The Iraqi Journal For Mechanical And Material Engineering, Vol.17, No1,March.2017

EXPERIMENTAL AND NUMERICAL INVESTIGATION OF HOSPITAL SURGERY ROOM AIR DISTRIBUTION THROUGH CANOPY

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ABSTRACT :-

This study present experimental and numerical analysis of airflow distribution through surgery operating room by using CANOPY. The experimental work include an experimental operating room in laboratory of Babylon University. Two cases were taken in analysis of air distribution. Both cases have a ceiling air supply system and the different between then was in design of air supply system. Both cases consist of patient bed, surgical staff around, overhead light, surgical light and electrical devices. Air is exhausted through four exhaust grills located in four corners at latitude about 0.25 m from ground. In numerical work a three-dimensional model of the experimental operating room was developed in Gambit and analyzed in FLUEN6.3.26.The results showed that ceiling system is a good ventilation system for air distribution in operating room. Curtain air system gave more protection from laminar flow system where isolate the patient bed from the rest of the room and air velocity above the patient be low. FLUENT program give a good and close results to reality .Good agreement between numerical and experimental results was obtained inside experimental operating room.

Keywords: Operating room, Air distribution, Ceiling system, Experimental investigation, Air parameters, CFD Application .

دراسة عملية ونظرية لتوزيع هواء غرف العمليات الجراحية للمستشفى بأستخدام نظام التوزيع السقفي

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الخلاصة :-

البحث يتضمن دراسة عملية ونظرية لتوزيع تدفق الهواء خلال غرف العمليات الجراحية عن طريق تصميم غرفة عمليات تجريبية في مختبر جامعة بابل. و قد تم دراسة تحليل الهواء في حالتين, كلتا الحالتين تتضمن تظام توزيع هواء عن طريق السقف اما الفرق بين الحالتين هو في كيفية تصميم ذلك النظام السقفي. وفي كلتا الحالتين تحتوي الغرفة التجريبية على سرير المريض و الجراحين حوله و مصابيح جراحية فوق المريض مع مصابيح اخرى و اجهزة كهربائية ايضا. كذلك يتم سحب الهواء عن طريق اربعة مشابك توضع في كل ركن من اركان الغرفة على ارتفاع 0.25 متر من مستوى الارض . اما الجزء النظري فيتضمن رسم موديل ثلاثي الابعاد لغرفة العمليات التجريبية في برنامج Gambit وتحليله في برنامج .FLUENT6.3.26 اظهرت النتائج ان النظام السقفي هو نظام جيد لتوزيع الهواء داخل غرف العمليات الجراحية.نظام الستارة الهوائة يعطي حماية اكثر من نظام التوزيع التدفقي حيث يعزل المريض عن باقي الغرفة بالاضافة الى ان سرعة الهواء فيه فوق المريض تكون قليلة جدا . برنامج ال FLUENT يعطي نتائج جيدة وقريبة للواقع حيث ان هناك توافق جيد بين النتائج النظرية والنتائج العملية التي تم الحصول عليها داخل غرفة العملية التجريبية

Received : 10 – 3 - 2016
Accepted : 8 – 5 – 2016

NOMENCLATURE :

EOR: Experimental operating room

CFD: Computational fluid dynamics

1. INTRODUCTION :-

The important requirement for any surgery room air distribution system is to minimize the risk of infection. Temperature control and room pressurization that controls both supply and exhaust rates play an important role in the operating room, both for the operating staff and the patient. A typical operating room has several heat sources, including the medical personnel, a number of high intensity lights, and all sorts of mechanical devices. Good ventilated and the way distribution air inside surgery rooms are an important part in hospitals; thus the studies were conducted and the experimental tests were made to give the results of the designs in real zones.

Memarzadeh et al. (2000) studied the performance of a ventilation system in a typical patient room using CFD modeling. They were able to predict the necessity of using baseboard heating in extreme weather conditions. Also the validation of various supply air diffuser models gave useful guidelines on CFD modeling. Stevenson (2002) determined experimentally the airflow patterns around a patient in an operation room and to determine the effect of the buoyant flow. Yin (2004) studied exhalation flow from a patient with air borne infectious diseases that impose health risks to caretakers and visitors and investigated experimentally the performance of both mixing and displacement ventilation by using a full-scale environmental chamber to simulate a one-person patient ward. The results showed that laminar flow system can obtain velocity about 0.1m/s at the operation table. Air velocity distribution in mobile operation room was tested by Forejt (2005), conclusions of field experiments and energy modeling indicate possible limitations of the calculation practice leading to underestimation of energy demand for such facility. Hjalmarsson and Lindberg (2006) showed that the laminar air flow ventilation gives a much more controlled flow where fewer particles reach the patient than with conventional mixed ventilation where it is more likely that the staff unconsciously disrupt the flow. Anil (2008) studied experimentally the design parameters of heating ventilation air conditioning system of sterile spaces in hospitals. Based on the obtained experimental results, it’s noted that there are considerable differences of design parameters between “in operation” and “at rest” states. Gulick and Zhang (2009) investigated experimentally the performance of both mixing and displacement ventilation by using a full scale environmental chamber to simulate a one-person patient ward. Honglu (2011) measured a full scale measurement in a climate chamber to analyze the performance of diffuse ceiling ventilation system used in an office room. Lstiburek (2011) measured ventilation air change rate, local mean age-of-air, and ventilation air distribution for two operation rooms. The results showed that laminar flow diffuser can obtain the optimal air velocity for the surgical work.

The main outcome of this research is the investigate experimentally and theoretically the air flow distribution and air parameters (velocity, temperature and relative humidity) inside operating room by using two different type of cool air ceiling supply system. In addition, it is determination of key design parameters that significantly influence the air distribution patterns, and quantities. Additionally, the data presented here are investigating the design of operating room air distribution systems in the computational domain .

