

COMPUTER SIMULATION OF INDOOR AIR QUALITY AND AIR FLOW REGIMES IN SURGICAL OPERATING THEATRES

Essam E. Khalil

*Professor of Mechanical Engineering, Faculty of Engineering,
Cairo University, Chairman CEB, Cairo, Egypt*

ABSTRACT

This paper reviews the previous attempts to evaluate the Indoor Air Quality (IAQ), investigates previously proposed IAQ factors and analyses the evaluation methods of these factors. The present work introduces, also, a new hypothesis of the optimum HVAC airside system design of the surgical operating theatres to achieve the comfort and hygiene levels. The present work is devoted to propose and formulate a new scale capable of adequately evaluating the airflow pattern in the surgical operating theatres. The proposed new scale is proposed to cover the local and overall air quality evaluations. A new Neuro fuzzy technique was applied to derive measures for indoor air quality indices. Indoor Air Quality (IAQ) is more critical in healthcare facilities due to the dangerous microbial and chemical agents present and the increased susceptibility of the patients. Hospitals and other healthcare facilities are complex environments that require ventilation for comfort and to control hazardous emissions. Surgical operating theatre is the most important and complex zone in the hospital, and requires more careful control of the aseptic conditions of the environment. Most of the previous researches aiming at evaluating the IAQ were based on the evaluation of the air distribution depending on the residence and leaving age of the air supplied to the enclosure. Other attempts were also reported to indicate the effectiveness of contaminant removal by the entire airflow pattern as an indication to the IAQ.

This paper recommends some designs of the supply air outlets to provide the vertically downward airflow as a practical solution. The near ceiling and near floor extract ports are to be used instead of the hypothetical complete floor extract as a practical solution.

KEYWORDS

Simulation, CFD, Air Conditioning

INTRODUCTION

Hospitals and other healthcare facilities are complex environments that require ventilation for comfort and to control hazardous emissions. Indoor air quality is more critical in health care facilities due to dangerous microbial and chemical agents present and the increased susceptibility of the patients. To achieve and maintain good Indoor Air Quality (IAQ) conditions, it is necessary to remove or dilute airborne contamination in the enclosed space. Ventilation air distribution pattern has a great effect on the IAQ in enclosed spaces especially healthcare applications. The primary tasks of ventilation system are to remove the contaminated air from the room and to supply the occupied region of the room with clean air (Etheridge and Sandberg, 1996). To build ventilation system that is capable of efficiently fulfilling all requirements is a great challenge.

The laminar airflow concept was introduced for the first time by (Michaelson et al, 1966). The research introduced that concept without any advice about the way of reaches that flow, or the suggested procedures. In earlier work (Scott, 1970) described laminar/linear flow ventilation and its application to surgery and indicated that these systems had been in use in operating rooms in the USA. The investigation of (Pfost, 1981) was the first reported work that concerns the airflow patterns and direction in the surgical operating theaters.

[†] Corresponding Author: Tel: + 20 233356080, Fax: + 20 233362433
E-mail address: khallie1@asme.org

Pfost introduced several types of the air supply positioning in the ceiling to reach the most probable situation. He advocated especially the completely perforated ceilings as optimum solution for the air conditioning inside the surgical suites. He suggested also the necessarily of extracting air near the floor to maintain the downward flow. The importance of ventilation systems to insure an optimum infection control was discussed by (Streifel, 2000). It was stated that the air distribution and direction play the more important role in the airborne-infectious-disease management; good IAQ starts with building design. The airborne bacteria in an operating room might not be eliminated even by providing "bacteria free" air from the air handlers, else if using directional and free turbulence airflow (Gurry, 2001). His recommendations are; the ventilating air is to be supplied from ceiling or high on the walls in each room, and the supplied air should then be exhausted from several inlets located near the floor on opposite walls.

