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Indoor Air Quality in a Cardiac Care Unit (CCU) under Different Ventilations

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Abstract

A proper ventilation offered warranty for a perfect indoor environment. Indoor air environment includes indoor thermal environment and indoor air quality (IAQ). In this paper a numerical investigation of the indoor environment in different ventilations was accomplished. The Cardiac Care Unit (CCU) in Al-Rifai hospital in Thi-Qar governorate was chosen to be investigated, and its thermal achievement and indoor air quality in the hot summer weather were simulated. For the numerical study, the fluent technique used to set up the physical and numerical model of CCU. An attention has been paid carefully to considerate the distributions of the temperature and the velocity fields, followed by an argument of two different ventilation patterns; up-in and up-out ventilation (UV) and displacement ventilation (DV). After making the comparison, it was noticed that the displacement ventilation (DV) is clearly super than that of the up-in and up-out ventilation (UV) due to improvement in the indoor air quality.

Keywords: cardiac care unit, displacement ventilation and up-in and up-out ventilation.

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1. Introduction

People spend about (70 % or above) of their time indoors. Therefore, they are aware well aware that the indoor air quality is more important than outdoor air quality. Thus, the quality of the indoor environments is closely relevant to people’s health, comfort, safety, etc. The safety of a person's physical and cerebral health must be among the first considerations of the indoor design [1].

Indoor air environments include indoor thermal environments and Indoor Air Quality (IAQ), and a proper ventilation offered a major warranty for an excellent indoor environment. By providing the fresh air for indoor, expulsion polluted gas, decreasing the concentration of indoor contaminants, ventilation can develop indoor thermal comfort.

The different ventilation patterns and the airflow modes achieve to various results of exclusion and dilution of indoor contaminants, this is about people's feelings around air quality [2]. Effected by a variety of topical parameters, the distributive principles of the ventilation arrangement are more difficult to appear. The classical method is the simulation experiments. This approach, selected by the limited experimental conditions, needs material resources in addition to many financial resources. In other words, simulation of the airflow in a complex space for all properties is very challenging.

To simulate the indoor airflow, a visual method was recently used to show the results in the Computational Fluid Dynamics (CFD) field and this tool was very effective and important. Also, it can be an effective way to study the arrangement of the indoor ventilation and design with the appropriate efficiency of the air-conditioning room [3]. To describe fluid motion in a computer, the CFD is the most useful numerical procedure that able to result reliably in differential equations.

The past ten years has been characterized by a more increase of all over the world by scientific database in indoor air environment. Since people spend about half a day of their time in the room, they are well aware that indoor air quality may be more important than the quality of outdoor air. Applications of heating, ventilation and air-conditioning (HVAC) systems are known to adjustment the indoor air quality by means of cooling humidification, dilution, and filtration of the outdoor air that will enter the occupied area. For example, a good use of the air filtration from the outside space may prevent environmental contaminants and microbes from penetrating into the conditioned buildings [4].

In this field some studies were achieved considering different ventilation modes [5-7]. A numerical comparison study was done by Yang Li [8] who targeted two kinds of airing modes, which are the displacement and the up-in and up-out airings. It was concluded that the displacement ventilation is more effectible on the indoor air quality than the up-in and up-out one. In addition, a numerical investigation has been accomplished by Son [9] on a thermal comfort. Two typical working places have been undertaking, which are a hospital operating room and an office. It was broached that a negative influence can happened by changing the inlet angle. Hakan [10] investigated the impact of (HVAC) locations. It has been proved that the one near the door has the best heat releasing. Moreover, 3D research on a for thermal comfort in a hospital operating room has been completed by Rosario [11]. The outcomes illustrated that an overall better performance can be reached by located the supply grilles thereabout the vertical centerline.

By considering the literature review and the authors' best knowledge, it can be easily concluded that a study on the environmental condition dominate in the Cardiac Care Unit (CCU) in Al-Rifai hospital of Thi-Qar governorate under different ventilation modes and occupation condition has not been achieved yet. Therefore, filling this gap will form the main aims of this research.

2. Methodology

2.1. The geometric model description

The dimensions of CCU were (6.2 m × 4.5 m × 3 m) for (length, width and height) respectively. The capacity of CCU is (8) persons. The geometry consists of two split units (one is vertical and the other is horizontal), two exhaust fans, one door, two windows, four monitors (two are located on the north wall while the others are placed on the tables), one refrigerator (located near the west wall), one closet, four beds, four tables, two air bottles and one cardiac shock device (placed on the table). The dimensions of each components are listed in Table 1. The windows are located in south wall and the door is located in the east wall. The schematic design of the geometry is shown in Fig. 1. The windows are usually closed. The heating, ventilation, and air-conditioning (HVAC) systems operates according to the needs of the occupants. As seen in the Fig. 1.