2. EXPERIMENTAL INVESTIGATION :-

An experimental operating room (EOR) as shown in **Figure (1)** with dimensions (4.9×4.9×2.4) m is designed and constructed in a laboratory of Babylon University. The EOR consist of patient bed, surgical staff around, overhead lights, surgical lights and electrical devices (two monitors and one anesthesia machine). Also, as ASHREA application 2015 EOR consist air exhausted through four exhaust grills with dimensions (0.2×0.2) m located in four corners of EOR at latitude about 0.25 m from ground for air exhaust as shown in **Figure (2**). Two cases were taken in analysis of air distribution. Both cases have a ceiling air supply system and the different between it was in design of air supply system. In case-1 cool air entering to EOR by air canopy located in the middle of ceiling above patient bed consist of two rectangular plenum boxes with dimensions (1.2×0.6) m for each one and four slots around it with dimensions (0.07×2) m, these dimensions are selected according to cooling load of room and from TUTTLE & BAILEY catalog. In case-2 cool air entering to EOR by two rectangular plenum boxes (without slots), as shown in **figure (3).** The amount of air that obtained from cooling load calculations of EOR is 0.519 m^3/s. In case-1 one-third of the amount air given to two plenum boxes in order to make a laminar flow of air above patient bed while two thirds of remaining air given to slots in order to making curtain air around patient bed.. In case-2 all air amount enter through two plenum boxes. Experimental mesurment at both cases include velocity measurement by suing hot film air mass meter, type HFM5, with range (0-15) m/s, temperature measurement by using NTC sensors with range (-40 to 135) ^oC. and relative humidity measurement by LGHTM-02A resistor type analog output humidity Sensor module w/shell with humidity range (0 -100) % with output voltage (0 - 3.3) V.

Measurements is directed by LABVIEW program due to high accuracy in terms of obtaining and presentation of results. The experiments tests is done using fifteen sensors for each velocity and temperature and seven sensors for relative humidity, all sensors distributed at three levels inside EOR (1,1.5 &2) m and in different locations as shown in **Figure (3)** for both cases. where line1,2 and 15 located under plenum boxes, line3,4,5 and 6 located under four slots, line7,8,9 and 10 located in four mid sides of room and line1,12,13 and 14 located in four corners of room. Temperature and velocity are measured in all fifteen lines while relative humidity is measured in seven lines (1,2,3,5,7&9) in EOR. The suitable values for the parameters of air inside the EOR was obtained after more than thirty minutes.

3. THE CFD APPLICATION AND GOVERNING EQUATIONS :-

A CFD method was applied to study air distribution and its parameters inside surgery operating room. The EOR with dimensions (4.9×4.9×2.4) m has modeled as a three dimensional structure by using Gambit program. The dimensions of structure inside EOR are shown in **table1.** Pave mesh type (Triangular) is used for surface mesh generation and created for the operating model room geometry on the outlet sections, surgical lights, table patient and inlet sections. After all the parameters mentioned previously have been meshed. The volume mesh Tet-hybrid (T- Grid) can be created, Ahmed Al-shawi (2011). The Stander k-ε model based on the commercial program FLUENT6.3.26 is used to perform the simulation. The governing equations are discretized with second order accuracy. SIMPLE algorithm is used to couple pressure and velocity. Buoyancy effect is considered by Boussinesq model. Velocity-inlet and outflow boundary conditions were used for supplies and exhausts respectively. Heat sources such as lamps, workstation and occupants were set with constant heat flux. The boundary conditions for parts inside EOR and its supply and exhaust opening are given in **table 1, 2, 3 and 4** for both cases.

4. RESULTS AND DISCUSSION :-

The results are presented as experimental, numerical, comparison between them and comparison with other Researcher as follows:

4.1 Experimental results

The Plane A-A as shown in **Figure (5)** was taken as a reference started at high=1 m (z=1m) from the ground, this level was located at the surgical table surface.**Figures (6** & **7)** represent the vector maps of air velocity for A-A plane in the EOR. The vector maps of air velocity gives the image of how the magnitude and the directions of the velocity field was distributed. It's noted that velocity above operating table near the patient in case-1 was smaller than in case-2, Also it can be noted that the velocity of air under slots was high and approach 3.6 m/s at high 2 m in case-1. This represent the air curtain around the patient bed, while in case-2 the highest value of velocity was directly under plenum due to all amount of air entering to EOR through plenum boxes. **Figures (8** & **9**) display the contour of temperature distribution at plane A-A. For case-1 it is seen that the temperature increases from less value near the canopy under slots to reach the highest value at the surgical table surface (293 K to 297 K) due to the air velocity high at the upper region; therefore the heat transfer process at this location is more efficient as result of reducing the temperature of the domain. For case-2 the air temperature distribution gives a different shape as well as different values for air accelerated under plenum for all the domain of the room from case-1. Another observation is that the temperature distribution mostly looks like the distribution of velocity for both cases. **Figures (10 & 11**) represent the contour maps of relative humidity for plane A-A. Relative humidity distribution, is a key factor of thermal comfort. For case-1 it can be seen that the upper part (near the inlet) had high relative humidity approach (50%) due to pressure very small change in the whole region and water vapor concentration does not change. In case-2 all air amount will entering to the EOR through the plenum boxes without slot. This gives a different shape for air relative humidity distribution as well as different values for air accelerated under plenum for all the domain of the room. Relative humidity at the surgical table was approach (50.5 %). **Figures (12 & 13)** show the value of velocity for three lines located under plenum boxes at three levels for both cases. It's noted that all velocities in case-2 was higher than in case-1 due to all amount of air entering to EOR through plenum boxes only. The velocity above patient at level (1 m) in case-1 (reach to 0.06 m/s) was smaller and more acceptable than case-2. The high of ceiling affects clearly on the air velocity where low height of ceiling leads to the arrival of the air at high velocity above the patient's bed especially in ceiling air distribution system. **Figure (14 & 15)** show the value of air velocity for four lines located under slots for both cases (in case-2 four lines located at the same positions under slots that in case-1 even there were no slots). At three levels it can be noted the high value of velocity that represent the air curtain in case-1 and also it can noted in case-2 the high value of velocity at level (1 m) due to impact between velocity of amount air that entering to EOR through plenum boxes with patient bed. This probably can be explains as case-2 need to increase the plenum boxes area in order to reduce the outlet air velocity. Also, the high of room ceiling effects on the velocity of air.

Figures (16 & 17) represent the temperature distribution for three lines located under plenum boxes for two cases. It’s noted that temperature in case-2 was lower than in case-1 due to all amount of air entering to EOR through plenum boxes only while in case-1 only one-third of amount air entering through plenum boxes. Temperature increasing from top to bottom. Generally, both cases have good and acceptable range of temperature. **Figures (18 & 19)** show the value of temperature for four lines located under slots for both cases. At three levels temperatures in case-1 higher than case-2 due to location under slots.**Figures (20 & 21)** represent the value of relative humidity in more points inside EOR at three levels. For both cases higher value of relative humidity will be at level (2 m) under supply air coming from canopy in case-1 approach 51% or from plenum boxes on ceiling in case-2 approach 59%. Relative humidity at level (1 m) above patient bed in case-2 is higher than case-1 due to all amount of cooling air entering to EOR through plenum boxes above patient bed. Line7 and line9 in both cases have smallest value of relative humidity due to higher value of temperature in these regions due to get away from the cold air supply on the middle of the ceiling.