Many of researches have been carried out to assess the air distribution influence on the air quality. In order to quantify the ventilation performance, various definitions of ventilation effectiveness have been developed, since firstly introduced by (Yaglou and Witheridge, 1937). Many investigations were performed to enhance the understanding of the airflow action and its influence on room characteristics (Sandberg, 1981), (Skaret and Mathisen, 1983), and (Peng et al, 1997). However, those investigations were limited to few configurations without any general design criterion, can be used as a comparative scale to the air distribution effectiveness. Most of previous researches were based on simple ideas to evaluate the IAQ based on the air distribution limited by the patterns of air velocities. Those previous attempts can be grouped into three efficiency scales that have been widely used as a measure of ventilation system, namely; mean age of air, air exchange efficiency, and contaminant removal efficiency (Roos, 1999), and (Sandberg and Sjoberg, 1983).

The extract effectiveness should be defined in parallel with the supply effectiveness, and they should be based on airflow pattern in the space but not on contaminant characteristics (Han et al, 2000). The measure of air age and measure of residual-life-time of air should be evaluated together to get the final evaluation of airflow effectiveness in a room (Han et al. 2000). The surrounding physical factors have a rather large impact to subject in subjective evaluating IAQ. As it may affect the confidence level of the final conclusion about IAQ subjective evolution, the magnitude of physical factors' interference should be quantitative assessment. The IAQ should be studied on a fuzzy synthetic discrimination basis (Han and Chen, 2001). The IAQ is affected by several factors and the level of it is a fuzzy idea (Zhu et al, 2001). They used the analysis of grey incidence as a base to evaluate the IAQ in different domains they found according to the analysis and comparison with other methods, that the grey assessment is an ideal method of assessing concerned with several parameters because the procedure is simple and the outcome is credible. As mentioned earlier, there were different investigations concerned with the IAQ evaluation based on the fuzzy basis.

(Lee and Awbi, 2001), and (Awbi and Karimipناه, 2001) used effectiveness formulae based on the solving of transport equation. Those formulae were local air change index (ϵ_p), room air change efficiency (ϵ_{ac}), and zone air efficiency (ϵ_z).

$$\epsilon_p = \tau_n / \tau_p \tag{1}$$

$$\epsilon_{ac} = \tau_n / 2\tau_{room} \tag{2}$$

$$\epsilon_z = \tau_n / \tau_{zone} \tag{3}$$

where τ_n = Total Volume/Volumetric Flow Rate

τ_{room} = is the room mean age

τ_{zone} = is a zone mean age

That models deal with the space (room or certain zone) as a one unit without any consideration of airflow details or concerning about the flow interactions (convection, diffusion, or shear interactions).

NEW HYPOTHESIS

To deal with the air distribution characteristics as individual factors on the evaluation of IAQ, a new criterion or standard scale to act as a reference to our evaluation should be proposed. To create the

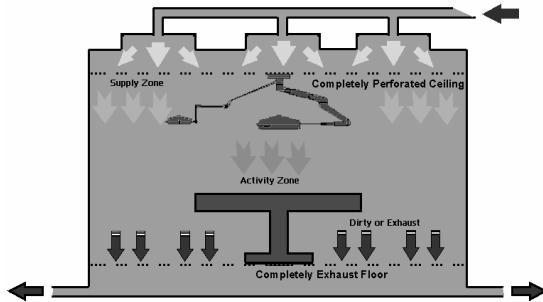


Figure 1: Hypothesis of ideal operating theatres air

new Index, the optimum air distribution in the operating theatres hypothesis should be established. In order to formulate the new index, the concept of using a complete perforated ceiling as the supply of the operating theatre is followed. Moreover we will suppose to reach the complete laminar downward flow and the sterile environment, that the exhaust air will be extracted from the floor to prevent any recirculation in the airflow. The present hypothesis, which depends on creating a curtain in the room, is shown in Fig. 1. That curtain will ensure no return flow, and will provide a complete sterile environment with no cross contamination. Also that assumption depends on ignoring any horizontal air movement, because the persistent supply penetration to the room space. To be able to formulate an analytical or even empirical expression relating the contaminant removal efficiency, airflow pattern and contaminant emission pattern, a correlation between contamination and airflow should be established. It is assumed that any contaminant, after it is either emitted inside the room or added to the room with the supply air, is perfectly passive; this assumption is not always valid.

