EXPERIMENTAL STUDY OF AIR DISTRIBUTION WITHIN OPERATION ROOM

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Abstract :-

The experimental analysis includes a patient lying on an operation table, surgical staff members, and surgical lights above the patient. The cold clean air is supplied to the room through grilles from ceiling diffusers and exhausted through low side walls. The first aim of the experimental study is to investigate the validity of air distribution within operation room and the effect of using the air filtering on the air flow distribution. Different air distribution system to what exists in the optical operation room, is also investigated by locating the inlet at the upper part of a side wall, while the exhaust grilles were in the lower part of the opposite side. From this study, it was found that the temperature and relative humidity in the surgical zone are 21.3^{o}C and 49.3% in the optical operation room. While, the values in the experimental operation room are 23.6^{o}C and 45.3%. These values in both operation rooms are in the acceptable range of the surgical conditions as well as for the carbon dioxide. Therefore, it can be using the wall air supply system in the operation room with good conditions for the surgical work.

KEYWORDS: Air conditioning, Ventilation, Operation room, Experimental operation room, Filtration.

دراسة عملية لتوزيع الهواء خلال غرفة العمليات

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الخلاصة:

تضمن التحليل العملي مريض يرقد على طاولة العمليات والفريق الجراحي حول المريض والمصابيح الجراحية فوق المريض. تم تزويد الهواء النقي البارد للغرفة من خلال شبكات (grilles) من خلال ناشرات الهواء السقفية وثم طرد الهواء من أسفل الجداران . الهدف الأول من الدراسة العملية هو اختبار نظام توزيع الهواء من حيث درجة الحرارة والرطوبة النسبية و سرعة الهواء وذلك لمعرفة مدى صلاحية نظام توزيع الهواء المستخدم حاليا في غرف العمليات . كما تم دراسة تأثير عملية التنقية باستخدام فلتر على توزيع جريان الهواء داخل غرفة العمليات. تم استخدام نظام توزيع هواء مغاير لما موجود في غرفة العمليات الواقعية وذلك بجعل نظام تجهيز الهواء من خلال (diffuser) في أعلى احد الجوانب أما منافذ السحب فقد كان في الجزء الأسفل من الجانب المقابل . من هذه الدراسة , تم إيجاد أن درجة الحرارة والرطوبة النسبية في نطاق منطقة العمل الجراحي هي 21.2^{o}C و 49.3% في غرفة العمليات الواقعية . بينما في غرفة العمليات التجريبية فأنها 23.6^{o}C و 45.3% . هذه القيم في كلتا غرفتي العمليات هي في المدى المقبول لشروط العمل الجراحي وكذلك بالنسبة لغاز ثنائي اوكسيد لكاربون. لذلك فانه من الممكن استخدام نظام تجهيز الهواء ألجداري في غرفة العمليات مع توفير شروط جيدة للعمل الجراحي.

1.INTRODUCTION

Good ventilated and clean room is 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. There are many researchers who studied this aspect of operation room when (Zhang, 1977) studied firstly the design parameters systems of sterile space in hospitals as a part of that study was the operation room, an experimental attempt has been performed to demonstrate the differences between the results of the "at rest" and "in operation" tests of an operation room. The operation room temperature, room relative humidity ratio, air velocity and particle concentration were measured continuously throughout a week. Hygienic tests in "at rest" condition have been performed by an independent validation company and the system has been certified. These measurements were conducted in an operation room and a sterile corridor of the operation suite in a hospital. The supply air temperature and relative humidity ratio data were measured and saved by the automation system. (Pelleu, 1979) evaluated the effectiveness of high efficiency particulate air filters in reducing the concentration of airborne microorganisms. Also, he studied experimentally thermal distribution inside the operation room. It was concluded that under normal working conditions an 800cfm filter unit is effective in reducing the concentration of air borne microorganisms by about 70 percent. (Stevenson, 2002) determine experimentally the airflow patterns around a patient in an operation room and to determine the effect, if any, 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. He 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. (Forejt, 2005) tested air velocity distribution in mobile operation room. Conclusions of field experiments and energy modeling indicate possible limitations of current 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, he 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.

In the present work, the parameters of the operation room has been measured to study the air distribution in it. These parameters are:

1. Temperature which is measured by advance sensors.
2. The humidity which is measured by a digital device.
3. Air velocity which is measured by a hot wire device.
4. Dioxide carbon CO_2 which is measured by advance sensor.

The experimental work consisted of two parts: The first was the measuring of the data in an optical operation room (in Safeer Al-Hussein hospital), while the second part was the

measurements in an experimental operation room (testing room was designed and constructed in engineering college at Babylon University).

2.EXPERIMENTAL WORK

The optical operation room was of (6m×6m×3m) dimensions and four surgical lights were located above the patient, with four air supply diffusers of the size (100cm×40cm) each, and the exhaust grills size (40cm×25cm) were located at a corner on the walls near the floor with flow rate at 2500cfm. The optical operation room walls consist of double walls of cement blocks and plaster sheets. There is a heat insulating material between these walls. The inside walls of the optical operation room were painted by anti-bacterial coating. In the optical operation room, it used curvature planes instead of the corners in order to prevent the particles and bacteria coalesce in these regions. While, the experimental operation room was designed and constructed in engineering college at University of Babylon. The dimensions of this experimental operation room are (3m×2m×3m). This room was constructed from a metal structure which covered with wooden boards and then insulated by glass wool layer. In this operation room, the inlet air diffuser was located at upper part in one of the walls with dimensions (35cm×35cm), while the exhaust air grills were two grills located in the corners of lower part of the opposite wall with dimensions (20cm×20cm).