Table 1 The dimesions of CCU components.

No	Components	Dimension (m)
1	Vertical unit split	0.6 × 1.9 × 0.3
2	Horizontal unit split	0.3 × 0.98 × 0.3
3	Exhaust fan	0.4 × 0.4
4	Door	1.8 × 2.1
5	Window	2 × 2
6	Monitors on the wall	0.4 × 0.27 × 0.15
7	Monitors on the tables	0.3 × 0.3 × 0.25
8	Refrigerator	0.6 × 1.6 × 0.6
9	Closes	0.5375 × 0.75 × 0.45
10	Bed	0.95 × 0.6 × 2.1
11	Table	0.45 × 0.5375 × 0.75
12	Air bottles	0.22 × 1.3
13	Cardiac shock device	0.25 × 0.3 × 0.2

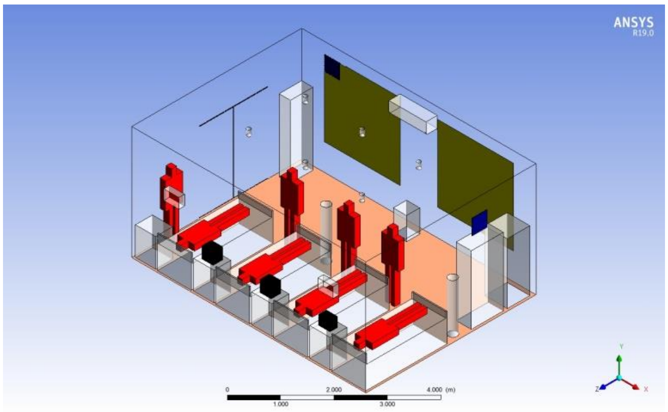


Fig. 1 The schematic design of CCU geometry.

The dimensions of all the objects are real, and the technical design is as detailed as possible in accordance with the architectural plan and the scheme of the artificial ventilation system, and the calculation efficiency is always taken into account. The south wall is exposed to the outdoor while the east wall adjacent to the corridor. The north wall is attached to another air-conditioned room. The west wall is exposed to shadow outdoor.

2.2. Numerical Calculation Method

There has been a lot of interest in developing computer software for computational fluid dynamics (CFD) over the past two decades to predict airflow patterns in air-conditioned rooms. The majority of this CFD program is based upon the solution for equations of Navier-Stokes, the energy, the mass, the concentration and the transport for turbulent velocity and its scale [12].

The CFD software usually includes three modules: preprocessing, compute a result and postprocessing. And consists of the conservation equations of mass, the conservation equations of momentum, the conservation equations of energy and the chemical species equations.

The numerical simulation and analysis of indoor ventilation organization of CCU are achieved by solving the mass conservation equation, momentum conservation equation, energy conservation equation. RNG's k-ε turbulence models were relying in this study.

The CFD approach numerically solves the previously mentioned equations listed below, along with the appropriate boundary conditions for temperature and airflow in the room [13].

1. The conservation equation of mass:

$$\frac{\partial \rho}{\partial t} + div\,(\rho U) = 0 \qquad (1)$$

2. The conservation equation of momentum:

$$\frac{\partial(\rho \bar{u}_i)}{\partial t} + \frac{\partial(\rho \bar{u}_i \bar{u}_j)}{\partial x_i} = -\frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_i}\left(\eta \frac{\partial \bar{u}_i}{\partial x_i} - \rho \overline{u_i u_j}\right) \qquad (2)$$

3. The conservation equation of energy:

$$\frac{\partial(ph)}{\partial t} + \frac{\partial(\rho u h)}{\partial x} + \frac{\partial(\rho v h)}{\partial y} + \frac{\partial(\rho w h)}{\partial z} = -p\,divU + div(\lambda grad)T + \varphi + S_h \qquad (3)$$

When $\boldsymbol{\varphi}$ is given by;

$$\varphi = \left\{2\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial z}\right)^2\right] + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)^2\right\} + \lambda divU \qquad (4)$$

4. κ-equation:

$$\rho \frac{\partial k}{\partial t} + \rho u_i \frac{\partial k}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\left(\eta + \frac{\eta_i}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right] + \eta_i \frac{\partial u_i}{\partial x_i}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \rho\varepsilon \qquad (5)$$

5. ε equation:

$$\rho \frac{\partial \varepsilon}{\partial t} \rho u_k \frac{\partial \varepsilon}{\partial x_t} = \frac{\partial}{\partial x_t}\left[\frac{\partial \varepsilon}{\partial x_t}\left(\frac{\eta_t}{\sigma_\varepsilon} + \eta\right)\right] + \eta_1 \frac{c_1 \varepsilon}{k} \frac{\partial u_i}{\partial x_i} - \rho c_2 \frac{\varepsilon^2}{k} \qquad (6)$$

The ANSYS19 (CFD) codes solves the time-averaged of these equations in steady and three-dimensional flows [14].

