INTERNATIONAL JOURNAL FOR NUMERICAL METHODS IN FLUIDS
*Int. J. Numer. Meth. Fluids* 2005; **47**:1137–1146
Published online 31 January 2005 in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/fld.909

# A preliminary parametric study on performance of SARS virus cleaner using CFD simulation

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SUMMARY

Severe acute respiratory syndrome (SARS) virus cleaner is a newly developed equipment that can provide a localized, more effective way to remove body fluids with SARS virus emitted by SARS patients inside SARS triage ward during the deep-cutting therapy. One of the major concerns is how to achieve the effective removal of poisoned fluid by such individual extraction system. The most realized way of gathering data for optimization would be to perform an *in situ* measurement. However, such a method is dangerous and ineffective since the virus is highly infectious and can hardly be visualized. With the merit of Computational Fluid Dynamics (CFD), large data can be generated by computational simulations. The parametric numerical simulation presented is a cost-effective study that makes use of CFD. In the numerical experiments, viruses are assumed as airborne contaminants and their dispersion is modelled by species continuity equation. In numerical simulations, coughing of patients is modelled by a sudden high velocity jet with contaminated air. To optimize the performance of the extraction system, different extracting flow-rates combined with different extraction hood plans are considered. It is expected to find out the optimal hood/room plan and the minimum possible virus spread via CFD simulations. The CFD results may also provide information for further improving the current prototype of SARS virus cleaner. Copyright © 2005 John Wiley & Sons, Ltd.

KEY WORDS: SARS virus cleaner; triage ward; extraction system; parametric study; numerical experiment

## 1. INTRODUCTION

The outbreak of the severe acute respiratory syndrome (SARS) in Hong Kong during March–June 2003 brings about significant impact on the whole society and attracts people's attention to the public hygiene and to the preventive action of such highly infectious diseases.

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Contract/grant sponsor: Hong Kong Research Grant Council; contract/grant number: CityU 1253/04E
Contract/grant sponsor: City University of Hong Kong, HKSAR; contract/grant number: 7001463 (BC)

*Received 27 April 2004*
*Revised 7 December 2004*
*Accepted 7 December 2004*

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During the outbreak periods, more than 1750 infectious SARS cases were recorded, 301 lives claimed, and, most unfortunately, clinical professionals sacrificed themselves for the public in this fireless war [1–3]. The chances of SARS infection are exceptionally high when nurses or clinical assistants assist SARS patients inside SARS triage wards because there is a high chance of contacting saliva containing SARS virus. Removal of such poisonous fluid is an obvious solution to reduce contamination risks to clinical workers. However, the existing conventional ventilation and air-conditioning systems in Hong Kong's hospitals are not designed for accommodating patients carrying highly infectious viruses. Currently, the return air from the SARS triage wards is mixed with fresh air and filtered. Unfortunately, the existing filtering system is mainly used for dust removal which is a fraction of a mm in size and is useless in virus removal since the virus can penetrate the filter and return to triage wards. Hence, triage wards which accommodate SARS patients are highly contaminated and are a threat to clinical staff.

Aforementioned, the existing filtering system cannot remove the SARS virus. Relocating the filter by active charcoal may enhance filtering ability; however, it will cause another engineering problem, i.e. a large pressure drop in ventilation system with countable energy penalty. Hence, it is necessary to search for an alternative way to deal with such a problem. With minimum changes of the existing ventilation and air conditioning system, using an individual extraction system would be a proper solution. The SARS virus cleaner is a newly developed equipment for removing the infected spitting from the SARS patient in the SARS triage ward by providing local extracting operation from the device and further preventing the spread of the SARS virus. However, the major concern is how to achieve the effective removal of poisoned fluid by such a system. Direct extraction of spitting fluid by the face mask would be the best solution, but it would interfere with the medical treatment of clinical staff, e.g. inserting flexible pipes into the throats of SARS patients. Concerning the potential danger of proceeding with *in situ* measurement, it would be safe to carry on a parametric numerical study of preliminary design and performance estimation at the initial stage by using the merit of Computational Fluid Dynamics (CFD) [4–10]. A parametric study can be processed in a cost-effective way by using the CFD approach. The CFD simulation aims to provide useful information and guidance for the initial design of the prototype and further improvement.