2.1.Measurment Instruments

2.1.1. Temperature Measuring Devices

In this study, two measurement devices have been used: the first was the digital thermometer while the second was the multi channels temperature recorder. A digital thermometer is an instrument that senses temperature which has a close electronic circuit with a digital monitor to display the values of temperature. This model of a digital thermometer which was used in optical operation room test is "YK – 2005AH" type. The resolution of the device is 0.03%. A multi channels temperature recorder is a digital instrument with multi sensors for measuring temperature. This device has 12 temperature sensors; therefore it is used for measuring the temperature for the largest possible number of points. It has sensors type J/K/T/S/ E/R, and the accuracy is about 0.4%. In the present work, it was used K type thermocouples.

2.1.2.Relative Humidity

A digital hygrometer is a measurement device of the relative humidity. The model of this digital hygrometer, which is used in this test, is "GRT-4448". The relative humidity range of this device is 0% to 97%, and the accuracy error is about 0.06%.

2.1.3.Dioxide Carbon CO_2

"Carbon dioxide device" is an instrument for the measuring carbon dioxide. The measuring of carbon dioxide is important in monitoring indoor air quality of an operation room. The most common principles for CO_2 device are infrared gas sensors (NDIR). The model of this device is "GCH-2018", while the device reading range is 0 ppm to 4000 ppm.

2.1.4.Air Velocity Measurement

The device which was used for measuring the air velocity in operation rooms is "remote vane digital anemometer" model "8901". The accuracy error of this device is about 0.04%.

All the measuring instruments used in the experimental work (temperature, humidity, air velocity and carbon dioxide devices) have been calibrated as detailed by (Abd Ali, 2014).

The experimental work for this study can be divided into two parts of work :
a. Measuring of data in optical operating room.
b. Measuring of data in experimental operating room.

a.The Experimental Work in Optical Operation Room

The data measuring in the optical operation room can be divided into two types as follows:

a. When the optical operation room is at rest: This means that the cooling system works as lighting and some machines but does not surgical work and staff.
b. When the optical operation room is with surgery work and full staff: This means that the operation room with full staff and during surgical work.

The air conditioning system consists of supply air handling unit, exhaust fan, air filters (HEPA filters) and air diffusers as shown in **Fig. 1**. Filtration is an important aspect of clean rooms to prevent the bacteria from passing to the operation room and to obtain clean space. Air filters are located at the end of air supply duct before the air diffuser to ensure highest level of sterilization inside the optical operation room as presented by (Leiden and Lobascio, 2004). Most filters are defined by their particle removal efficiency and air flow rate.

Experimental Procedure

First, person must wear a special type of the clothes to enter the operation room. Then, the appropriate places to measure the air parameters inside the optical operation room were determined. These spaces were specified by numbering from 1 to 7 as shown in **Fig.2**. The air condition system must be operated for period of time from 35 min to 45min in order to reach the optical operation room to the thermal stability and obtain the suitable conditions for the surgical work. Temperature was measured in the optical operation room by using the digital thermometer. The sensor of the digital thermometer was placed in the specific point inside the optical operation room. The measurements were taken in seven points at different three levels of the distance for each point as shown in **Fig. 2**.

b. Experimental Operation Room

The experimental operation room was designed and constructed in engineering college at University of Babylon. The dimensions of this experimental operation room are (2m×3m×3m). This room was constructed from a metal structure which covered with wooden boards and then insulated by glass wool layer. In this operation room, the inlet air diffuser was located at upper part in one of the walls with dimensions (35cm×35cm), while the exhaust air grills were two grills located in the corners of lower part of the opposite wall with dimensions (20cm×20cm) for each. The air parameters air velocity, temperature, relative humidity and CO_2 were measured in different points as shown in **Fig. 3**. Where, the numbered points represents the locations of measuring instruments.

Experimental Procedure

The air cooler was operated until reach the temperature inside the operation room to operation limit of temperature as 25.5^{o}C. Appropriate points have been chosen in the domain of room dimension in order to measure the air parameters inside the operation room. Thermocouples type K were fixed in the exact locations in order to record the temperature at these locations, while the data logger was out of the experimental operation room. In each point, temperature, relative humidity, velocity, and carbon dioxide were measured. The measurements of air parameters were taken after twenty minutes of cooling unit working. At that time the air parameters reached the suitable values of operation surgery.

3. RESULTS AND DISCUSSION :

Fig. 4 displays the domain of the optical operation room. **Fig. 5** shows the contour map of air velocity for x-y plane in the optical operation room. It can be seen that the point (0,0) is located at the surgical table surface, which is at level 1m from the ground. Therefore, the vertical distance from this point to the ceiling is 2m as shown. Velocity field was plotted on the filled speed contour background. It gives the image of how the magnitude of the velocity field was distributed. The cool air flow entered the optical operation room vertically through the inlet at the roof centre at uniform full speed (0.84 m/s). In this figure, it can be seen that the air velocity distributes from the high value at the air inlet and then it reduces through the domain. Air velocity decreases through the domain is due to the friction of air layers and the impact of air with items. It can be seen that the velocity at the surgical table is about (0.4m/s). The range of air velocity in this plane is (0.84m/s - 0.28m/s). This is consistent with the results which were obtained by many researchers such as (Yin, 2004). **Fig. 6** displays the contour map of air velocity for y-z plane in the optical operation room. It can be seen that the air velocity decreases from (0.8m/s) near the inlet supply air to reach (0.3m/s), while the velocity at the surgical table is about (0.4m/s). In this figure, it can be seen that the air velocity at upper region is relatively high due to the effect of entering air to increase the velocity.