2.3. Validation of the program and the boundary conditions

Shui Yu [15], used a trade program to achieve his investigation of the considered application. By default, the code uses the finite volume method and the reverse of a wind difference scheme for the convection expression. The converged criterion was developed such that the respective sum of the absolute residuals must be less than 10^{-3} [15].

In the present study, as a first step, the ANSYS19 program was validated against the previous research [15]. For this purpose, the ANSYS19 program was used to design a room of dimensions (L = 10 m × H = 3.5 m × W = 8 m), similar to that considered in the previous compared with research work.

The studied case is a room located on the 10th floor of the residential building in Shenyang. The model shown in Fig. 2 includes a bedroom, living room and kitchen. The room size is X × Y × Z = 10 m × 3.5 m × 8 m, the window dimensions are X × Y = 1 m × 0.9 m and the door dimensions are X × Y = 2.1 m × 1 m.

The main objective of the previous study is how the use of natural ventilation in closed places contributes significantly to reducing pollutants and thus improving the quality of indoor air. In addition, it mainly contributes to energy conservation. In the previous study, the outdoor conditions were 28.2 °C dry-bulb temperature, 65 % of relative humidity and 1.2 m/s as the average wind velocity. Assuming that the sources of pollution are mainly distributed from the floor, the concentration of the pollution is 5×10^{-9} kg/s. The ceiling, interior walls and floor are set as insulated [15].

The computations were performed under steady state conditions by solving equations of the conservation of mass, momentum, energy and concentrations. Preprocessing requires the build of geometry and generate the mesh. This was done with the software gambit, linked to Fluent for the pervious study, while in the present study case all the above steps are done using ANSYS19 program.

Fig. 3 shows the stream-lines of the airflow modes in a z-planes at y = 1.1 m in both previous and present study. When comparing these results, it is found that there is only a 5 % difference between the two studies these results may be considered as a reasonable approach for this study to use the ANSYS program.

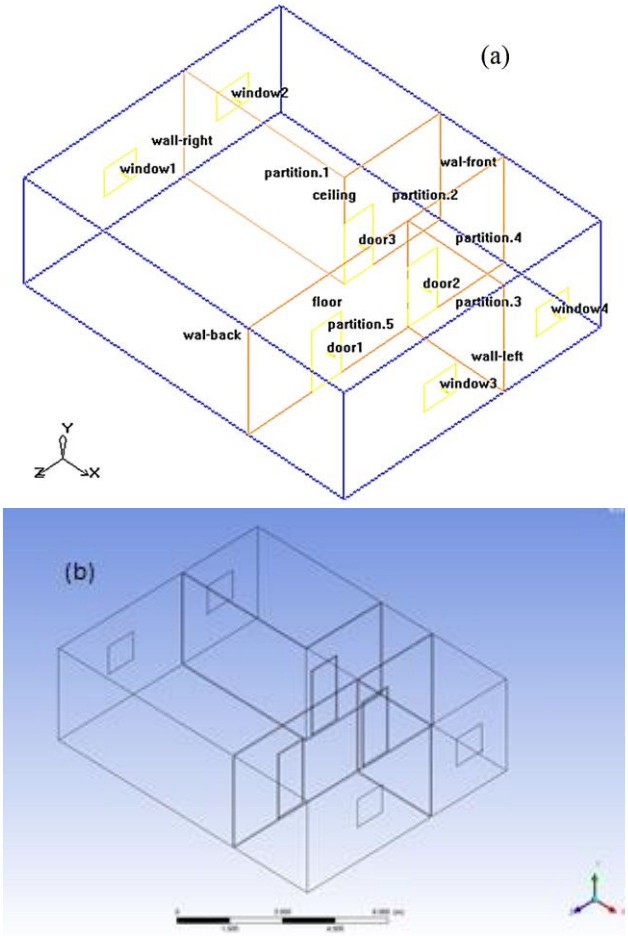


Fig. 2 Schematic design of room employed in the study (a) previous study [15], (b) verification case.

