100-micron droplets are capable of virus spreading from an infected (left) person towards an unaffected worker hiding behind the safety screen at the right hand side of the room. The aerosol source has been placed at the face of infected person. Its flow rate was taken from a reasonable estimate of typical time-averaged value. Shown in **Fig. 1-3** are predicted 3D iso-surfaces (blue clouds) of variables C7 and C8. These are the relative mass fractions (with respect to their values at the source) of 10-micron and 100-micron droplets respectively. Predicted are two scenarios - one for left exhaust fan ON, and another for left exhaust fan OFF. The displayed 1% and 0.1% clouds contain gas volumes with corresponding C7 and C8 values larger than 0.01 or 0.001. The arrows depict the velocity vectors of the air-droplet flow.



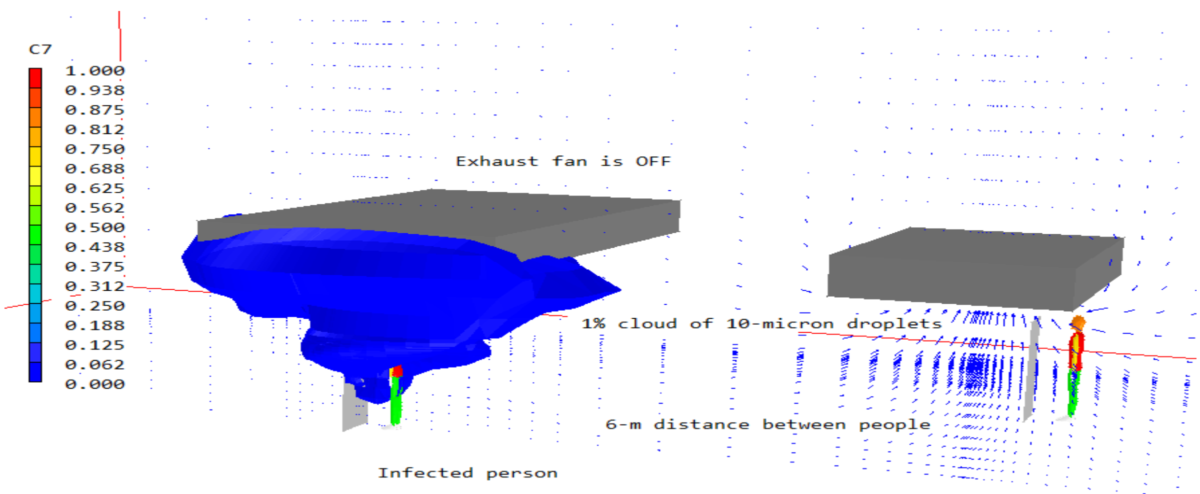


Fig. 1 Spread of cloud of 10-micron droplets with and without ventilation

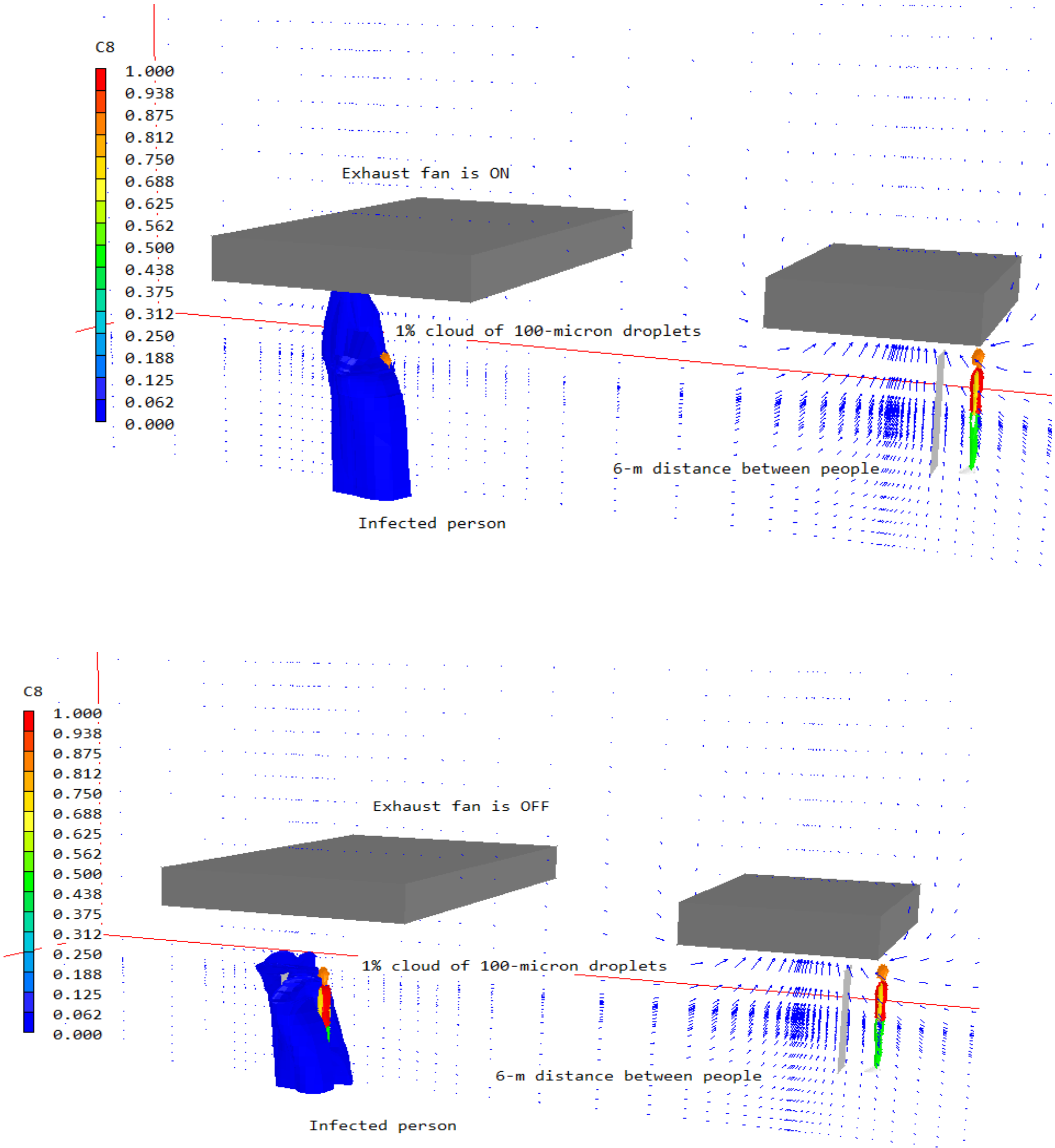
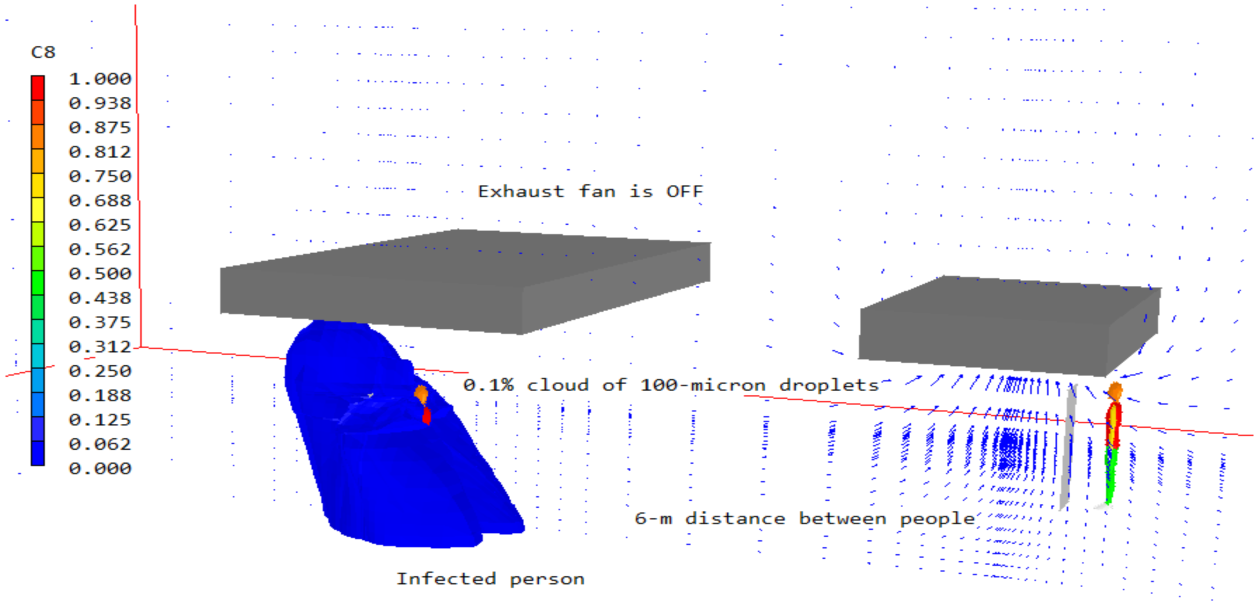