## 2. MATHEMATICAL FORMULATION

In numerical experiments, flow characteristics are transient, isothermal, incompressible, and turbulent. The Reynolds Averaged Navier–Stokes (RANS) approach is adopted to simulate the air movement inside the interested space. The standard $k$–$\varepsilon$ model, the most widely used turbulence model in multi-disciplinary areas, is selected to model the turbulent effect by virtue of the concept of eddy-viscosity hypothesis. SARS virus is assumed as airborne matter and its transportation is governed by species equation. The whole equation set is listed below:

*Continuity equation*:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho U) = 0 \tag{1}$$

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*Momentum equation*:

$$\frac{\partial(\rho U)}{\partial t} + \nabla(\rho U \otimes U) = -\nabla p' + \nabla[\mu_{\text{eff}}(\nabla U + (\nabla U)^{\text{T}})] \tag{2}$$

where

$$p' = p + \frac{2}{3}\rho k + \left(\frac{2}{3}\mu_{\text{eff}} - \zeta\right)\nabla U, \quad \mu_{\text{eff}} = \mu + \mu_{\text{T}}, \quad \text{and} \quad \mu_{\text{T}} = C_\mu \rho \frac{k^2}{\varepsilon}$$

*Turbulence equation*:

$$\frac{\partial(\rho k)}{\partial t} + \nabla(\rho U k) - \nabla\left(\left(\mu + \frac{\mu_{\text{T}}}{\sigma_k}\right)\nabla k\right) = P - \rho\varepsilon \tag{3}$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \nabla(\rho U \varepsilon) - \nabla\left(\left(\mu + \frac{\mu_{\text{T}}}{\sigma_\varepsilon}\right)\nabla \varepsilon\right) = C_1 \frac{\varepsilon}{k} P - C_2 \rho \frac{\varepsilon^2}{k} \tag{4}$$

where

$$P = \mu_{\text{eff}} \nabla U(\nabla U + (\nabla U)^{\text{T}}) - \frac{2}{3}\nabla U(\mu_{\text{eff}} \nabla U + \rho k)$$

*Species equation*:

$$\frac{\partial(\rho \Phi)}{\partial t} + \nabla(\rho U \Phi - \Gamma_{\text{eff}} \nabla \Phi) = S \tag{5}$$

## 3. CASE SPECIFICATIONS

### *3.1. Case description*

To estimate the performance of the extraction system, different extracting hood plans combined with different extracting flow-rates is considered in the study (Figures 1–3). The room sizes are assigned as $6\,\text{m}(L) \times 3\,\text{m}(W) \times 3\,\text{m}(H)$ and the ceiling diffuser is of $0.3\,\text{m}(L) \times 0.3\,\text{m}(W)$A continuous, uniform fresh air supply is specified at the ceiling diffuser with velocity of 3 m/s. A standard ward bed with sizes of $2\,\text{m}(L) \times 1\,\text{m}(W) \times 1\,\text{m}(H)$ is located in the symmetrical position. In simulations, the coughing of the patient is modelled by a sudden, short, high velocity jet, carrying contaminated air, at $t = 0$ with flow rate of 7 l/s elapsing for 0.1 s. The total time period for simulation is assigned as 4 s. Under the current computer capacity, two mesh schemes of 1 and 1.5 million control volumes are used to justify the impact of mesh scheme.

### *3.2. Hood arrangement*

In conventional design of the ventilation system, both air diffuser and return-air grill are arranged in a pattern that aims to provide a well-mixed air environment. Such arrangement is expected to provide sufficient amount of fresh air to dilute the unwanted substances existing in room space. Thus, in human perception, an acceptable indoor environment can be provided.

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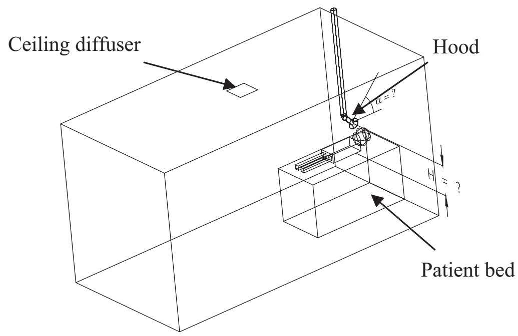


Figure 1. Plan I of SARS triage ward.

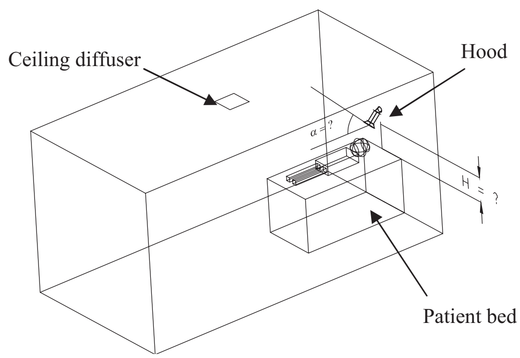


Figure 2. Plan II of SARS triage ward.