For example, relatively large dust particles will be influenced by gravity, and another example is the heavy gases. As mentioned earlier, the airflow has a great influence on the aseptic environment of the activity zone (between one-meter to the two meters above floor level). Need for a criterion capable to get the air distribution effectiveness in the activity zone for different design, is urgent to assist the designers to construct the optimum HVAC design for the given architecture design. This index should take in its consideration the influence of the presence of the horizontal and vertical flow in the activity zone, and the influence of the flow that comes from the neighboring zones especially the exhaust zone (near floor area up to one-meter level). So the index will depend on the weighting of the flow direction to the ideal case that was presented in the present investigation. And the index will consider the air age as a criterion to that recirculated flow enters the activity zone.

NEW METHOD: NEURAL NETWORK

1. Back propagation

In the present work, the fuzzy technique used to help the Artificial Neural Network (ANN) to be learned. This network is constructed with one hidden layer contain 10 neurons and 1 bias input. The inputs of the network are 2 or 3 neurons with 1 bias input according to each approach. The output layer of the network contains 1 neurons. Fig. 2 shows the flowchart of the Error back propagation training (EBPT) algorithm.

2. Selection of Parameters

The evaluation of IAQ in the present work will depend on the evaluation of airflow distribution only without the presence of the thermal factors. So, the subjective evaluating IAQ is an important aspect in IAQ research field, which should be based on comprehensive analyzing involved environmental factors.

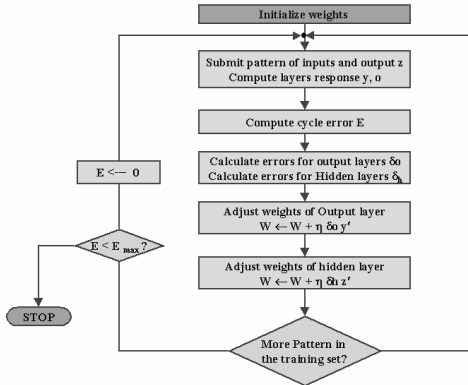


Figure 2: Flowchart of Error back propagation training (EBPT) algorithm

A lot factors effect on the IAQ evaluation or Local Ventilation Index (LVI). In the present work, the all factors will be geometrical and fluid factors. LVI is a function of (Geometry, Air Particle Path, Scavenging Flow, and Turbulence). From selection analysis of the IAQ parameters, it can conclude that the final IAQ parameters are as follow;

$$\phi_g = Z_p / H, \quad \phi_f = \tau_p / \tau_n, \quad \phi_t = \Delta\tau_p / [[\Delta\tau_p, k/\varepsilon]]$$

3. ANN Approaches

The first approach depends on the geometrical and fluid parameters only to introduce an index of the air effectiveness. The second approach depends on the geometrical, fluid parameters, and turbulence characteristics to introduce an index of the air effectiveness. It will be assumed that the flow at the perforated ceiling as a clean air (has grade 1 as a datum) and the flow at the exhaust ports in the floor as most pollutant air (has grade 0 as a datum).

4. Validation of input data and ANN Model

The results of input are compared with the numerical results of (Chow et al, 2000). The comparisons show a qualitative agreement with a maximum difference around 15%. The comparison in the operating area shows a good agreement. Also, the comparison of the ANN model gives a good indication about the training results of the present ANN model, with respect to the huge number of data used for training (Kameel, 2002).

PARAMETRIC CASES

Table 1 represents the configuration of the parametric cases in the present study for the surgical operating theatre in the Fig. 3.