Fig.2 Spread of cloud of 100-micron droplets with and without ventilation



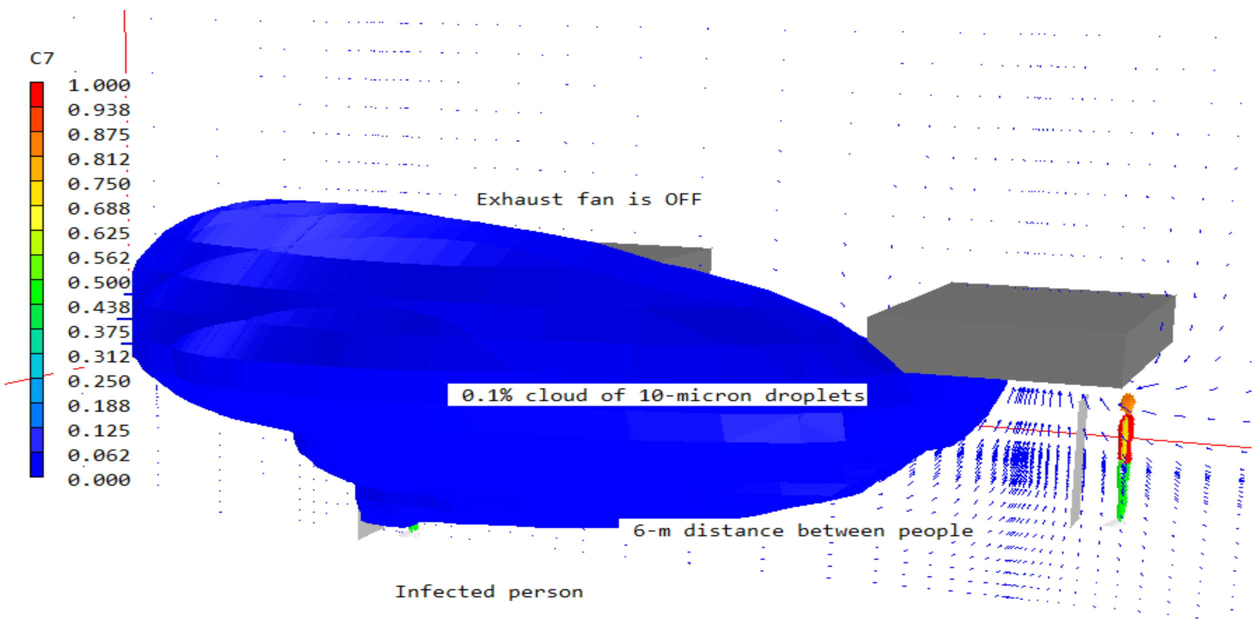


Fig.3 Spread of 0.1% clouds of 100-micron and 10-micron droplets without ventilation