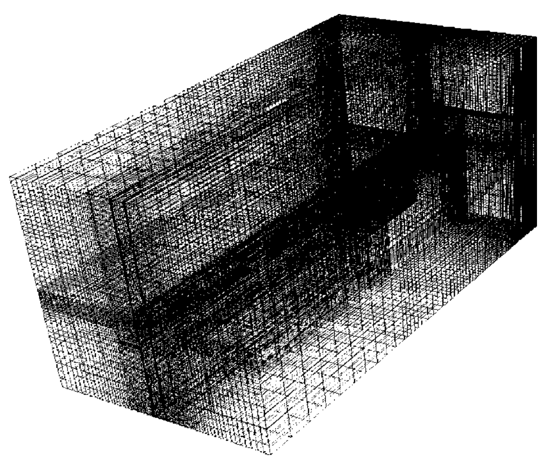

Figure 3. Computational mesh scheme.

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However, in case of the indoor pollutant air containing fatal virus, e.g. spitting air from SARS patient, the well-mixing is no longer required. Hence, immediate removal of poisoned air is needed to prevent the virus dispersion. Direct extraction of the patients' spitting fluid by a fully sealed face mask appears as an attractive but impractical solution. With a localized extracting system, a shorter path can be provided to collect/extract the coughing air from patients and aim to prevent virus dispersion. In this study, two plans for hood arrangement are proposed. In the first plan, the hood is extruded from the up-back of the patient and in the second one, the hood is located in up-front of the patient. In plan I, the hood is located at the height of 20, 40 and 60 cm above the bed under an extracting flow rate of 20(l/s). For Plan II, the hood is again arranged at the heights of 20 and 40 cm above the bed with the same extracting rate.

## 4. NUMERICAL RESULTS AND DISCUSSIONS

Figure 4 presents the airflow patterns inside the designated ward for both plans. The resultant airflow fields are mainly induced by two sources, one is the ceiling diffuser, and the other is the extracting hood. It can be noticed that the hood extracting system can provide a localized suction effect. However, due to the larger air momentum produced by the ceiling diffuser, the room air in the occupied zone mainly moves across towards the air stream created by the ceiling diffuser. Due to the existing gap between the hood and the patient, it is hard to achieve 100% extraction by the localized extracting system. Part of the coughing air released by the SARS patient may still have a chance of being spread with the cross-moving airflow induced by the ceiling diffuser (Figure 5). These spreading areas are a potential danger to the occupants in surrounding areas, e.g. clinical staff.

To understand the concentration variations of coughing air inside the ward, the maximum concentration, which is independent of the location of the domain, is selected to monitor the decay characteristics of the poisoned matter. Figures 6 and 7 indicate the decay of the maximum concentrations of coughing air inside the ward for all cases. It can be seen that, in Plan I, the sharp drops in concentration occur within half a second after the patient's cough. It means that the majority of 'coughing air' is collected and extracted by the hood system. While, in Plan II, the concentration decays can be divided into two steps, i.e. the first sharp drop due to the direct extraction of hood and the second gradual reduction probably due to convection and diffusion between 'coughing air' and surrounding air. Figure 8 indicates the rebounding pattern simulated for Plan II. A high speed jet is created when the SARS patient is coughing. Part of the released coughing air may hit the hood cover due to the jet momentum and rebound to the surroundings before further extraction and decay. This implies that the extracting area of the hood is sensitive to the hood location, hood shape, etc. Directly facing the coughing jet may not produce a complete, instant extracting effect and the extracting efficiency is hardly estimated. The scheme in Plan I can provide continuous instant extraction without interruption with proper ratio of jet flow rate/extracting flow rate. It is also noticed that, under the same scheme, the hood at a lower height produces slightly higher decay rate than the one at higher location (see Figure 6).

As a numerical study, grid sensitivity analysis is a necessary step to assure the confidence of the numerical results obtained. Such an analysis is also carried out in the study based on the available computer capacity. Figure 9 presents the grid impact of the final numerical results.