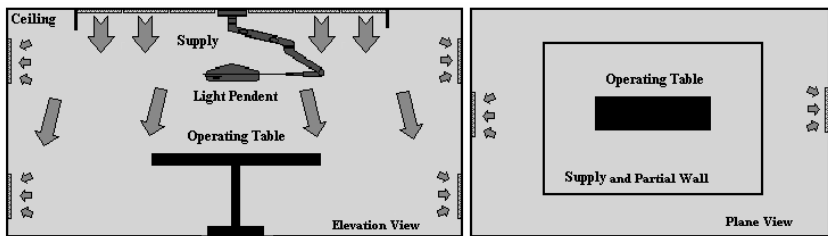


Figure 3: Operating Theatre Configuration

Table 1. The parametric cases in the present study

Case	SL/L x SW/WD	H _{LL} /H (2 sides)	H _{UL} /H (2 sides)
1	0.3 x 0.36	0.266	0.73
2	0.5 x 0.36	0.266	0.73
3	0.667 x 0.36	0.266	0.73
4	0.3 x 0.6	0.266	0.73
5	0.5 x 0.6	0.266	0.73
6	0.667 x 0.6	0.266	0.73
7	0.3 x 0.8	0.266	0.73
8	0.5 x 0.8	0.266	0.73
9	0.667 x 0.8	0.266	0.73

Room Dimension L x WD x H = 6.0 x 5.0 x 3.0 m Supply Dimension SL x SW, m
 Any Extract Port Dimension is 0.4 x 2.0 m Operating Table: 2.0 m Length, 1.0 m Width, 1.0 m Height .
 Partial Walls falls from ceiling 0.5 m in all cases. All cases ACH = 40
 LEH: Lower Extract Grille Center Height from the floor UEH: Upper Extract Grille Center Height from the floor
 All cases are calculated at supply temperature = 12 °C

RESULTS AND DISCUSSIONS

Such global indicator will aid HVAC systems designers to select the optimum HVAC designs to match available architectural design constraints. Certainly, the global indicator will depend on the results of the LVI obtained by the first and second approaches. The two approaches succeeded to obtain the LVI at each finite control volume at the whole domain. So the Global Ventilation Index (GVI) will be the volume averaged of the Local Ventilation Index (LVI). In the present work, the GVI will be calculated according to the first and second approaches, GVI_1 and GVI_2 based on the first and second approaches respectively. Also, the room air change efficiency ε_{ac} is calculated according to the equation 2. Fig. 4 represents the curves of the values of GVI_1 , GVI_2 , and ε_{ac} with the dimensionless groups (SL /L) and (SW/ WD). This figure represents contrasted trends of the global ventilation index proposed in the present work and the air change efficiency. The global ventilation index lies between one and zero, so it can be used to evaluate the enclosure HVAC system effectiveness relative to known datum (the most optimum enclosure that was proposed earlier). The increasing of the global ventilation index means more distributed air, acceptable distribution of the air according to its age, and effective turbulent air distribution is capable to remove or dilute the airborne contamination. On the other hand, the increasing of the air change efficiency does not mean a good distributed air, but in contrast, it means bad air distribution in some applications. Also, the air change efficiency is not capable to be used as comparative index, which each case represents another HVAC system design, another operational conditions, and architectural design. Indeed, the choice of the optimum HVAC system design will be more accurate, if this choice depends on the two measures, global ventilation index and air change efficiency.

RECOMMENDATIONS

The following statements summarize the most important conclusions of the present investigation: Downward flow developed through the use of central or separate individual ceiling supply diffusers designs, would yield better air distribution and smaller age. It is strongly believed that airside flow designs should be focused on the formation of protective curtain of air that prevents any transverse movement of particles from dirty air zone below operating table level to the clean operating zone air.

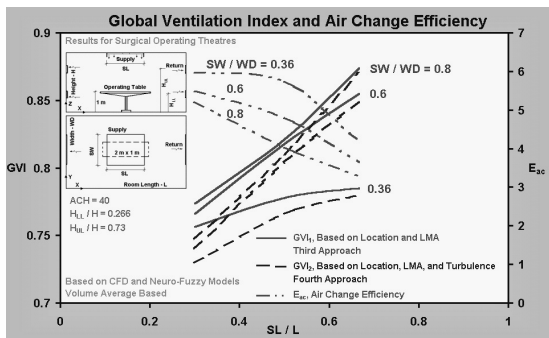


Figure 4: Numerical results of the proposed parametric cases

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