INVESTIGATION OF FLOW REGIMES IN HOSPITALS

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ABSTRACT
In this paper the factors that affect the Indoor Air Quality (IAQ) in surgical operating theatres are introduced. The reasons for deviation from obtaining optimum IAQ are shown. The air conditioning systems serving the operating rooms require careful design to minimize the concentration of airborne organisms. The present work describes and analyses the flow and heat transfer regimes inside surgical operating theatres through investigating a typical operating room. Numerical approach was utilized to adequately identify the airflow patterns temperatures and relative humidity distributions.

Keywords – CFD;Operating Theatres;Fluid Mechanic;Comfort

1. INTRODUCTION
Hospital air conditioning resumes a more important role than just the promotion of comfort. In many cases, proper air conditioning is a factor in patient therapy; in some instance, it is the major treatment. Studies shows that patient in controlled environments generally have more rapid physical improvement than do those in uncontrolled environments, ASHRAE Applications 2011. Air quality must also be maintained to provide a healthy, comfortable indoor environment. Sources of pollution exist in both the internal and external environment. The indoor air quality is controlled by removal of the contaminant or by dilution.

1.1 Air movement
Air-conditioned flows are normally classified as jet flow in confined spaces (i.e. round or rectangular jet flow in the spaces to be air-conditioned). The air distribution in a space can be treated as a recirculating flow in a confined space, in which the transverse and the reverse flows take place. The buoyancy and deflection have an influence on the air distribution. All these parameters insure turbulent mixing between the different air streams.

1.2 Temperature and Humidity
If the ambient indoor air temperature is too warm, people perceive the environment to be stuffy with little airflow. Furthermore, high temperatures may cause increased outgassing of toxins from furnishings, finishes, building materials, etc. Alternatively, ambient temperatures that are too cool can cause occupant discomfort such as shivering, inattentiveness, muscular and joint tension. Relative humidity affects our

comfort in numerous ways both directly and indirectly. Comfort complaints about dry nose, throat, eyes and skin occur in low humidity conditions. In hot climates, it is recommended to set the temperature from 16 ^oC to 22 ^oC at the working domain with relative humidity of 45% to 55%.

1.3 Pressure Relationships and Airflow (Pressurization)

Design of ventilation system must, as much as possible, provide air movement from clean to less clean areas. In critical care areas, constant volume systems should be employed to assure proper pressure relationships and ventilation, except in unoccupied rooms. Positive pressure is recommended in operating theatres with high air changes per hour.

2. MATHEMATICAL DESCRIPTION

Three time averaged velocity components in X, Y, and Z coordinate directions were obtained by solving the governing equations using a "SIMPLE Numerical Algorithm" [Semi Implicit Method for Pressure Linked Equation] described earlier in the work (Spalding and Partanker, 1974), (Launder and Spalding, 1974), (Khalil 1978). The present work made use of the Computer Program FLUENT, which solves the differential equations governing the transport of mass, three momentum components and energy in three-dimensional configurations. The different governing partial differential equations are typically expressed in a general form as:

$$\mathrm{Div}\,(\rho V\Phi - \Gamma_{\Phi,\mathrm{eff}} \cdot \mathrm{grad}\,\Phi) = S_\Phi \quad (1)$$

Where:

ρ = Air density, kg/m^3

Φ = Dependent variable.

V = Velocity vector.

$\Gamma_{\Phi,eff}$ = Effective diffusion coefficient.

S_Φ = Source term of Φ.

The Computational Fluid Dynamics (CFD) model utilizes the following approximations in calculating the turbulence quantities, such as isotropic turbulence and the Boussinesq eddy viscosity concept.

Boundary Conditions

The solution of the governing equations can be realized through the specifications of appropriate boundary conditions. The values of velocity, temperature, kinetic energy, and its dissipation rate should be specified at all boundaries. A non-slip condition at all solid wall is applied to the velocities. The logarithmic law of the wall (wall function) of Launder and Spalding (1974) was used here, for the near wall boundary layer. At inlets, the air velocity was assumed to have a uniform distribution; inlet values of the temperature were assumed to be of a constant value and uniform distribution. All velocity components were set as zeros initially, and temperatures were assumed to be equal to the steady state value of the comfort condition.