4.2 Numerical Results

The velocity under plenum boxes at all levels in case-1 was smaller than in case-2 due to all amount of air entering to EOR from plenum boxes only, this is shown by vector map of velocity for plane A-A in **figures (22 & 23)** and contour of velocity in **figures (24 & 25)** that represents how the curtain air surrounding the patient bed and surgical staff. For case-1 the temperature was higher and relative humidity was smaller than in case-2 for the same plane in region under plenum above the patient bed due to all amount of air entering to EOR through plenum boxes. For both cases the temperature increase and relative humidity decrease in the areas far from the patient's bed, this is shown in **figures (26 to 29)**

4.3 Comparison between the Experimental Work and Numerical Work

Figures (30 to 35) show the comparison between the experimental and numerical air velocity, temperature, and relative humidity results in EOR for two cases for horizontal line located at y= 2.45 m and height (z=1m) above the bed of patient in the middle of EOR there lines started from the one side of the room passing above the patient's bed and down to the other side. It is interesting to note that the results obtained from CFD simulation were in good agreement with the results obtained from experiments. And the average error in reading was 11% for velocity and 11% and 4.6 % for both temperature and relative humidity respectively this due two some effect like calibration and instruments defect.

4.4 comparison with other Researcher

Comparison between contours of temperature for the present work for case-2 has been done. It was noted that a good agreement of both study results and published results by Sasan Sadrizadeh et. al. as shown in **figures (36 & 37**) . It can see that the temperature is started from 19 ^{o}C and ended at 25 ^{o}C for both results with percentage error 0.15 %.

5. CONCLUSIONS :-

According to the previous discussion of the obtained results, the following conclusions can be extracted:

1. LABVIEW was used successfully in this work to control the whole experiments.
2. FLUENT program gave a good and close results to reality. Good agreement between numerical and experimental results was obtained inside the EOR.
3. The results showed that ceiling system is a good ventilation system for air distribution in operating room.

4. Both air curtain and full laminar flow systems can offer effective protection for the patient if designed correctly.

5. Air curtain system gives more protection than laminar flow system where it isolate the patient bed from the rest of the room and air velocity above the patient is very small.

6. The height operating room ceiling is a very important factor among other air parameters especially the air velocity.

7. Generally, temperature increase and relative humidity decrease through the domain of EOR especially in some positions like surgical lights, over the patient bed .

Table.1 dimensions and boundary conditions of the parts inside EOR

Part	Dimensions	Boundary	Thermal conditions
Patient (top surface of box)	2m × 1m at high 0.9 m from ground	wall	Heat Dissipation = 46 W Heat generation Rate = 0 (W/m^3)
Surgical staff	0.25 m × 0.30 m × 170 m	wall	Heat Dissipation = 4100 W each Heat generation Rate = 0 (W/m^3)
Surgical light ×2	0.2 m × 0.2 m × 0.2 m	wall	Heat Dissipation = 150 W each Heat generation Rate = 0 (W/m^3)
Overhead light ×4	0.07 m × 0.95 m	wall	Heat Dissipation = 180 W each Heat generation Rate = 0 (W/m^3)
Equipment	0.33 m × 0.33 m × 1.3 m 0.33 m × 0.33 m × 1.22 m	wall	Heat Dissipation = 200 W each Heat generation Rate = 0 (W/m^3)

Table.2 values of inlet boundary conditions at supply parts for case-1

Part	**Type of boundary**	**Temperature (k)**	**Velocity (m/s)**	**Water vapor concentration kg/kg $_{air}$**
Plenum boxes	Velocity inlet	293.5	0.12	0.007
Slots	Velocity inlet	293	0.6	0.007

Table.3 values of inlet boundary conditions at supply parts for case-2

Part	**Type of boundary**	**Temperature (k)**	**Velocity (m/s)**	**Water vapor concentration kg/kg $_{air}$**
Plenum boxes	Velocity inlet	292	0.36	0.0073

Table.4 value of boundary conditions at outlet grills for two cases

Part	**Type of boundary**	**Value of boundary**
Exhaust Grills	Outflow	0.85 % of inlet volume

Figure (1) Experimental Operating Room

a- Two plenum box

b- Four slots

c- Exhaust grills

d- Surgical lights

e- Devices (monitor and stand)