The detailed analysis of the predicted distributions pictured above is left to the interested reader. That and the inspection of the rest of predictions obtained appear to the present authors to justify the following important conclusions: (a) all the results generated are qualitatively realistic and quantitatively credible; (b) they have been attained easily and economically; (c) the computed predictions give very useful insight into the influences of ventilation of built in environments and sizes of aerosol particles on locations and sizes of aerosol clouds and consequently on spread of the virus attached to them.

Based on these predictions and successful validation of underlying method reported elsewhere one can begin using engineering CFD in the development of safe designs of ventilation systems. The main advantage of this approach is that it allows engineers to evaluate new design alternatives in a fraction of time that is usually required with more sophisticated and consequently more computer power hungry and mentally demanding CFD software. All the HVAC engineers have to do is to change the parameters of the model, such as geometry of workplace, ventilation locations, operating conditions etc., and re-run the analysis in order to determine the effects of the design change they are considering. Using economical CFD simulation, engineers can now evaluate far more alternatives and determine how proposed designs perform. Both the development cost and development time of the safe ventilation system can be substantially reduced as well. Fewer physical prototypes and experiments are needed because engineers can now eliminate ineffective designs using simulation so that only a few optimized designs need to be tested.

The CFD modeling in its PHOENICS/FLAIR embodiment is recommended as a tool for developing the effective health and safety mitigation measures (proper separation distances, ventilation, barriers, masks, etc.). The application of modeling technique can obviously be of great help in identifying the locations of hot spots of largest aerosol agent (and associated virus) concentrations and by this providing an important insight into safe organization of working environments and public spaces.

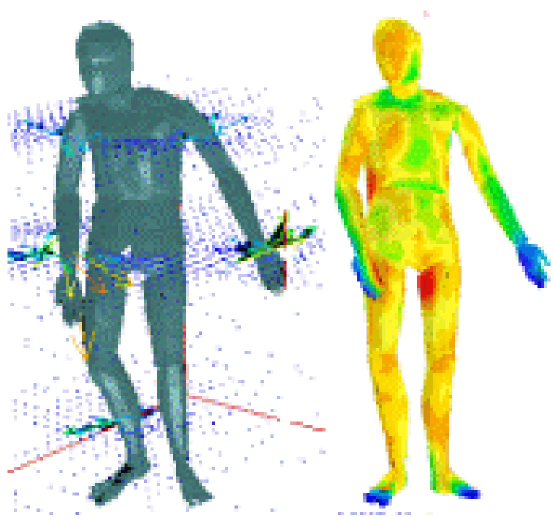


Fig. 4 Predicted flow vectors around moving human body (left) and skin temperature distributions (right)

The other engineering applications of extended CFD methodology related to the current topic could include the evaluation of different scenarios of a response of human thermo-physiological system on working conditions in PPE (Personal Protective Equipment) exposed to the hazardous environment. The physiological impact of protective clothing on stationary and moving persons with effects of physico-chemical and operational properties of protective cover can also be predicted.

The predictions such as shown on **Fig. 4** would reveal the key physiological parameters such as deep body temperature, skin temperature, skin blood flow, sweat rate and skin wettedness - all as functions of the quality of room ventilation and air flow conditioning.

In conclusion we would like to stress again that CFD modeling of workplaces and public spaces will help in developing the right health and safety measures aimed at reducing and/or preventing the virus spread in these built environments. The accumulated experience of its practical applications shows all indications that the engineering CFD technique may be confidently used to account, satisfactory for most of the decision-making purposes, for practically observed properties of the real-life aerosol clouds and associated transmission of viruses emerging from the human occupants of built environment. The other related CFD applications should also be seriously considered and re-evaluated if and when appropriate.