Numerical Procedure

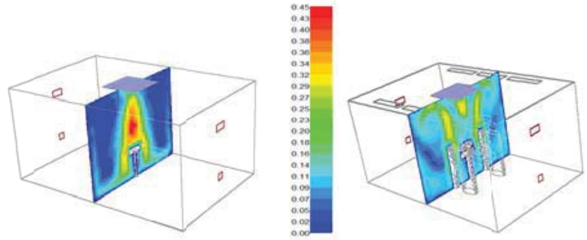
The Computer Program, FLUENT was used to solve the time-independent (steady state) conservation equations together with the standard k-ε model as Launder and Spalding (1974), and the corresponding boundary conditions. The numerical solution grid divided the space of the surgical operating theatre into discretized computational cells of the order of 900,000 cells. The predictions of flow and turbulence characteristics are in general qualitative agreement with the corresponding experiments and numerical simulations published by others, (Neilsen, 1989). Nevertheless discrepancies exist and particularly in the vicinity of recirculation zone boundaries.

3. PARAMETRIC CASE STUDY

In this article different parameters were investigated in a typical surgical operating room whose dimensions were 6 m x 4 m and 3 m height. Computational Fluid Dynamics (CFD) model was used to compare between different cases in the room. Air was supplied from central ceiling perforated outlets with 20 ACH and extracted from wall extracts at two levels. The air flow distribution, temperature and relative humidity contours were studied in the case of an empty room and in case of taking full account of surgery team, room furniture and lighting physically and thermally. The effect of adding a partition wall around the supply outlet was studied. The air distribution characteristics were studied when the depth of the partition wall is 0.2m and 0.5m. The effect of tilting the pendent light with a 45 degree angle was then studied.

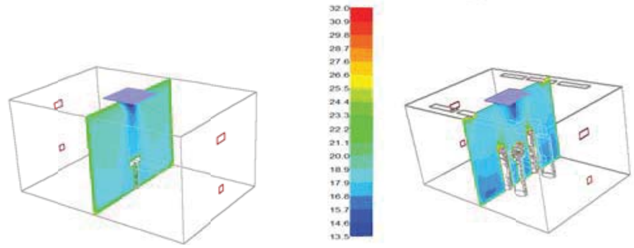
3.1.Effect of people and light

The predicted velocity contours at x=3m are shown in Figure 1 in a Y-Z plane. The contour (a) was obtained in a room with only the operating table in the middle of the room. The predicted flow regimes are well characterized by a nearly symmetrical flow. Flow velocities in the vicinity of the operating table were of the order of 0.045 m/s which are well below draft velocity limit proposed by ASHRAE (0.25 m/s at 1.2 m above finished floor). The flow contours shown to the left identify the effect of the surgical team and the patient on the bed. One can see that the surgical team member acted as physical blocks to the flow field, thus causing flow regime disturbance and alteration, the flow symmetry is still observed to a large extent. The surgical team members are closely located near the bed and consequently have a strong effect of deflecting the flow pattern. In Figure 2, the corresponding temperature predictions are shown, again the contours to the right are without the surgical team nor did the patient, the ones on the left demonstrate the effect of the surgeons and patient. Air temperature increased from a 13^{o}C at the supply grille outlet to nearly 23 ^{o}C at the bed. Shown in Figure 3 are the corresponding relative humidity predictions, again the contours to the right are for an empty operating room without the surgical team nor the patient, the ones on the left demonstrated the effect of the surgeons and patient. Relative Humidity decreased from 85% at the supply grill to nearly 50% at the bed.



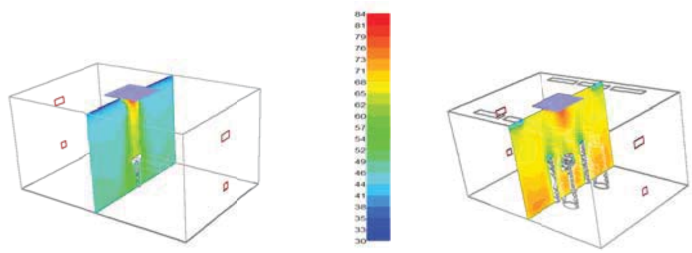
(a)With no patient and no surgeons (b) with patient and surgeons