Fig. 7 displays the isothermal contour of temperature distribution for x-y plane in the optical operation room. The low temperature of the supply air from inlet is concentrated mostly at the upper part. In the far surroundings, the temperature distribution seems uniform in general, but the values are higher. It can be seen that the temperature increases from 18.2^{o}C near the supply diffuser to reach about 20.5^{o}C at the surgical table surface, while it reaches 23^{o}C in the remote regions of the plane. This is due to high air velocity at the upper region. Also, the supply air stream itself has low temperature; therefore it will decrease the temperature in this part. Another observation is that the temperature distribution is mostly looks like the distribution of velocity. This agrees with the result of (Rees,.and Haves, 2013). **Fig. 8** shows the isothermal contour for y-z plane in the optical operation room. In this figure, it can be seen that the temperature at upper part near the inlet is relatively low. **Fig. 9** displays the contour map of relative humidity for x-y plane. The relative humidity distribution, is a key factor of thermal comfort. From this figure, it can be seen that the upper part (near the inlet) has relatively high relative humidity. This is due to the change pressure in the whole region is very small and water vapor concentration does not change. Therefore, the relative humidity was mostly depended on the temperature distribution, where, the upper part has low temperature and high relative humidity values. Relative humidity at the surgical table is about 48.5%. **Fig.10** illustrates the contour map of relative humidity for y-z plane in the optical operation room. It can be seen that the upper region has high relative humidity as shown in the previous figure. It can be seen that the value of the relative humidity at the surgical table is about 48.5%. This is consistent with the results of (Lewis, 2000).

Fig.11 displays the contour map of carbon dioxide for x-y plane in the optical operation room. It can be seen that the values of carbon dioxide increase at the lower part of the plane. This is due to that the CO_2 releasing during the breathing of the persons and from the machines. These releasing values of carbon dioxide were carrying by the supply air stream inside the domain towards the exhaust grilles. When, the entering air contain low value of carbon dioxide by the air filtering effect. **Fig. 12** represents the contour map of carbon dioxide for y-z plane in the optical operation room. The value of the carbon dioxide also increases through the domain.

Secondly, it was studied the experimental results of the experimental operation room which are shown in **Fig 13**. **Fig.14** displays the contour map of air velocity for y-z plane. The point (0,0) of the plane is located at the surgical table level; therefore the distance from this location to the ceiling is about 2m. It can be seen that the upper region of the plane has relatively high air velocity, then the velocity decreases with increasing the vertical distance from the ceiling. This is due to the effect of entering air from the inlet, which increased the velocity at the upper part of the domain, where, air velocity is high near the inlet. **Fig. 15** illustrates the contour map of air velocity for x-z plane in the experimental operation room. It can be seen that the velocity increases with varying the distances. This is due to the entering air stream effect. Therefore, the region near the diffuser has relatively high velocity. **Fig. 16** illustrates the isothermal contour of the temperature distribution for y-z plane in the experimental operating room. In this figure, it can be seen that the upper part has lower temperature than the other regions in the domain. This is attributed to the effect of cold air stream from the air inlet, which leads to reduce the temperature at region near the supply diffuser. This is consistent with (Forejt, 2005).

Fig. 17 displays the isothermal contour of the temperature distribution for x-z plane at $y = 0$. It can be seen that the minimum temperature can be obtained in the high velocity region by the effect of cold supply air from inlet to reduce the temperature. **Fig. 18** displays contour map of relative humidity for y-z plane in the experimental operating room. It can be seen that the relative humidity at the surgical table is about 45%. **Fig. 19** shows the contour map of relative humidity in x-z plane at $y = 0$. The relative humidity distribution can be seen through this plane. This plane is represented the top view of distribution at the surgical table. **Fig. 20** illustrates contour map of carbon dioxide for y-z plane in the experimental operation room. **Fig. 21** shows contour map of carbon dioxide for x-z plane in the experimental operating room.

4. CONCLUSION :

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

1.Temperature and relative humidity increase through the domain of the operation room at the surgical work. Where, the temperature and relative humidity at surgical zone for no load are 19.5^{o}C and 48.4%. while, the values increase to reach 21.3^{o}C and 49.3% at the surgical full load in the optical operation room. The value of the temperature and relative humidity in the experimental operation room are 23.6^{o}C and 45.3%. The value of carbon dioxide in the optical operation room increases at the surgical work from 421p.p.m to 477p.p.m, because of the gas, which is rising from the anesthesia machine, during the operation. While, the value of carbon dioxide in the experimental operation room is 465.2p.p.m.

2. The optimum range of temperature, relative humidity, and carbon dioxide for the surgical work is 21^{o}C-24^{o}C, 40% to 60%, and 400p.p.m to 600p.p.m respectively.

3. The value of the carbon dioxide increases at the lower part of the domain towards the exhaust grilles to reach 492p.p.m.