f- Device (anesthesia machine

g- Velocity and temperature sensors placed on stand

h- Relative humidity sensor

i- Absolute pressure sensor

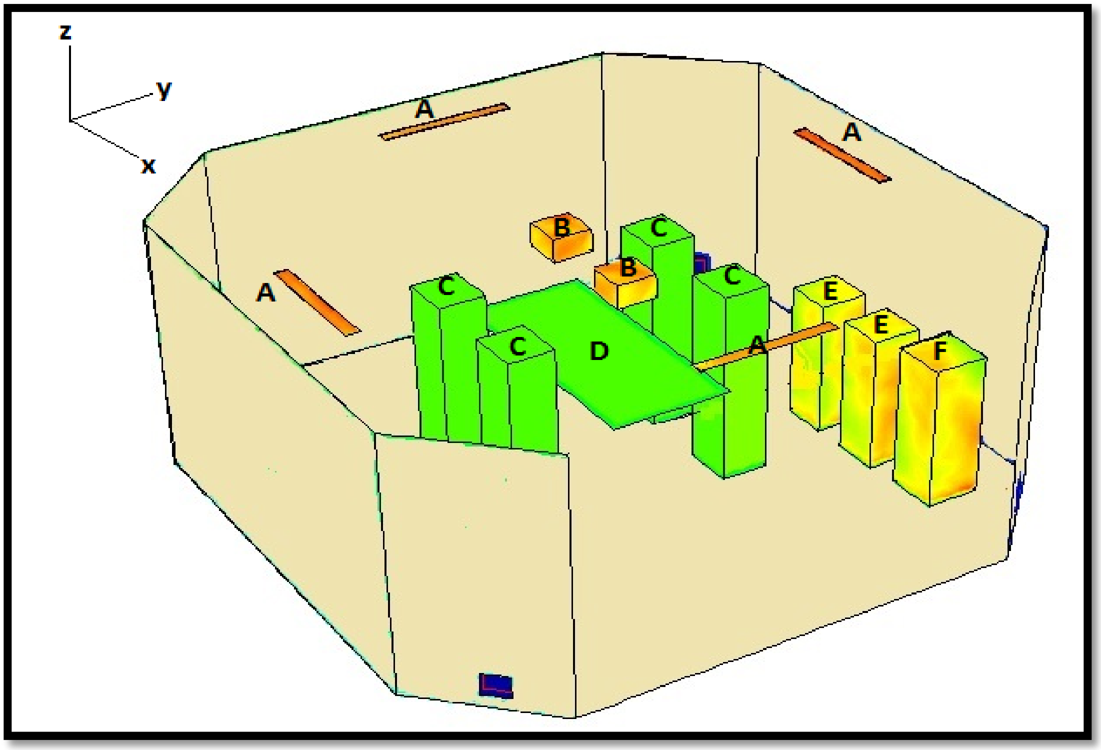


Figure (2) Experimental operating room with contents where, (A): Overhead light on the ceiling, (B): surgical light, (C): surgical staff, (D): patient bed, (E & F): Equipment.

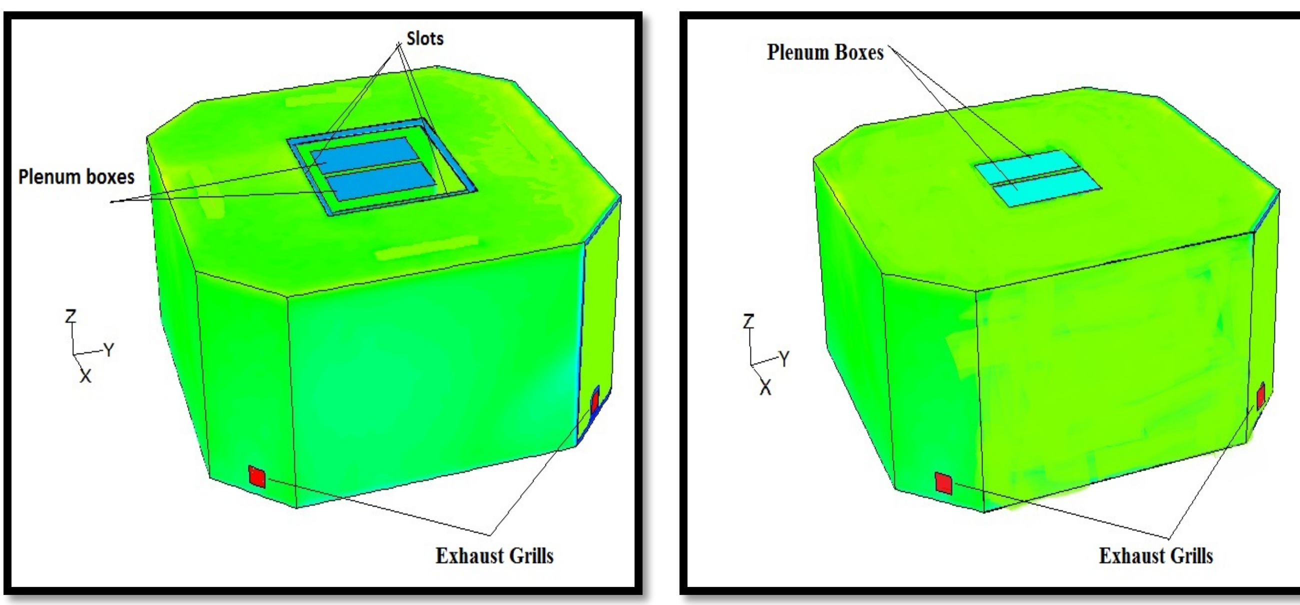
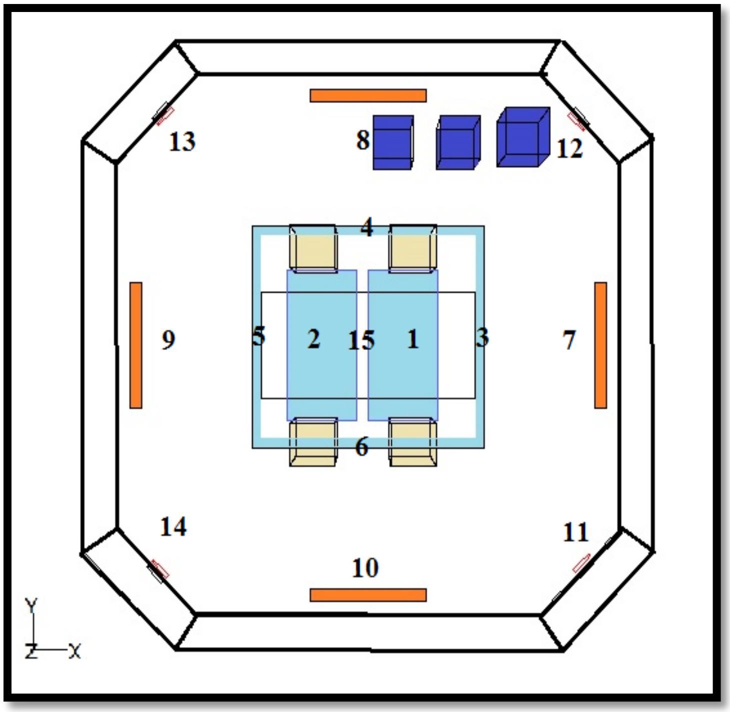
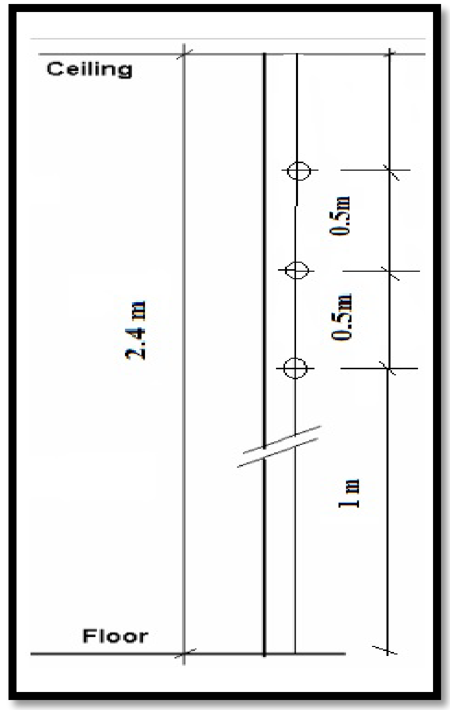