Figure1: Predicted Velocity Contours ,Y-Z plane at X=3 m



(a)With no patient and no surgeons (b) with patient and surgeons

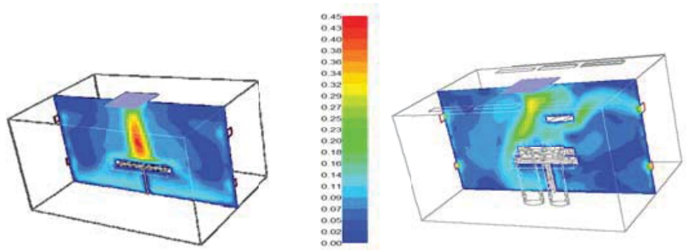
Figure2:Predicted Temperature Contours , Y-Z plane at X=3 m



(a)With no patient and no surgeons (b) with patient and surgeons

Figure3:Predicted Relative Humidity,% Contours,Y-Z plane at X=3 m

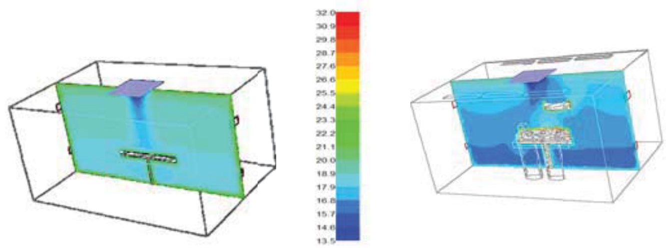
The predicted velocity contours were also obtained at a Y-X plane at z=2 m and are shown in Figure 4. The flow contours shown to the left identify the effect of the patient on the bed and the pendent light. One can see that the pendent light acted as physical blocks to the flow field, thus causing flow regime disturbance and alteration. Due to the existence of the pendent light the flow is pushed away from the center of the room towards the patient feet.



(a)With no patient and no pendent (b) With patient and horizontal pendent

Figure4:Predicted Velocity Contours , Y-X plane at Z=2 m

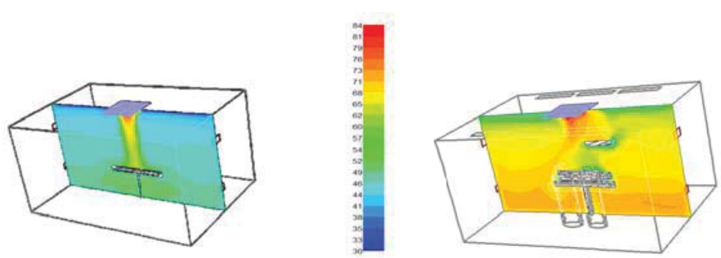
In Figure 5 the temperature distribution predictions are shown without the surgical team, patient and pendent light on the right and the contours on the left demonstrate the effect of the patient and pendent light. We can notice the deviation of the temperature contours away from the patient's feet.



(a)With no patient and no pendent, (b) with patient and horizontal pendent,

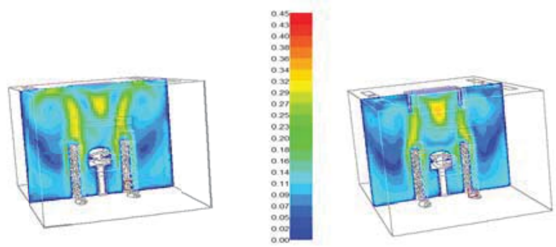
Figure 5: Predicted Temperature Contours at Z=2 m (Y-X plane)

The predicted relative humidity contours at z=2 m are shown in Figure 6 in X-Y plane. Again the flow contours shown to the left identify the effect of the patient on the bed and the pendent light. The relative humidity is about 85% at the supply grill and decreases to about 65% at the patient feet and reaches 50-55% at the head.