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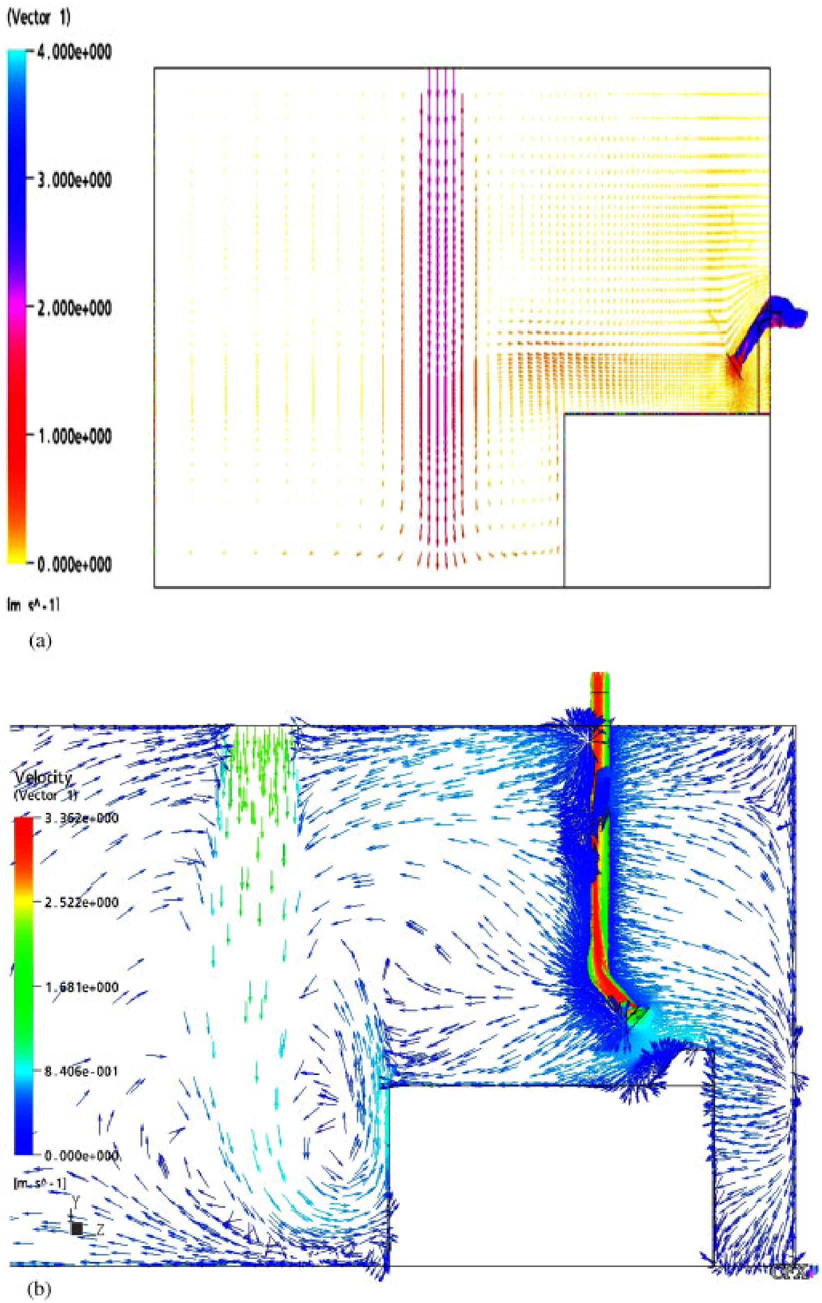


Figure 4. Flow patterns inside the ward with both plans: (a) Airflow field in Plan I, $H = 20\,\text{cm}$; and (b) airflow field in Plan II, $H = 20\,\text{cm}$.