Figure (3) two different types of air supply system





Locations of sensors at different lines from top view of EOR **Locations of sensors at different levels for each line inside EOR**

Figure (4) locations of line inside experimental operating room

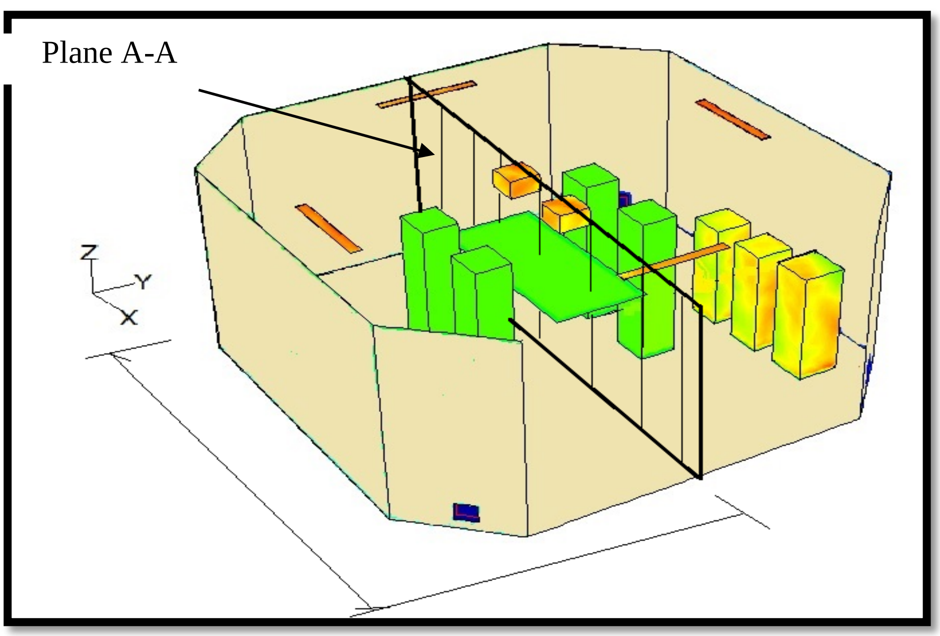


Figure (5) location of plane A-A in middle of EOR

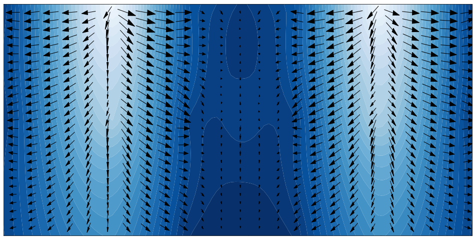


Figure (6) Vector map of velocity for case-1

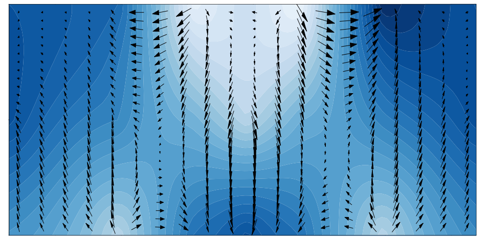


Figure (7) Vector map of velocity for case-2

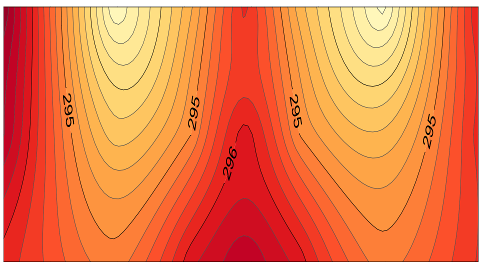


Figure (8 Distribution of air temperature,case-1

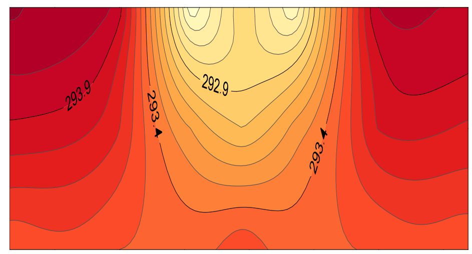


Figure (9)Distribution of air temperature,case-2

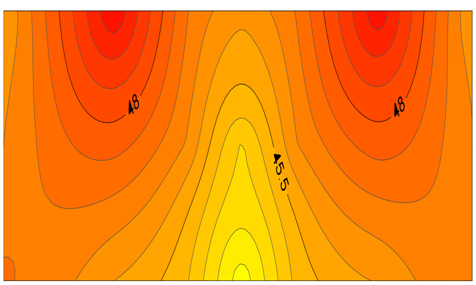


Figure (10) Relative Humidity Contour, case-1

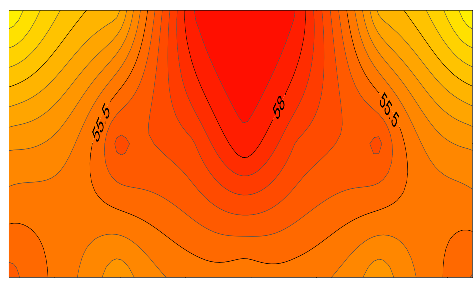


Figure (11) Relative Humidity Contour, case-2

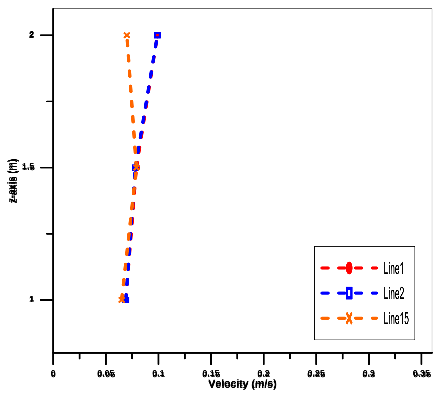


Figure (12) velocity distribution for case-1 for three lines located under plenum

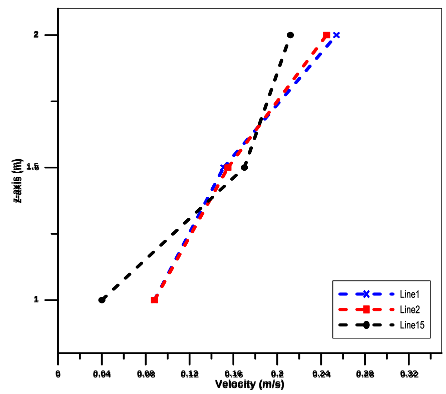


Figure (13) velocity distribution for case-2 for three lines in same position of case-1