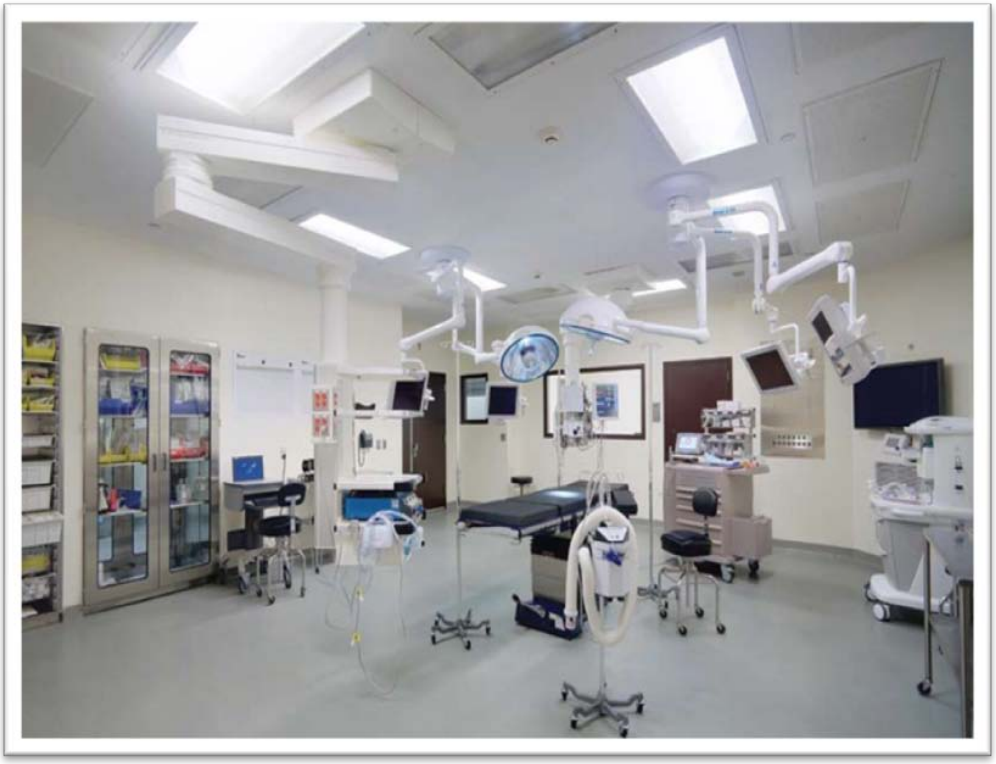


Fig. 1 View of optical operating room.

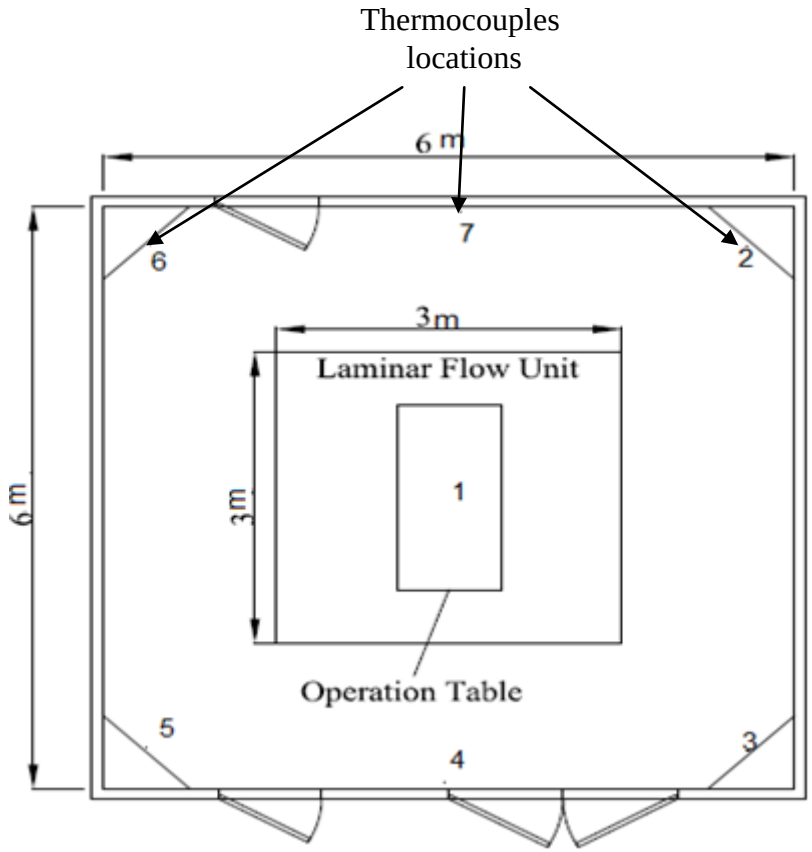
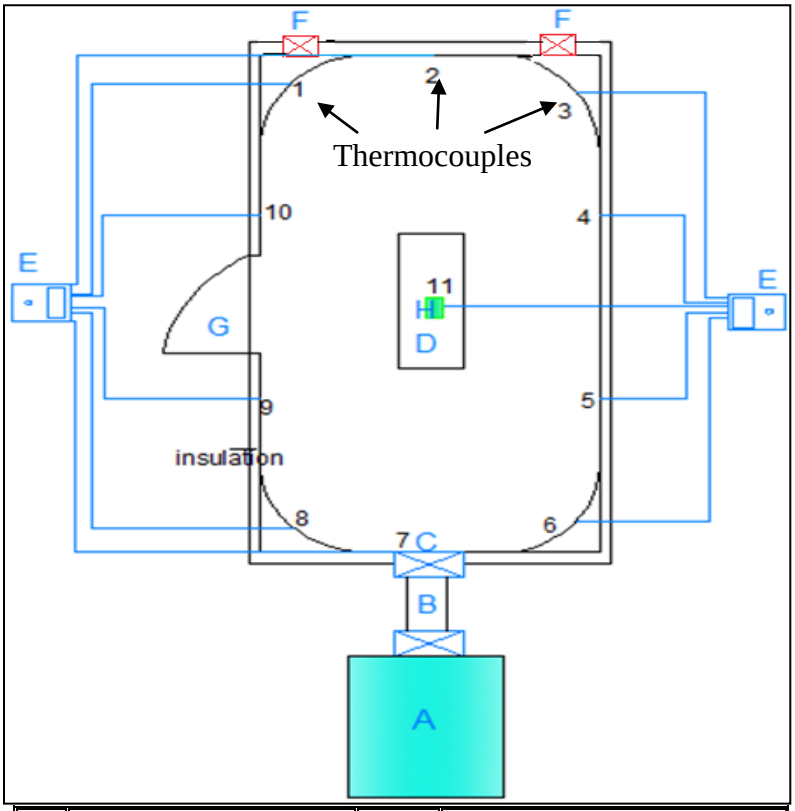


Fig. 2. Schematic diagram of the optical operating room (top view).



	Air velocity	F	Outlet grill
B	Flexible duct	G	Door
C	Inlet air diffuser	H	Surgical light
D	Operating table	I	Insulation
E	Measuring device	J	Thermocouple

Fig. 3 Schematic diagram of experimental operating room (top view).