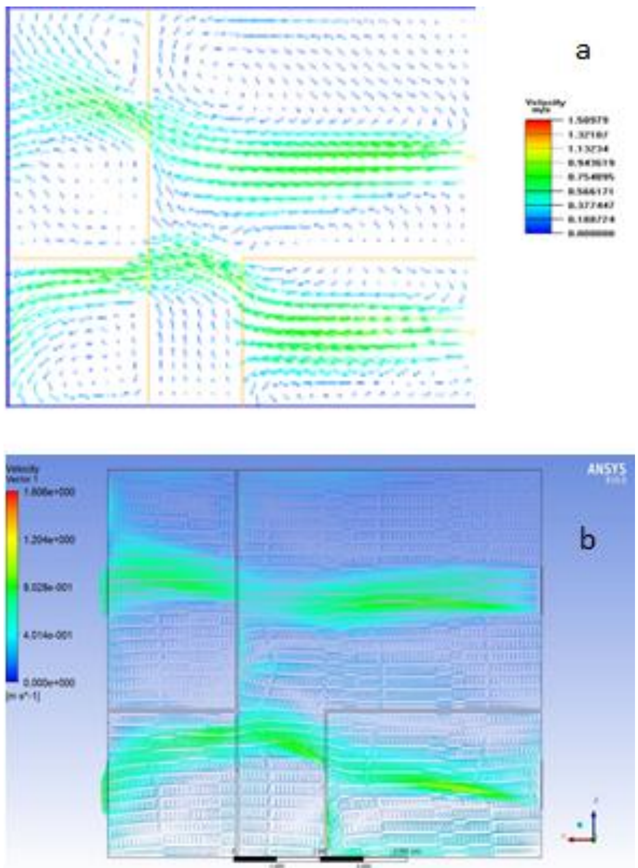


Fig. 3 Velocity stream-lines showing the airflow modes in x-z plane at y = 1.1m in the studied room of (a) previous study [15], (b) verification case.

3. Results and Discussion

In current study two different modes of ventilation are tested, in the Cardiac Care Unit (CCU) in Al-Rifai Hospital of the Thi-Qar governorate, the two modes are displacement ventilation and up-in and up-out ventilation. The steady-state condition and the negative gravity are adopted in this study.

In order to start modeling using ANSYS19 Program, it is mandatory to give the programs the required information to perform the analyses and see the output. The first fundamental input for both cases as follow; mass flow rate of each inlet was 0.3295 kg/s, the mass outlet was 0.988 kg/s, temperature inlet was 20 °C, led is constant temp, heat transfer coefficient for glass equal to 15 W/m^2. K and all wall were set as insulated.

In the displacement ventilation, the air is entered to the room from three inlets opening (0.6 m × 0.3 m) that is located in the south wall near the floor, while is exhausted from one outlet opening (0.98 m × 0.3 m) in the upper of the same wall. While in the up-in and up-out ventilation, the air is introduced to the room from three inlets opening also (0.6 m × 0.3 m) that is located on the upper of the east wall, while is exhausted from one outlet opening (0.98 m × 0.3 m) in the upper side of the opposite wall.

3.1. Displacement ventilation

The geometry of CCU with displacement ventilation is shown in Fig. 4 below.

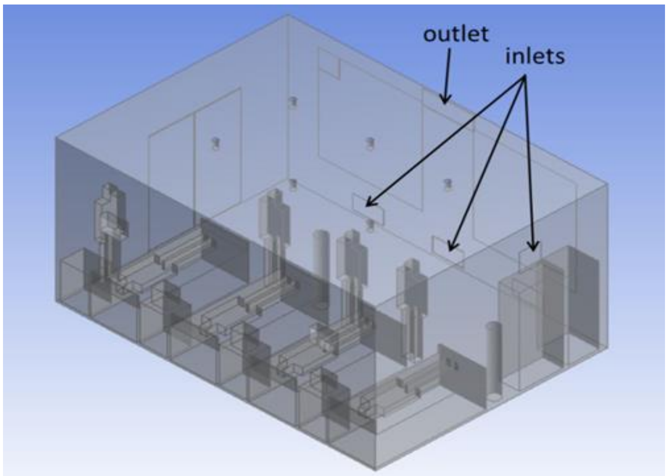


Fig. 4 The geometry of CCU with displacement ventilation.

Fig. 5 shows the velocity stream-lines in case of displacement ventilation. The velocity and temperature distributions for DV are plotted at three different z-plane locations (0.5 m, 2 m and 4 m).