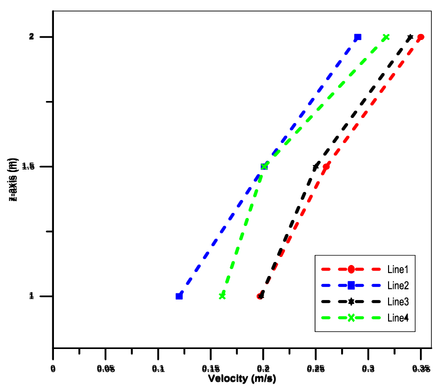


Figure (14) velocity distribution for case-1 for four lines located under slots

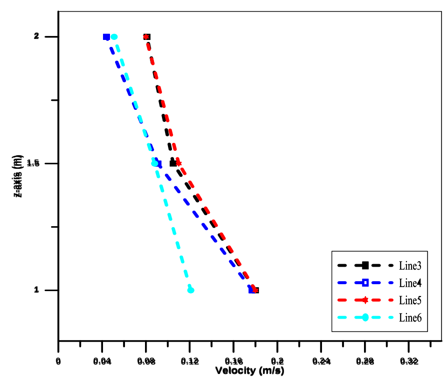


Figure (15) velocity distribution for case-2 for four lines in same position of case-1

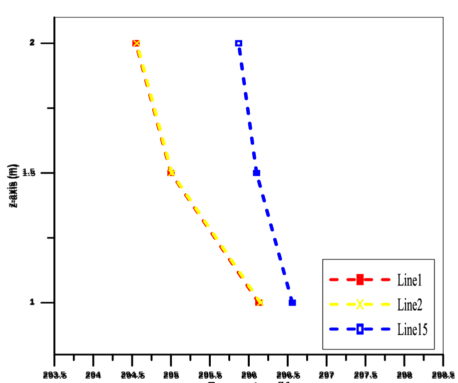


Figure (16) temperature distribution for case-1 for three lines located under plenum

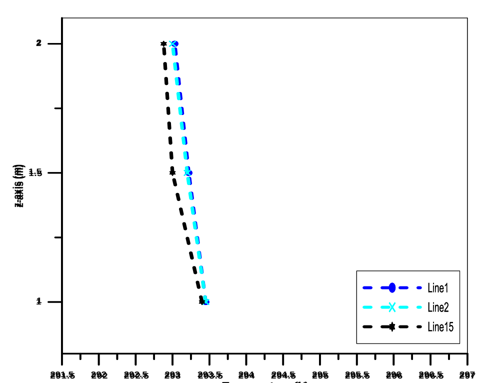


Figure (17) temperature distribution for case-2 for three lines in same position of case-1

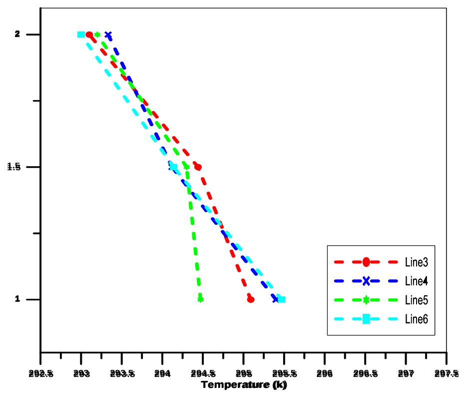


Figure (18) temperature distribution for case-1 for four lines located under slots

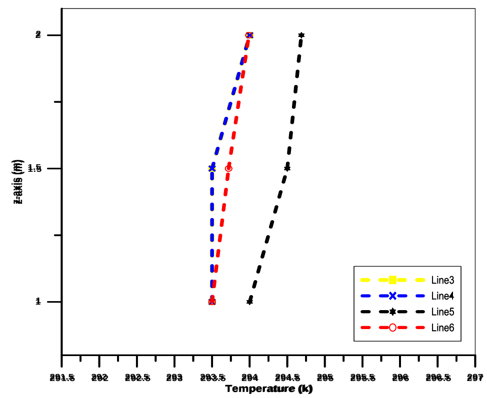


Figure (19) temperature distribution for case-2 for four lines in same position of case-1

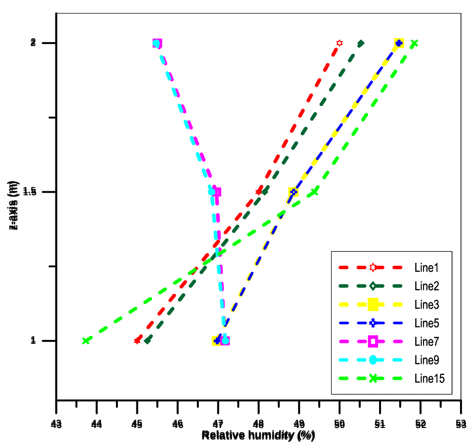


Figure (20) relative humidity distribution for case-1 for lines located in different positions inside EOR

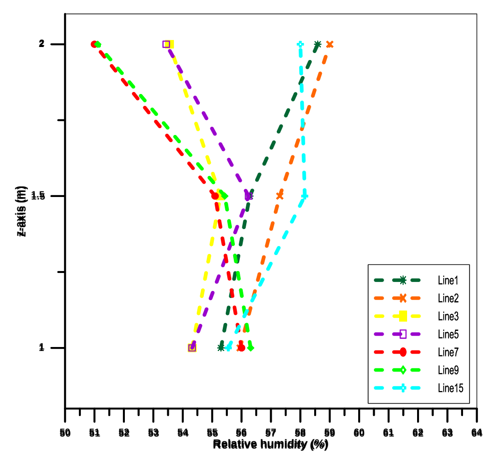


Figure (21) relative humidity distribution for case-2 for the same position of lines in case-1