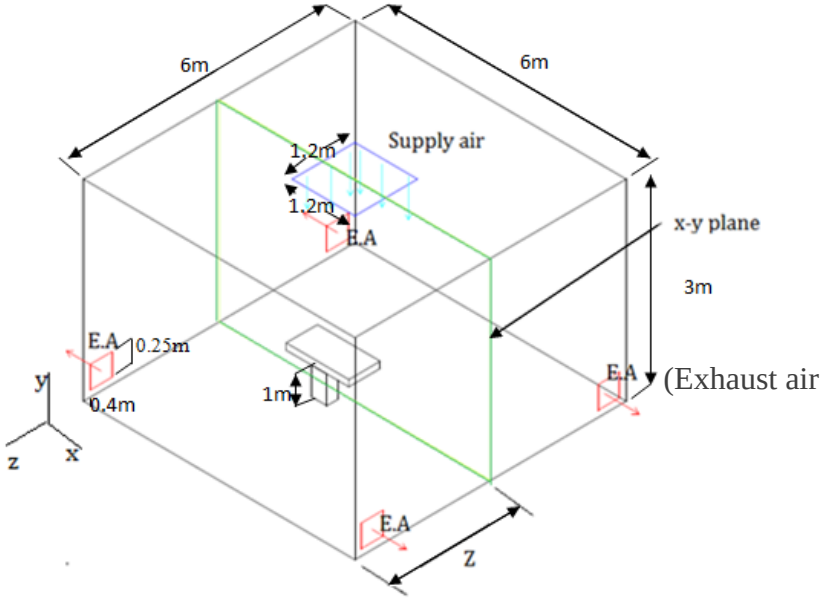


Fig. 4 The domain of the optical operating room.

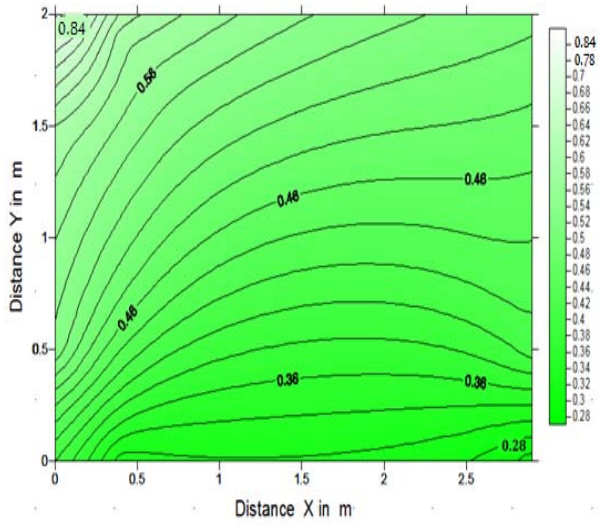


Fig. 5 Contour map of air velocity for x-y plane in the optical operating room.

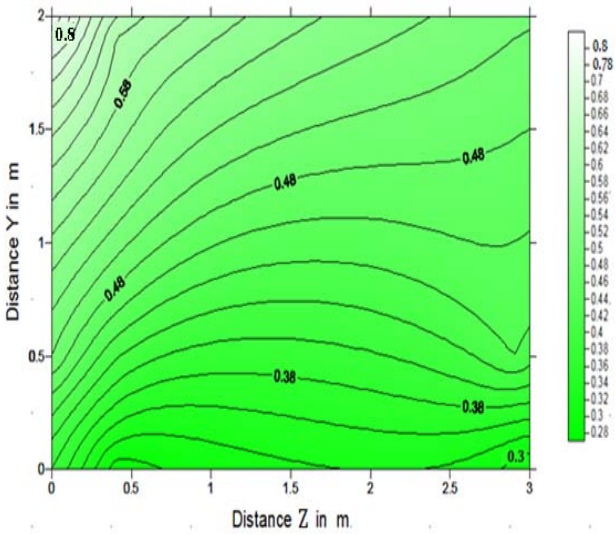


Fig. 6 Contour map of air velocity for y-z plane in the optical operating room.

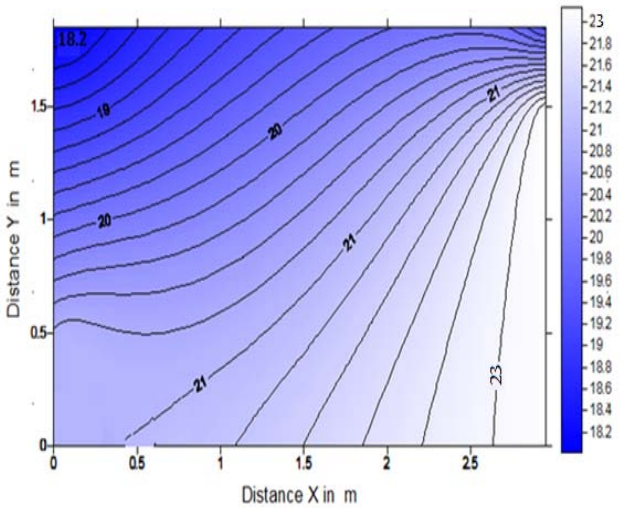


Fig. 7 Isothermal contour of temperatutre distribution through x-y plane.

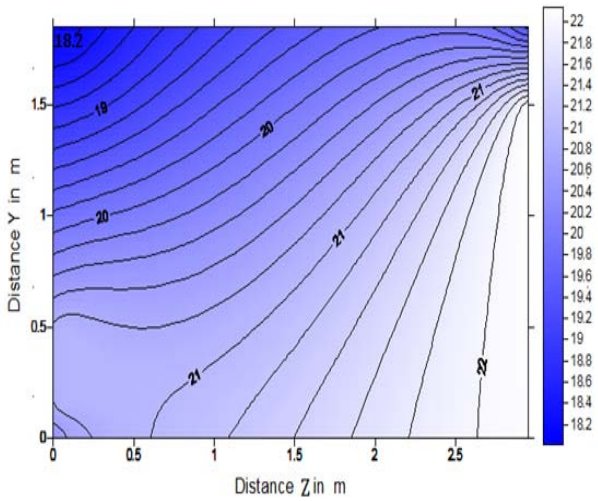


Fig. 8 Isothermal contour of temperatutre distribution through y-z plane.