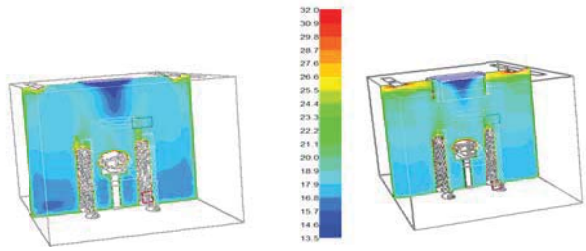
(a)With no patient and no pendent (b) with patient and horizontal pendent,

Figure 6:Predicted Relative Humidity Contours at Z=2 m, (Y-X plane)



(a) No partition (b) With 0.5 m partition

Figure 7: Effect of partition wall (0.5 m) on Velocity predictions at Y-Z plane at X=3 m

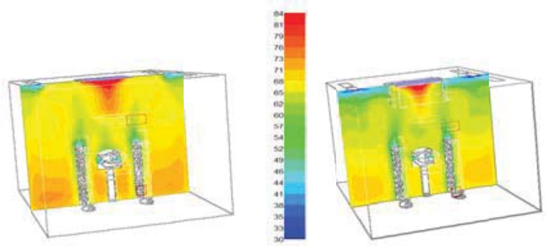


(a) No partition (b) With 0.5 m partition

Figure8:Effect of partition wall (0.5m) on Temperature predictions, at Y-Z plane at X=3 m

3.2. Effect of partition wall:

The effect of adding a partition wall is shown in figure 7 in a Y-Z plane. The contour on the right was obtained in a room with a partition wall of 0.5m depth. As a result of adding the partition wall the flow is more concentrated in the center area of the room.
The partition wall acts as a barrier that helps obtaining a more centered flow. The predicted temperature contours at x=3 m are shown in Figure 8 in Y-Z plane. In the case of using partition wall the temperature contours are more concentrated towards the center of the room. Lower temperatures can be noticed around the surgeons' heads. The predicted relative humidity contours at x=3 m are shown in Figure 9 in Y-Z plane. Again the flow contours shown to the left identify the effect of the partition wall. The relative humidity in case of using the partition wall is less around the doctor's head.

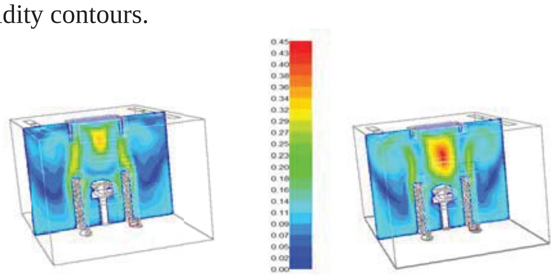


(a) No partition (b) With 0.5 m partition

Figure9:Effect of partition wall(0.5m) on Relative Humidity predictions, at Y-Z plane at X=3 m

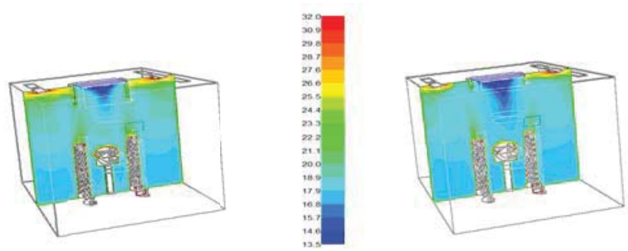
3.3. Effect of changing partition wall height

The effect of partition wall height on flow velocities, air temperatures and relative humidity contours was also investigated at two heights of 0.5 and 0.2 m respectively. Figure 10 demonstrated these comparisons between the air flow patterns at 0.5 m and 0.2 m respectively. The partition wall results in reducing the high velocity region and the air curtain formation is more pronounced as shown at 0.5 m partition wall height.
The velocity contours patterns did not change largely at the floor level vicinity while the supply top zone the mushroom shaped pattern is more pronounced at smaller height. The corresponding effects on the air temperature and relative humidity contours are shown at figures 11 and 12. It can be seen that the air temperature distribution is less affected by the partition wall height. The same comment applies to the relative humidity contours.