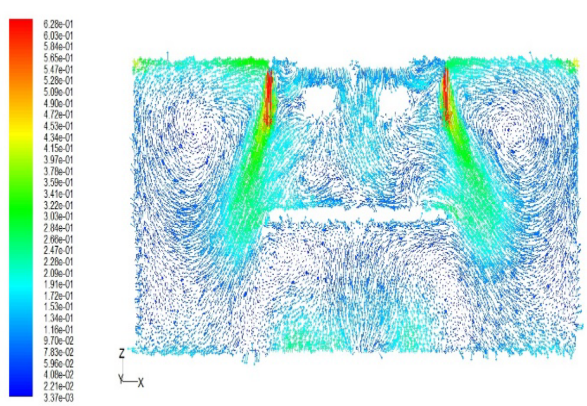


Figure (22) Air Velocity Vector, case-1

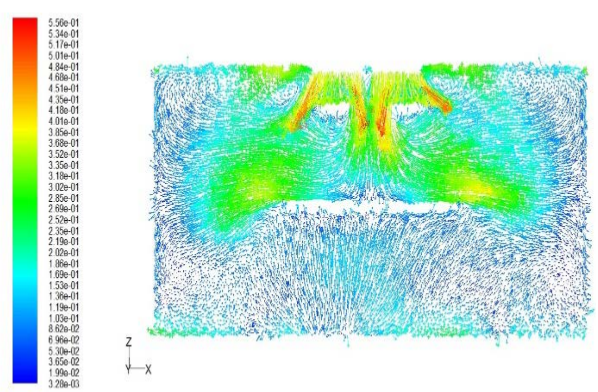


Figure (23) Air Velocity Vector, case-2

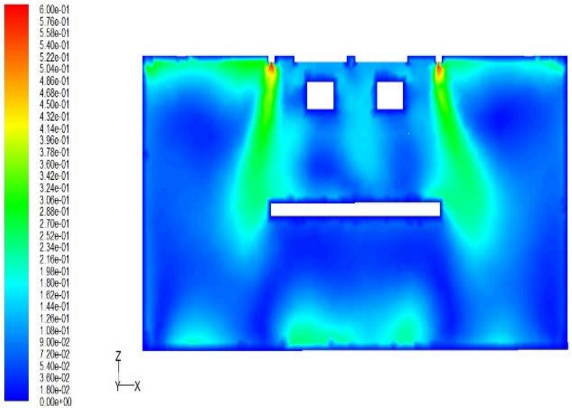


Figure (24) Air Velocity Contour, Case-1

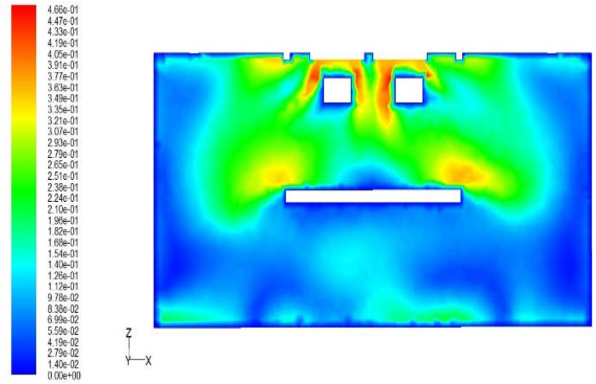


Figure (25) Air Velocity Contour, Case-2

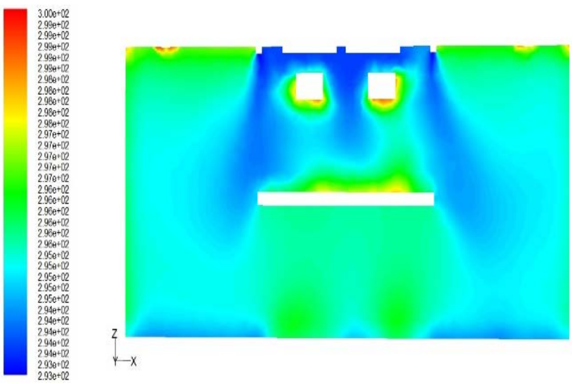


Figure (26) Temperature Contour, Case-1

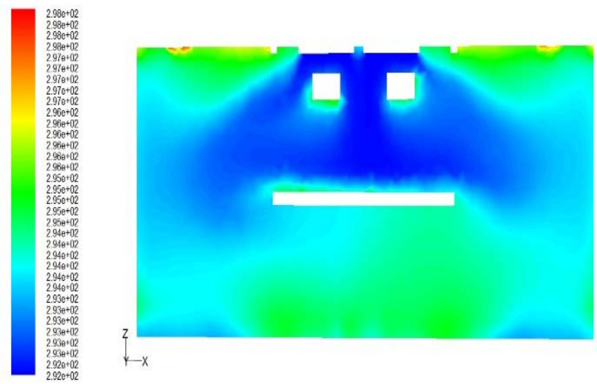


Figure (27) Temperature Contour, case-2

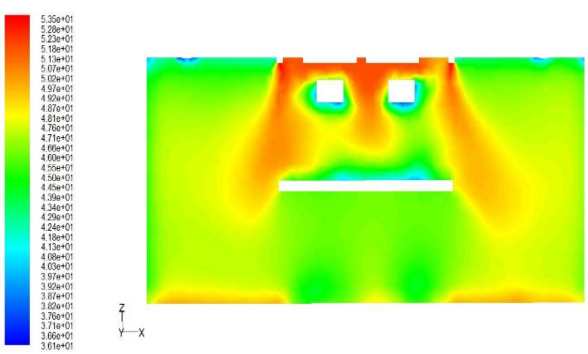


Figure (28) Relative Humidity Contour, case-1

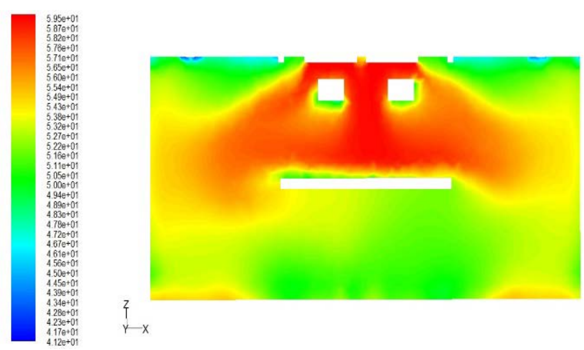


Figure (29) Relative Humidity Contour, case-2

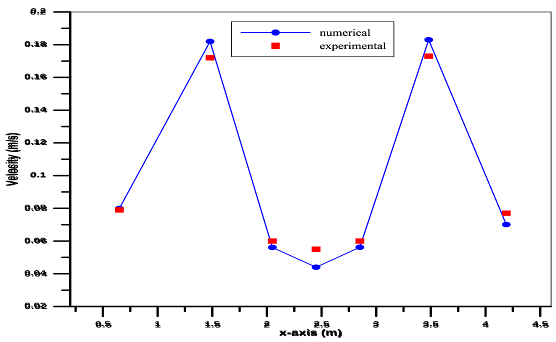


Figure (30) comparison between numerical and experimental results of velocity at z=1 m and y= 2.45 m for case-1