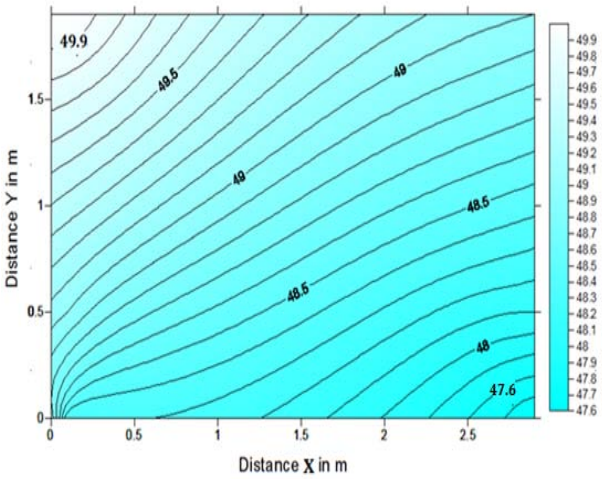


Fig. 9 Contour map of relative humidity for x-y plane in the optical operating room.

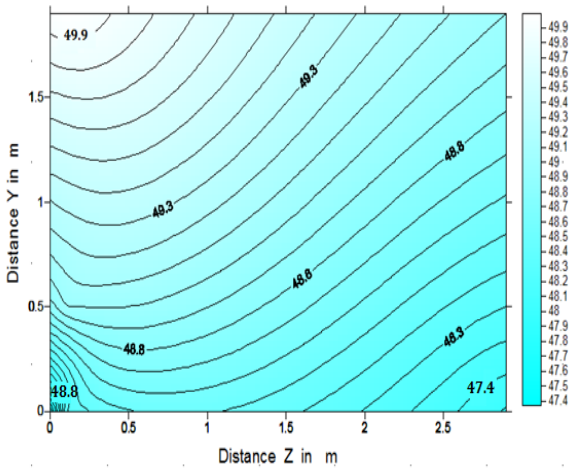


Fig. 10 Contour map of relative humidity for y-z plane in the optical operating room.

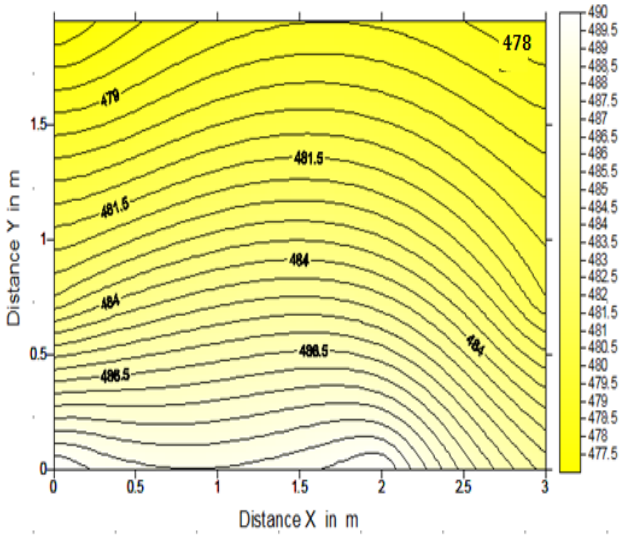


Fig. 11 Contour map of carbon dioxide through x-y plane.

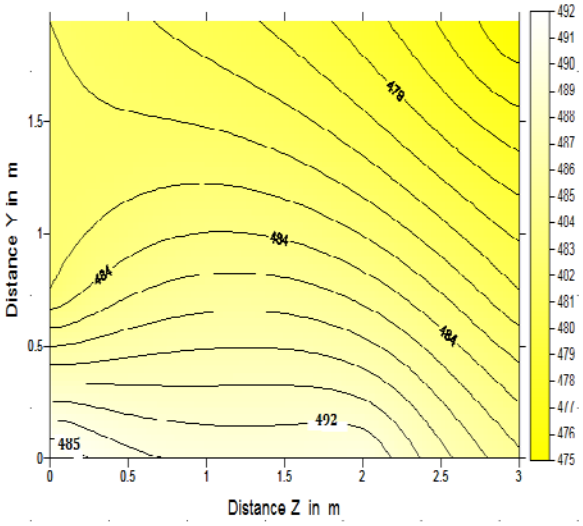


Fig. 12 Contour map of carbon dioxide through y-z plane.

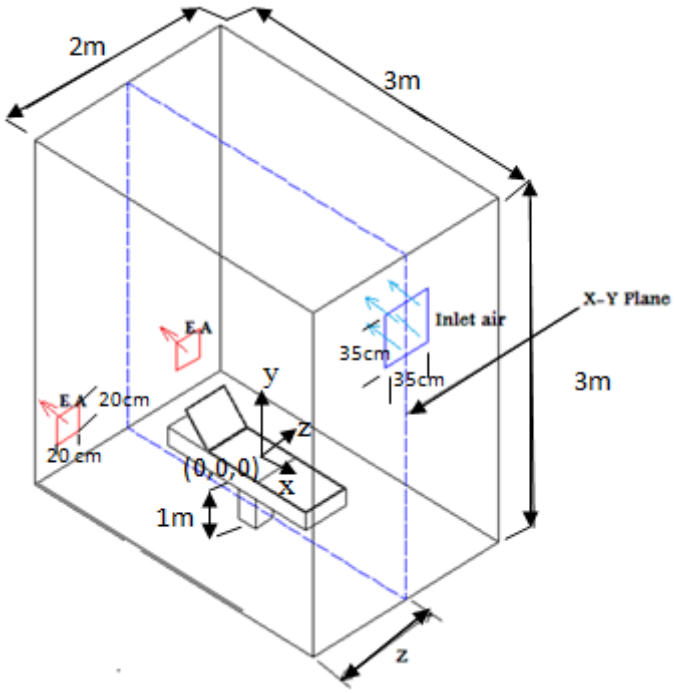


Fig. 13 The domain of the experimental operating room.

