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Aerodynamics simulation of operating rooms

N. El Gharbi* A. Benzaoui*R. Bennacer**

*Faculty of Physique Laboratory of Thermodynamics and Energetic of Systems
BP 32. El Alia Bab Ezzouar 16111, Algiers, Algeria
University of Sciences and Technology Houari Boumediene, Algiers, Algeria
**University of Cergy Pontoise, Paris, France

Abstract

The hospital is the place where we find simultaneously people whose health state is weakened, or vulnerable, and pathogenic micro-organisms able to worsen their health. Because these, the quality of the air in hospital must be in conformity with precise criteria in the buildings such everyday usage, and in particular in the buildings where some risk of specific pollution exist as in operating rooms.

In this paper, we present a modelisation and three dimensional numerical study made in an operating room. Results could be used when new operating rooms must be conceived or others existing will be modified. It could be used to avoid risks and to allow all controls of any risks. The air flow modelling aim, by analysing the stream coherence, is to control the contamination in the operating area by bringing out the contamination dispatching within the operating room. It will allow to clearly understanding the complex coupled phenomena thanks to animation and to virtual 3D reality. The use of real data of the studied operating room (geometry, volume, extracted and blown air flow, temperature and hygrometry) will allow the determination of the drainage of air, the distribution of temperature, and the zones of poor air distribution.

To be able to find the exact distribution zones of the contaminants, the chosen turbulent model has to be accurate with a good ability to predict the recirculation of the air. The obtained results show that only one of the four tested models can correctly define the recirculation of the air.

Keywords: Operating room, aerodynamics simulation, turbulent model, comfort, Airflow, Indoor air quality.
Introduction
The air conditioning system of a hospital operating room must provide a comfortable and healthy environment for the patient and the surgical team. Thermal comfort can be achieved by controlling the temperature, the humidity, and the air flow. A healthy environment can be achieved by minimizing the risk of contamination through appropriate filtration and air distribution scheme.
To ensure these optimal conditions, a study of the aerodynamics flow in a conditioned operating room must be made, by using the digital simulation.

1 Choice of the turbulent model
According to literature, Nielsen P.V (1974), was one of the first researchers having used the k-ε turbulent model in 2D, to study the air movement and heat transfer in conditioned room [5]. Murakami et al (1994). From the University of Tokyo quoted by [6] added to the standard k-ε model a wall function to model the air flow, in a clean room where the number Air Change by Hour (ACH) is very high.
Chow and Yang (2003) used the standard k-ε model using eddy viscosity hypothesis for their numerical predictions on the ventilation of an operating theatre in a hospital of Honk Kong, [2]. Similarly the work made by Monika et al(2004), who used the same turbulent model and the flow near the boundaries were represented by using the standard logarithmic law [4]. They focused on the contaminant diffusion in an experimental operating room.
Chen (1995) [1] studied five modified k-ε models and compares the obtained numerical results with existing experimental results. The RNG k-ε model was found slightly better than the standard k-ε model for simulating air flow displacement.
While Luo(2003) [3] compared three turbulent models, RNG k-ε, realizable k-ε and SST k-w , where an enhanced treatment near the walls was used for the two k-ε models. The study of the 3D ventilation shows that the SST k-w model predicts better the velocity profiles in the vicinity of floor.
For our study the choice of the turbulent model is crucial to well predict the air recirculation. Such recirculation will be favourable for the accumulation of the contaminants. Four turbulent models (two equations) were studied:
- The standard k-ε model with walls function
- The realizable k-ε model with non equilibrium walls function ;
- RNG k-ε model with non equilibrium walls function;
- SST k-w model.

The choice of the treatment associated to walls as each models was concludes from the results of the literature search [3].

2 Adopted methodologies
The first phase is the determination of our operating room characteristics:

2.1 Specific
- Area with very high risks for the patients (class 4 according to NF S 90-351 or ISO 5 according to ISO'S DIN 14644-1).

2.2 Aerodynamic
- The distribution of air is diagonal
- The renewal of air is 40% of new air and 60% of recycled air, with 6.08ACH
- The air flow ventilation is equal to 1852m3 / h, with a velocity of 0.51m/s.
- The recycled flow is equal to 1110m3 / h, with a velocity of 0.61m/s.
• The stale flow is equal to 495m³/h, with a velocity of 0.27m/s.
• The blowing temperature is 17.5°C with 40% humidity.

2.3 Geometrical
The following parameters were measured:
• Volume of the room.
• Dimensions of the walls and of the doors.
• Dimensions and positions of the various objects in the room (Scialytic-operating table-medical equipment-staffs).
• Dimensions and positions of the inlet and outlet diffuser.