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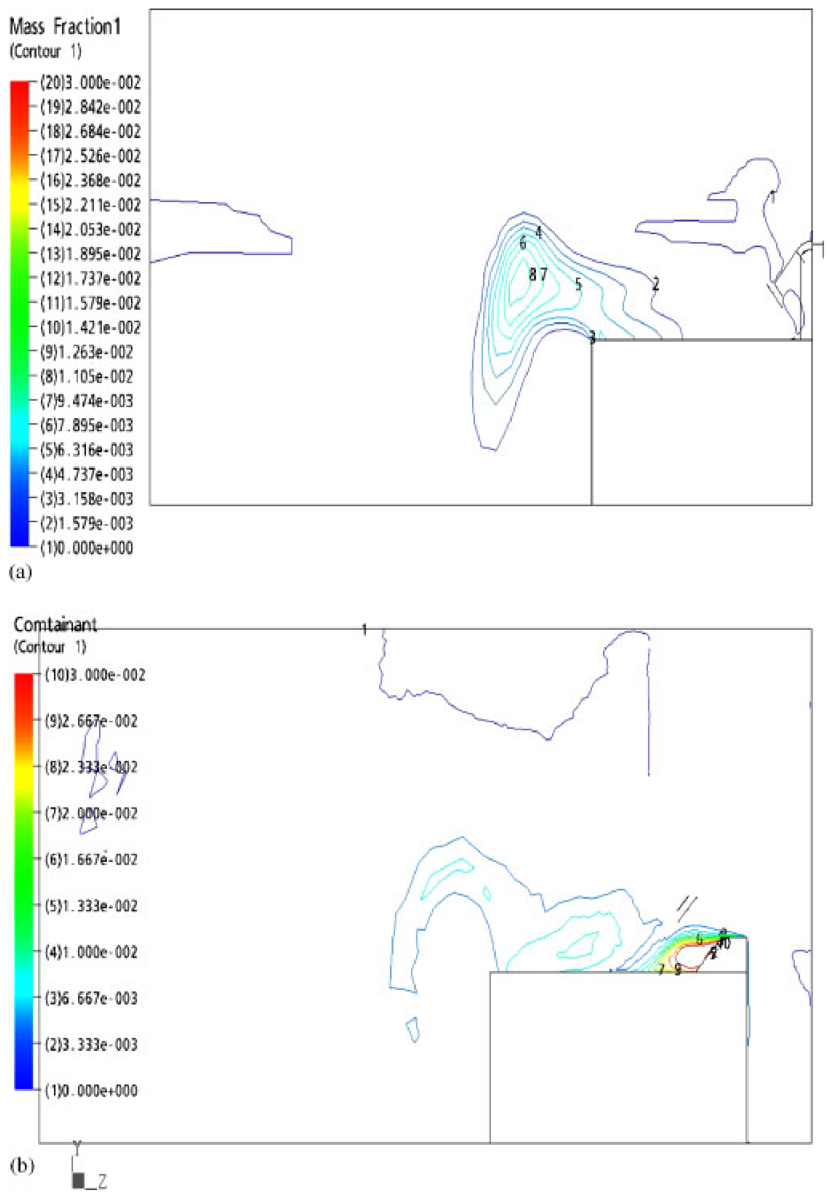


Figure 5. Distribution of remaining coughing air inside the ward in both plans at $t = 4$ s: (a) Contour of air with virus in Plan I, $H = 20$ cm; and (b) contour of air with virus in Plan II, $H = 20$ cm.

Two mesh schemes are specified to the same case, i.e. Plan II with hood at 20 cm above the bed. It can be noticed that the simulation did not achieve the grid independent results even with 1.5 million control cells. Further refinement of the mesh scheme is still needed at the current stage.

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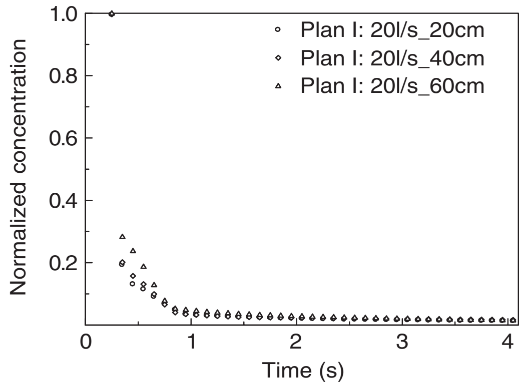


Figure 6. Decay of maximum concentrations for Plan I at different hood heights.

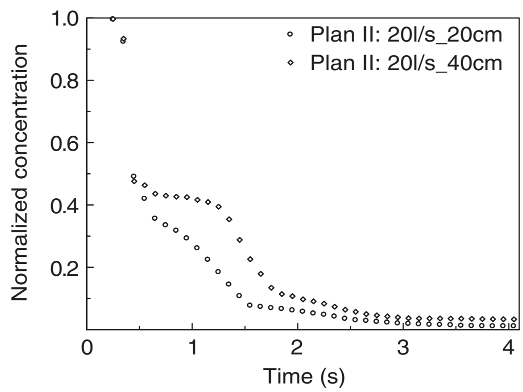


Figure 7. Decay of maximum concentrations for Plan II at different hood heights.

The main drawback of the study is lack of experimental validation. Such work is expensive and very time consuming, which will be considered in the future research plan.