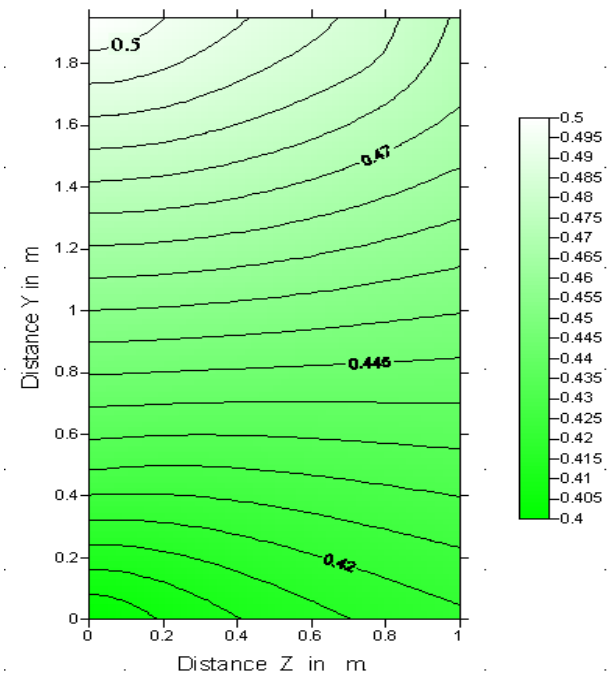


Fig.14 Contour map of air velocity for y-z plane.

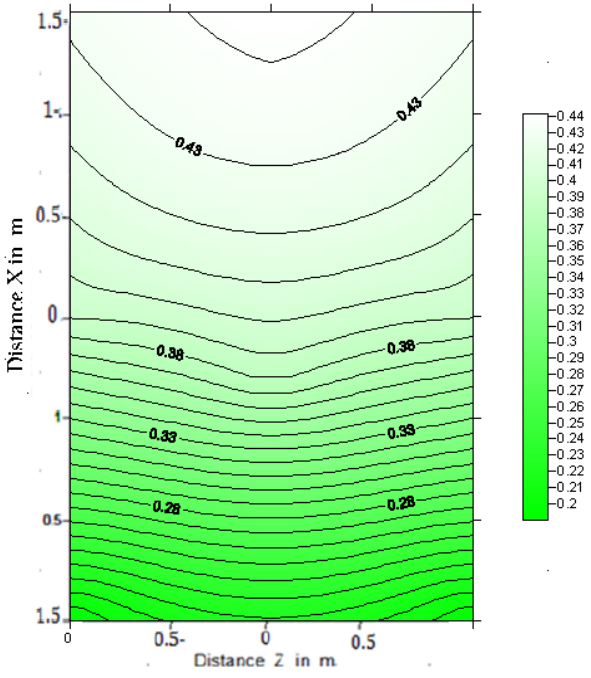


Fig.15 Contour map of air velocity for x-z plane.

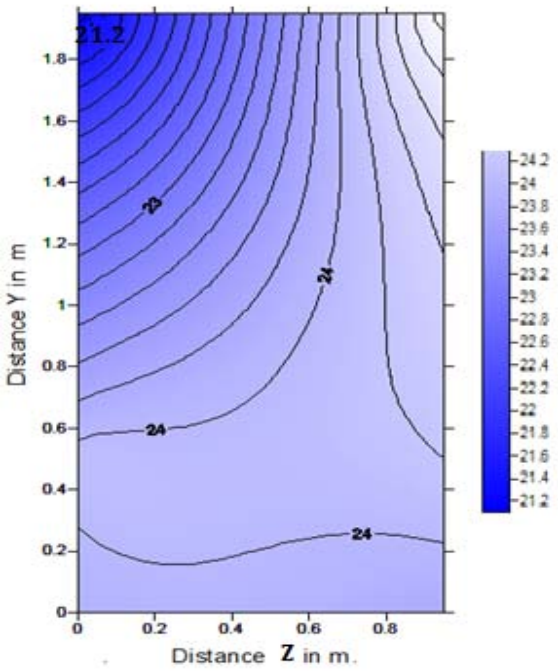


Fig. 16 Isothermal contour of temperature distribution at y-z plane.

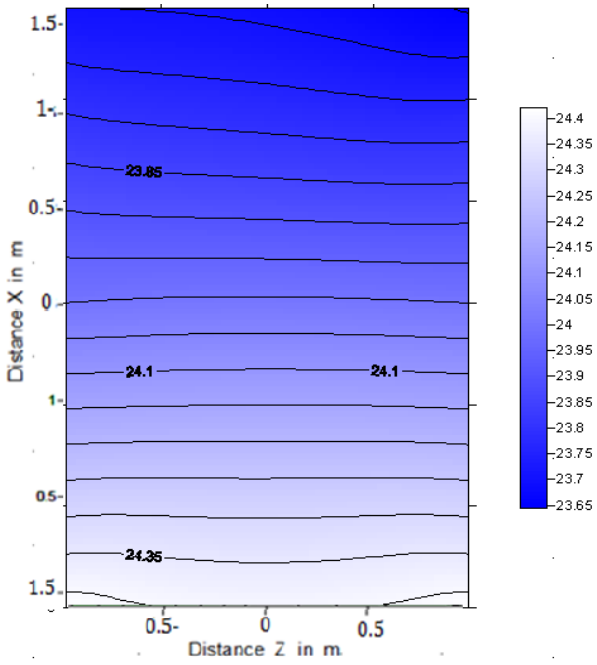


Fig. 17 Isothermal contour of temperature distribution at x-z plane.