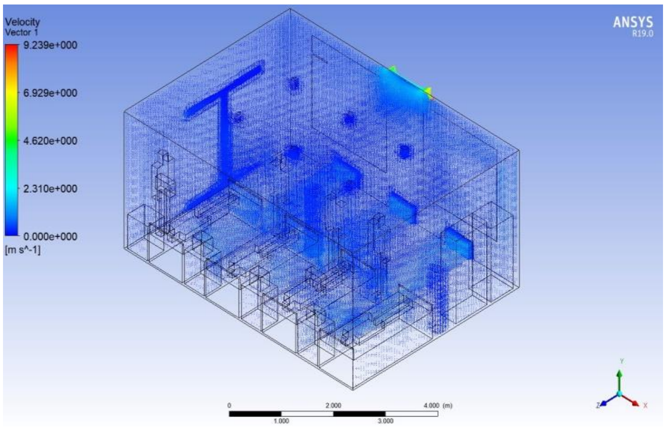
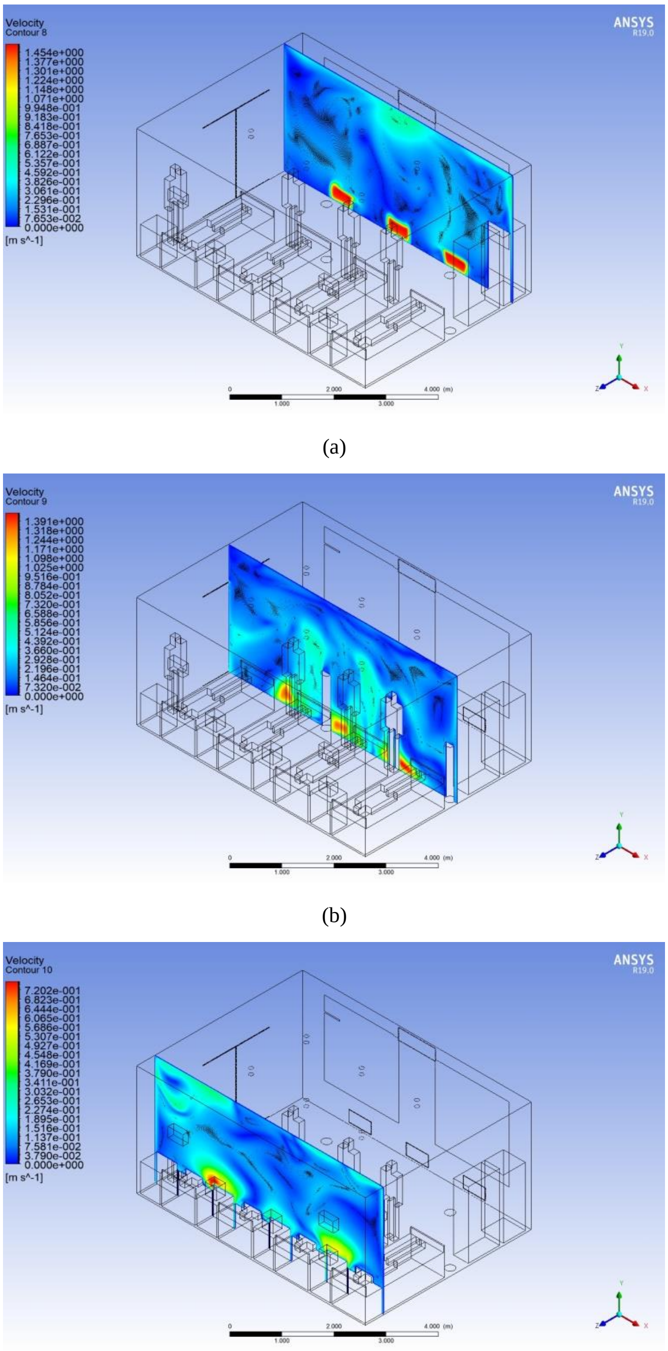


Fig. 1 Velocity stream-lines of displacement ventilation.

Fig. 6 shows the velocity distribution for DV at indicated planes previously.

At z = 0.5 m, Fig. 6 (a) shows that the maximum velocity is 1.45 m/s at the zone near the inlet opening, and the velocity is decreased away from the inlet on the same plane. Fig. 6 (b) and Fig. 6 (c) shows the same trend of velocity distribution at z = 2 m and z = 4 m respectively. In the (z = 2 m) plane, Fig. 6 (b) shows that the maximum velocity is 1.35 m/s, which is found near the floor zone, while it is decreased at the roof zone. In the (z = 4 m) plane, Fig. 6 (c) shows that the maximum velocity is 0.72 m/s, which is noticed to be around the patient beds.



(a)

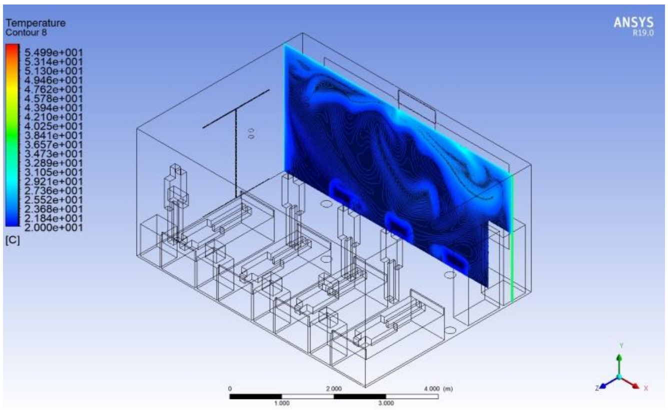
(b)

(c)