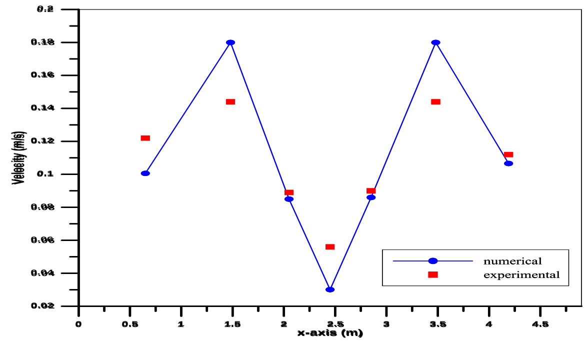


Figure (31) comparison between numerical and experimental results of velocity at z=1 m and y= 2.45 m for case-2

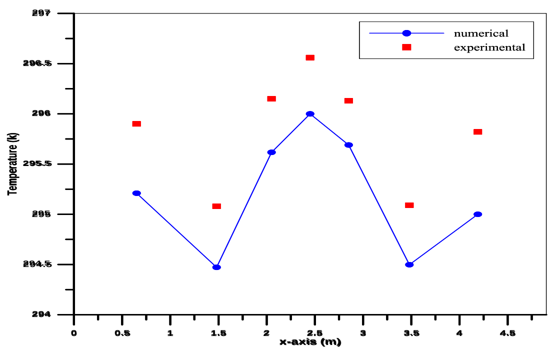


Figure (32) comparison between numerical and experimental results of temperature at z=1 m and y= 2.45 m for case-1

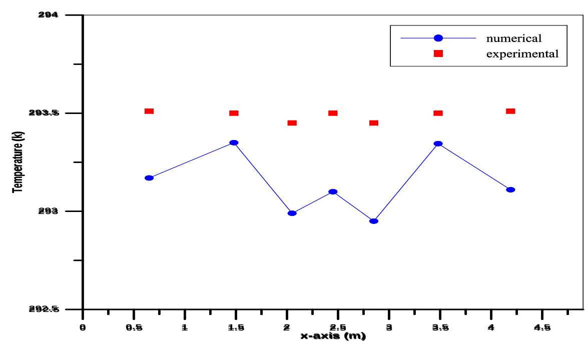


Figure (33) comparison between numerical and experimental results of temperature at z=1 m and y= 2.45 m for case-2

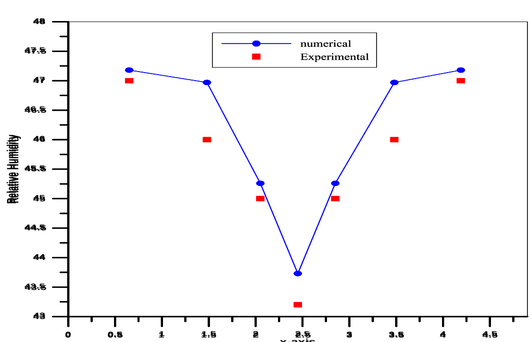


Figure (34) comparison between numerical and experimental results of relative humidity at z=1 m and y= 2.45 m for case-1

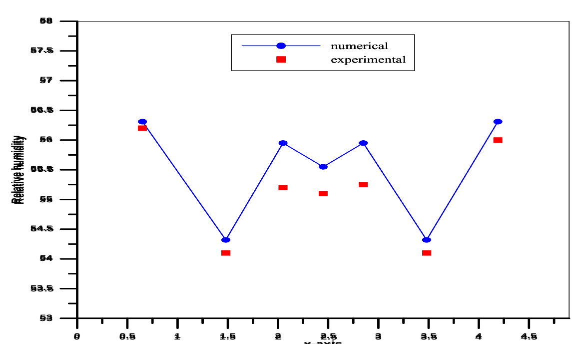


Figure (35) comparison between numerical and experimental results of relative humidity at z=1 m and y= 2.45 m for case-1

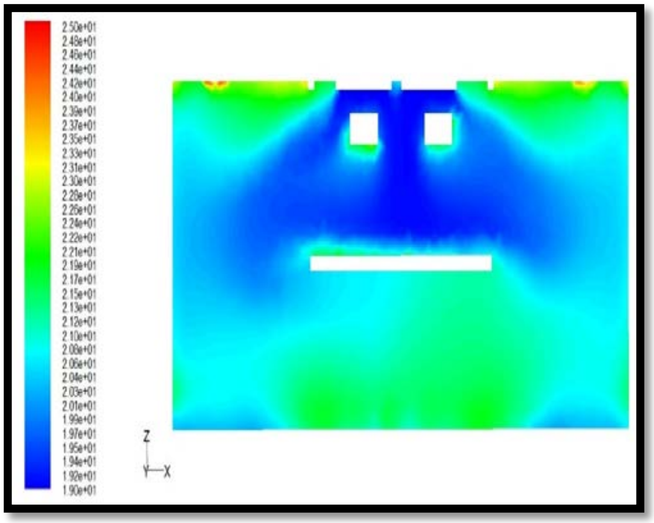


Figure (36) Numerical Contour of Temperature for Case-2

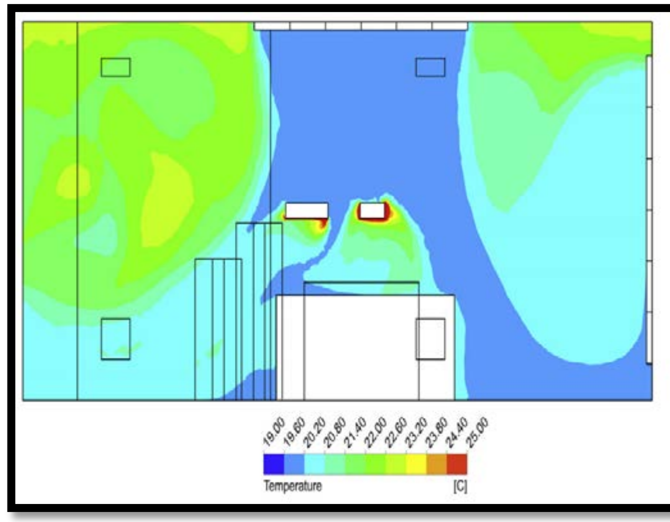


Figure (37) Contour of Temperature by Sasan Sadrizadeh et. al

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