The second phase consists in calculating the heat flows released by the occupants, lighting, by the machines and transmission, to be able to use them as boundary conditions.

3 Presentation of the operating room
The studied operating room is assigned to the service of the neurosurgery. The arriving air in the room is already filtered in the station of air treatment, using primary filters of 88% and 95% effectiveness, and then in a second time on the level of the inlet diffuser using HEPA filters.
For our study, we consider the room empty without staff neither patient nor medical equipment, to define the air recirculation without presence of disturbance which can increased these recirculation.

4 Numeric simulations
A non uniform grid (1037497 tetrahedral cells) was used with a refinement on the level of the inlet and outlet diffuser of the lamps and the operating table;
The following heat flows were taken into account:
<table>
<thead>
<tr>
<th>Item</th>
<th>Heat flux [w/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>wall NE</td>
<td>1.3565</td>
</tr>
<tr>
<td>wall SO</td>
<td>0</td>
</tr>
<tr>
<td>wall SE</td>
<td>0</td>
</tr>
<tr>
<td>wall NO</td>
<td>2.7409</td>
</tr>
<tr>
<td>ceiling</td>
<td>7.8576</td>
</tr>
<tr>
<td>floor</td>
<td>6.6687</td>
</tr>
</tbody>
</table>

Table 1 The heat dissipation

The fluid is supposed incompressible and a second order scheme is used to discretize the diffusion terms. The solution is obtained in primitive variable P-V and the pressure and velocity coupling is obtained by the SIMPLEC algorithm. The convergence criterion was based on the maximum error less than a prescribed value taken equal to $10^{-6}$ for energy, and $10^{-4}$ for the other equations.

plans were selected Each plan is localised in the middle of the inlet diffuser represented on figure 2 and localised at:

- $z = 1.13m$ in the medium of the first inlet diffuser.
- $z = 2.54m$ in the medium of the second inlet diffuser.
- $z = 3.95m$ in the medium of the third inlet diffuser.
- $z = 4.47m$ in the medium of the fourth inlet diffuser.

5 Results and discussion

We notice about the time duration of the iterations made with these four turbulent models: standard K-ε, realizable k-ε, RNG k-ε and SST k-w, the first two models converge more quickly compared to the last two models. After the convergence of the four models, we obtain the following results:
• At the plan $z = 1.13\text{m}$

![Image of flow fields at $z = 1.13\text{m}$ with different models: Standard $k$-$\varepsilon$, Realizable $k$-$\varepsilon$, SST $k$-$\omega$, and RNG $k$-$\varepsilon$.]

Figure 3 The recirculation at $z = 1.13\text{m}$

With the four turbulent models, there are some recirculation areas of the air with a return of the velocity vectors in the opposite direction of the flow when it runs up against the wall. These recirculation’s are visualized on the level of the floor with SST $k$-$\omega$ model, still better with the standard model $K\varepsilon$, on the other hand RNG $k$-$\varepsilon$ model reflects very well these recirculation’s in the interior of the room.

• At the plan $z = 2.54\text{m}$

![Image of flow fields at $z = 2.54\text{m}$ with different models: Standard $k$-$\varepsilon$ and Realizable $k$-$\varepsilon$.]
With the realizable k-ε model and SST k-w model, one does not visualize the zones of recirculation, this recirculation are weak with the two other models.

- At the plan $z = 3.54m$

It is the plan which passes by the operating table, the realizable k-ε model does not envisage recirculation of air, with SST k-w model we observe a weak recirculation meadows of the diffuser inlet, on the other hand with the standard k-ε these recirculation’s are very well visualized under the table, similar for the model RNG k-ε which, in addition to the recirculation under the table, appear other ones in the room.
• At the plan \( z = 5.47m \)

![Flow field visualizations](image)

*Figure 6 The recirculation at \( z = 5.47m \)*

From this point of view one can also see the two outlet extraction of the air, always with the realizable K-\( \varepsilon \) model it does not have there recirculation of the air, one can visualize with SST k-\( \omega \) model, but visualized well with the two last models.

**Conclusion**

Aerodynamics modelling makes it possible to optimize the way of air flow, in order to decrease for the patients, any contamination risks inside the protected zone. The visualization of the zones of recirculation of air in the studied operating room, with the four models turbulent, makes it possible to conclude that model RNG k-\( \varepsilon \) is the best to be adapted to define these zones of recirculation in all the room. The results obtained during this study, tend to confirm the practical interest of modelling. This solution makes it possible to bring concrete answers for the control of contamination, by highlighting the zones of bad distribution of air potentially contaminated.
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