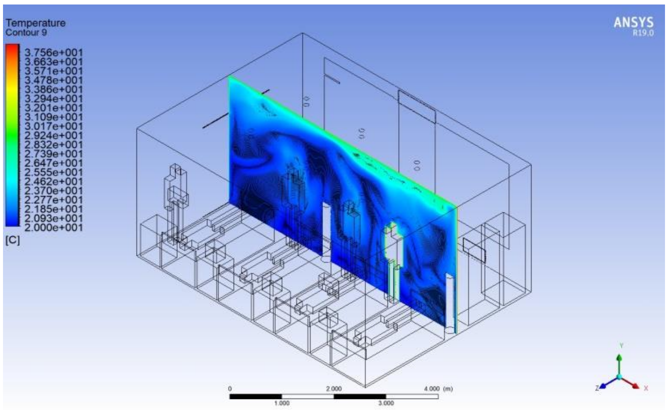
Fig. 2 The velocity distribution for DV at xy-plane, (a) z = 0.5 m, (b) z = 2 m and (c) z = 4 m.

The temperature distribution of DV in CCU is also plotted for the same planes (0.5 m, 2 m and 4 m) as shown in Fig. 7. The maximum temperature in CCU is 40 °C as shown in Fig. 7 (a), it is found to be on the west wall behind the refrigerator. This is due to the heat emitted by the refrigerator condenser.

In the other two z-planes (2 m and 4 m), the maximum temperature is 32 °C as shown in Fig. 7 (b) and Fig. 7 (c), respectively. This increase in temperature is due to disinclination from the inlet air zone.



(a)



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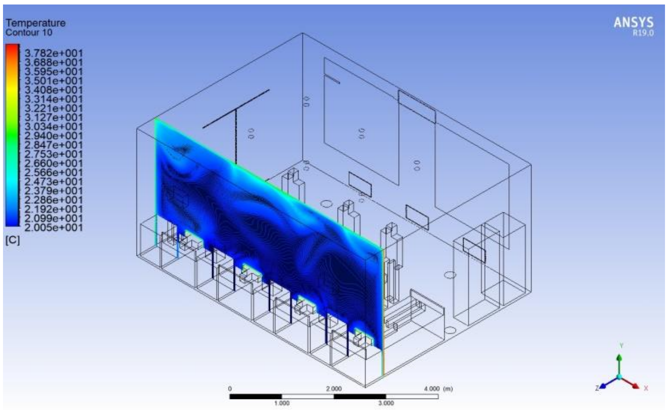


(c)

Fig. 3 The temperature distribution for DV at xy-plane, (a) z = 0.5 m, (b) z = 2 m and (c) z = 4 m.

3.2. Up-in and up-out ventilation

The geometry of the CCU with up-in and up-out ventilation is shown in Fig. 8 below.

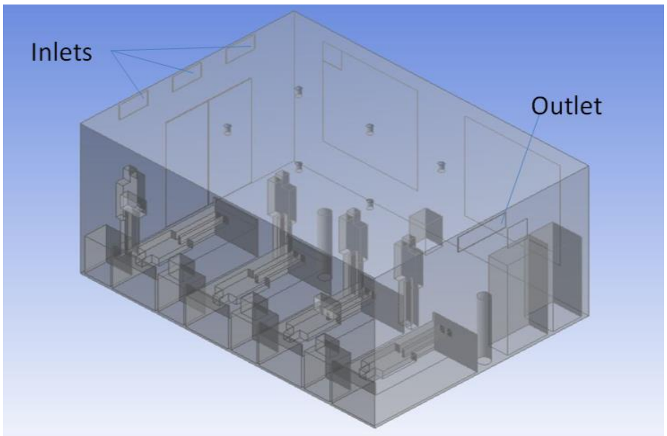


Fig. 4 The geometry of the CCU with up-in and up-out ventilation.

Fig. 9 shows the velocity stream-lines in case of up-in and up-out ventilation. The velocity and temperature distributions are plotted for the z-planes (0.5 m, 2 m and 4 m) as shown in Fig. 10 and Fig. 11 respectively.

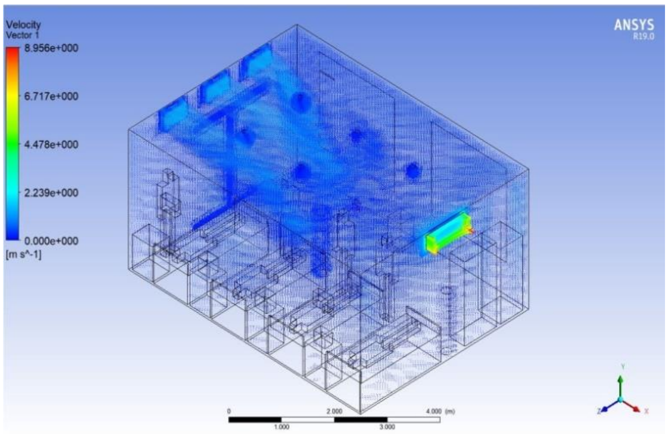


Fig. 5 Velocity stream-lines of up-in and up-out ventilation.