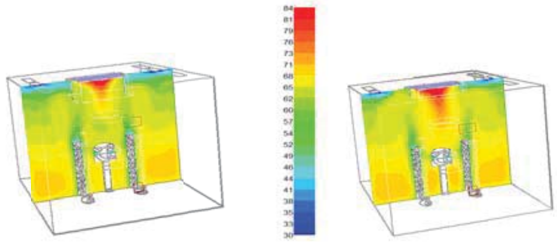
(a) 0.5 m height (b) 0.2 m height

Figure10: Effect of partition wall dimensions on flow pattern for two partition wall height of 0.5 m and 0.2m



0.5 m height 0.2 m height

Figure11:Effect of partition wall heights on Temperature predictions

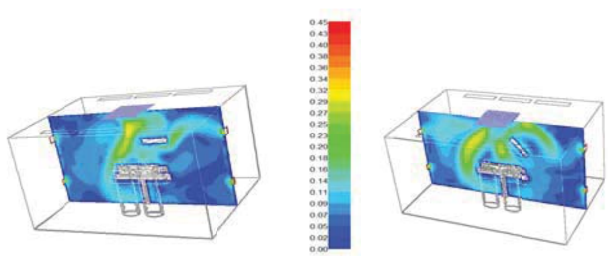


(a) 0.5 m height (b) 0.2 m height

Figure12:Effect of partition wall heights on Relative Humidity predictions

3.4. Effect of tilting the pendent light:

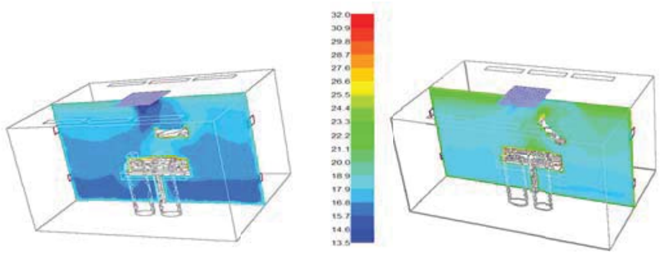
The effect of tilting angle of the pendent light on flow velocities, air temperatures and relative humidity contours was also investigated at two angles. Figure 13 demonstrated these comparisons between the air flow patterns at two angles respectively. The tilting of the pendent greatly affects the flow pattern. Similar comment applies to the temperature and relative humidity contours.



(a) Horizontal Pendent, (Y-X plane) (b) Inclined Pendent, (Y-X plane)

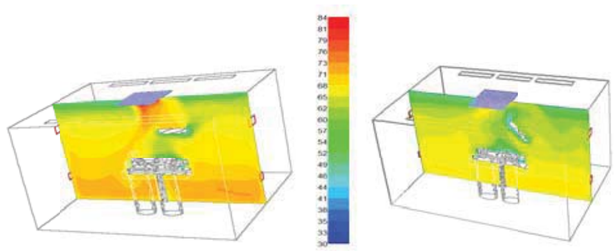
Figure 13: Effect of pendent tilting angle on flow pattern for angles of 0 and 45

The air flow pattern was shown to change particularly in the vicinity of the light pendent. Temperature and relative humidity contours were less affected by this tilting as indicated in figures 14 and 15 below.



(a) Horizontal Pendent, (Y-X plane) (b) Inclined Pendent, (Y-X plane)

Figure 14: Effect of pendent light tilting angle on Temperature predictions for angles of 0 and 45



(a) Horizontal Pendent (b) Inclined Pendent

Figure 15: Effect of pendent light tilting angle on Relative Humidity predictions for angles of 0 and 45

4. DISCUSSION AND CONCLUSIONS

The parametric investigation highlighted in this work indicated the effects of the light pendent opposition and angle of inclination as blockage in the air passage from the supply grilles in the ceiling to the activity zone where surgeons and patient are localized. The effect of the presence of the surgical team and patient were considered as both a physical block and also as a candidate source of heat and moisture in operating rooms. The use of partition wall at supply was recommended to guide the supply air downward and to prevent any short circuiting to extract ports or undesired recirculation zones. The present work attempted to display the various effects of the equipment and persons in the operating theatre on the air flow patterns, thermal; contours and relative humidity values. Previous trials of airside designs and previous researches of energy efficiency and IAQ performance guided current research to appropriately account for energy costing and efficient utilization. The ultimate goal is to attain comfortable and hygiene design that is energy efficient and environmentally green and sustainable.

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NOMENCLATURE

X,Y,Z	Coordinate directions.
L,W,H	Length, width, height of the theatre.

GREEK SYMBOLS

ε	Turbulence dissipation rate.
Φ	General dependent variable.
Γ	Exchange coefficient.
ρ	Density of air, kg/m3.

SUBSCRIPTS

I, j, k	Denoting Cartesian coordinate direction takes the values of axes X, Y, Z