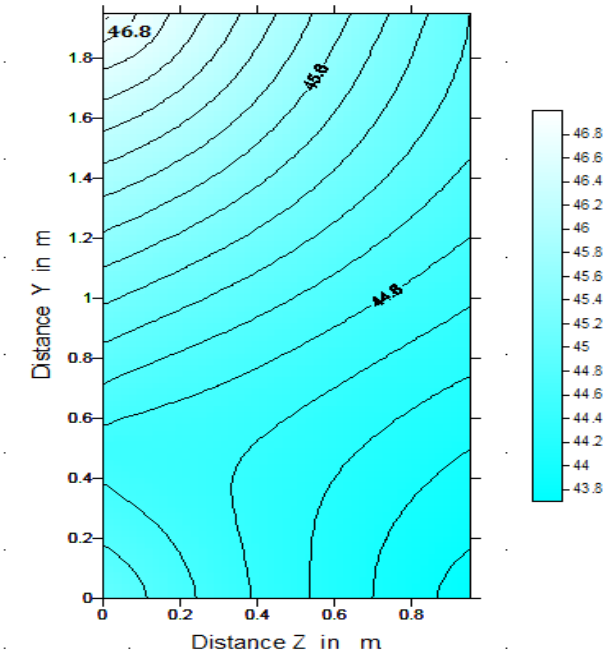


Fig. 18 Contour map of relative humidity for y-z plane.

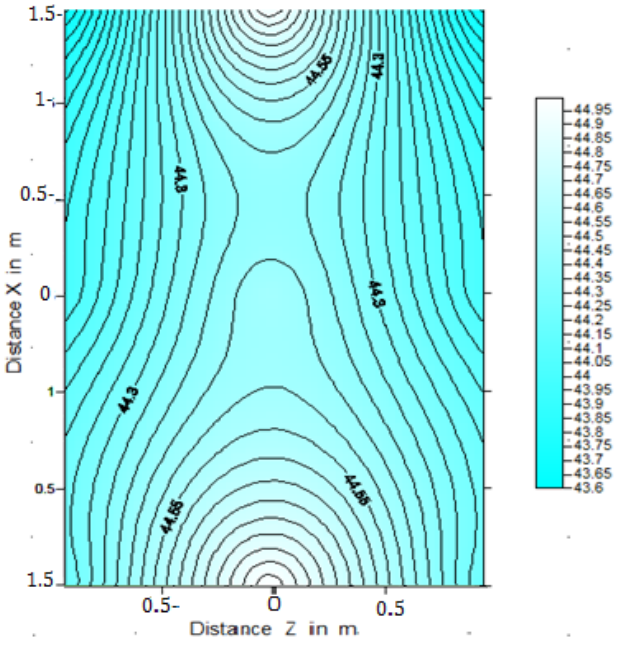


Fig. 19 Contour map of relative humidity for x-z plane.

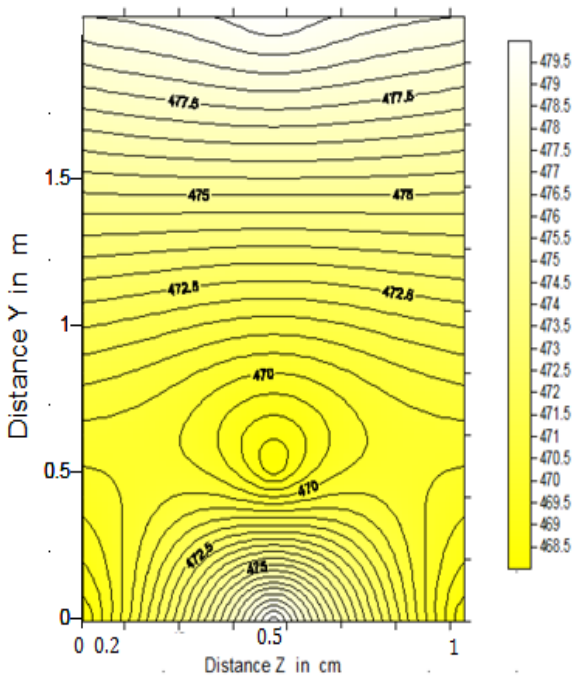


Fig. 20 Contour map of carbon dioxide for y-z plane.

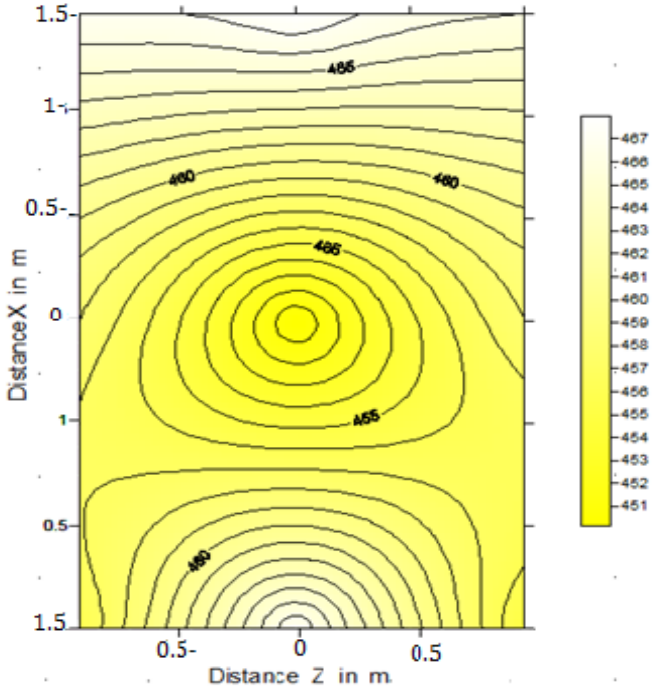


Fig.21 Contour map of carbon dioxide for x-z plane.

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