The maximum velocity in the (z = 0.5 m) plane is 0.5 m/s, which can be noticed near the ceiling and above the refrigerator near the east wall, as shown in Fig. 10 (a).

In the (z = 2 m) plane the velocity is shown uniformly distributed. The maximum velocity is 5 m/s near the outlet opening, while the minimum value is 2 m/s at the zone mediates the floor of CCU, as shown in Fig. 10 (b).

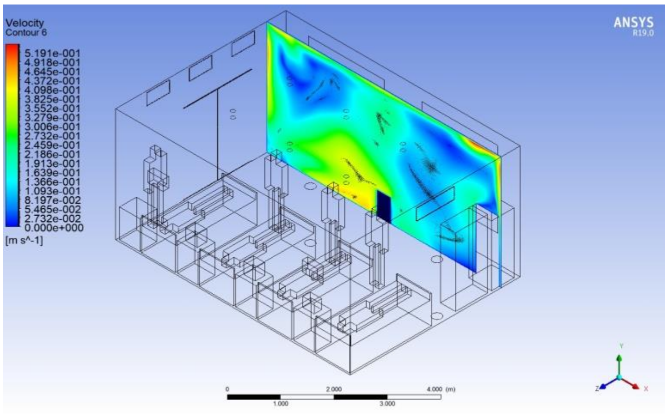
In the (z = 4 m) plane the velocity is also uniformly distributed, and it has a maximum value of 5.7 m/s at the zone represented by mediates space of CCU and then reduced to 2 m/s around the patient zone, as shown in Fig. 10 (c).

The temperature distribution in CCU with UV is also plotted for the three z-planes (0.5 m, 2 m and 4 m), as shown in Fig. 11.

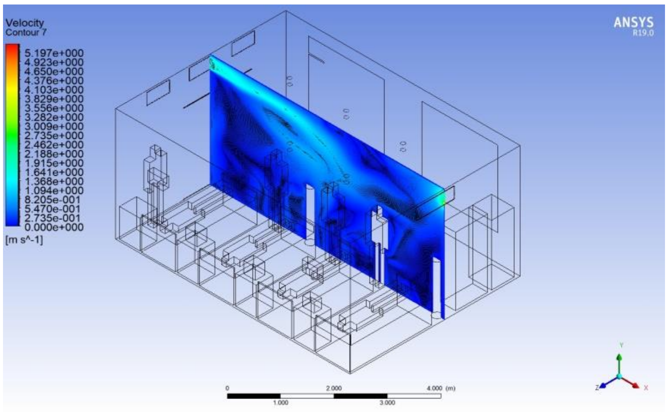
The maximum temperature value is 40 °C in the (z = 0.5 m) plane, which is found to be behind the refrigerator, (as it has been noticed in DV), and this temperature is decreased to 22 °C near the floor, while it is found to be about 24 °C in the other locations of (z = 0.5 m), as shown in Fig. 11 (a).

In the (z = 2 m) plane the prevailing temperature is 25 °C, while near the floor the temperature is 22 °C, as shown in Fig. 11 (b).

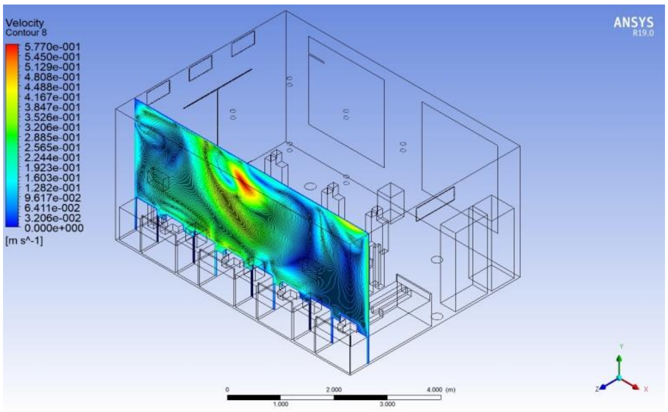
In the (z = 4 m) plane, the prevailing temperature is 21.5 °C specially around the patient zone, as shown in Fig. 11 (c).