## 5. CONCLUSION AND RECOMMENDATION

A series of parametric study of performance estimation of SARS virus cleaner by using the CFD approach is reported in this paper. The results show that the localized extracting system is a useful attempt to reduce the virus spread and further prevent the potential infection in a SARS ward. The results also indicate that the effectiveness of the extracting hood strongly depends on the location of the extracting hood; however, the possible rebounding effect in some cases demands careful attention. In addition, such an individ-

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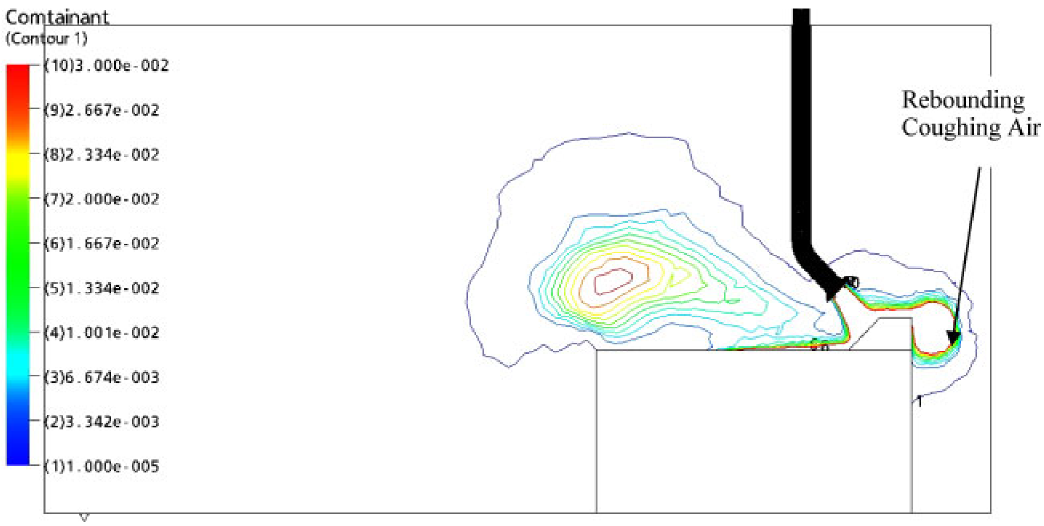


Figure 8. Rebounding pattern of coughing air at $t = 1$ s after patient's coughing.

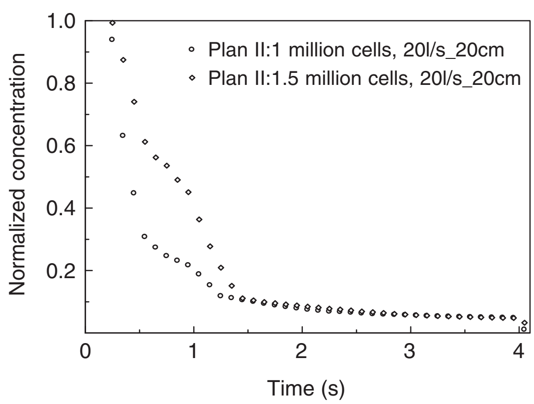


Figure 9. Mesh impact on numerical results.

ual extracting system causes little impact on the existing ventilation system but collecting/extracting the majority of poisoned air in a cost-effective way. The main drawback of the study is lack of experimental measurement. More attention will be paid in future research to this aspect to improve the performance of the system and to develop the quantitative assessment.

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## NOMENCLATURE

| | |
|---|---|
| $p$ | = pressure |
| $p'$ | = modified pressure |
| $U$ | = velocity |
| $\rho$ | = density |
| $k$ | = turbulent intensity |
| $\varepsilon$ | = turbulent dissipation rate |
| $\mu$ | = viscosity |
| $\mu_{\mathrm{eff}}$ | = effective viscosity |
| $\mu_{\mathrm{T}}$ | = turbulent viscosity |
| $\sigma_k$ | = Prandtl number of $k$ |
| $\sigma_\varepsilon$ | = Prandtl number of $\varepsilon$ |
| $\Gamma_{\mathrm{eff}}$ | = effective diffusivity |
| $\Phi$ | = gaseous species |
| $\zeta$ | = bulk viscosity |
| $C_1, C_2$ | = empirical constant |

## ACKNOWLEDGEMENTS

The work described in this paper was partially supported by RGC CERG Grant # CityU 1253/04E from Hong Kong Research Grant Council and Strategic Research Grants # 7001463(BC) from City University of Hong Kong, HKSAR.

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