(a)

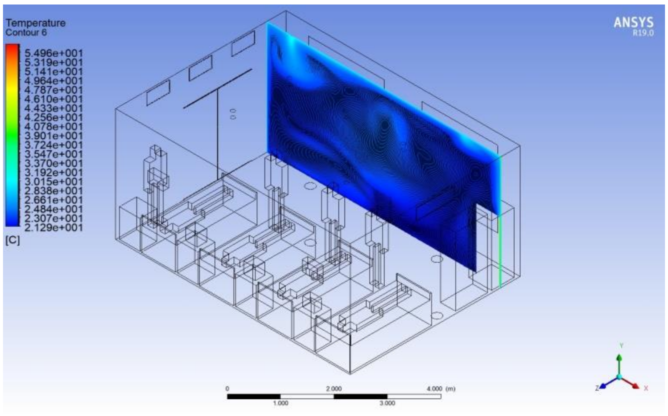


(b)

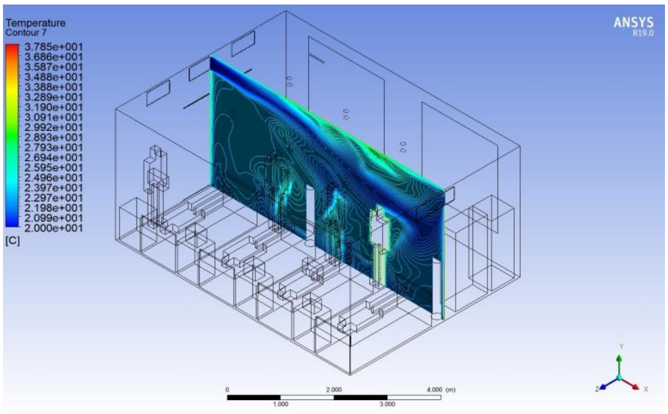


(c)

Fig. 6 The velocity distribution for UV at xy-plane, (a) z = 0.5 m, (b) z = 2 m and (c) z = 4 m.



(a)



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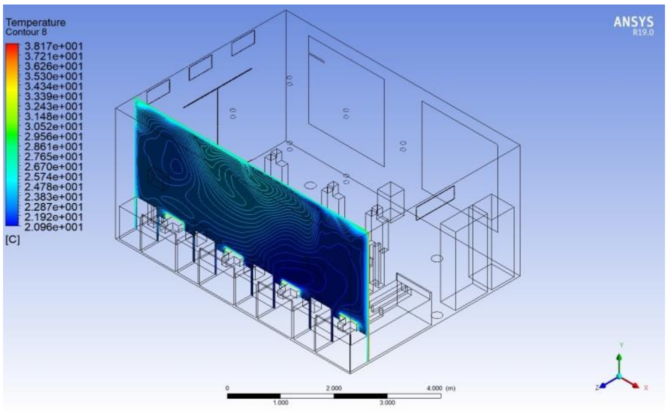

(c)

Fig. 7 The temperature distribution for UV at xy-plane, (a) z = 0.5 m, (b) z = 2 m and (c) z = 4 m.

4. Conclusions

Indoor air environment includes indoor thermal environment and air quality. When comparing the effect of the displacement ventilation and the up-in and up-out ventilation the following conclusions are reported.

1. Displacement ventilation gives better velocity distribution for the air-conditioned space, and also better temperature distribution for human activity and improve indoor thermal comfort efficiently.
2. With displacement ventilation, the indoor air quality is the best, where the environment contaminants can be replaced quickly and easily.

3. Therefore, compared with up-in and up-out, displacement ventilation is healthier, faster, more efficient and comfortable.
4. Some previous researchers suffer from some problems such as: complex construction technology, initial high investment, etc. the engineering program (ANSYS 19), which is accredited in this research work gives many facilities, comprising, air-conditioning system design, model construction …., etc. with saving time, cost and effort.

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Nomenclature

Symbol	Description
CFD	Computational Fluid Dynamics.
HVAC	Heating Ventilating Air Conditioning.
IAQ	Indoor Air Quality.
CCU	Cardiac Care Unit.
EESL	External Energy Saving Lab.
DV	Displacement Ventilation.
UV	Up-in and up-out Ventilation.
Nu	Numerical.
ρ	Density (Kg/m^3).
V	Velocity vector (m/s).

Biographies

Assist Prof. Ali A. Monem was born in Basra, Iraq. He got his degree in Mechanical Engineering B.Sc. in 1976 and M.Sc. in 1978 in Mechanical Engineering (Thermal Mechanics) from Basrah University, College of Engineering. He is currently a lecturer in the Mechanical Engineering Department, University of Basrah to teach and supervise undergraduate, and M.Sc. students.

Emad A. Khazal was born and raised in the city of Basrah. He is one of the teaching staff in the Mechanical Engineering Department, College of Engineering, University of Basrah. He obtained a bachelor's degree from the University of Basrah in 1997, then he studied high graduate studies there to obtain a master's degree in 1999, and then a doctorate in 2011 with a specialization in thermal and he continues to teach at the same university, Department of Mechanical Engineering.

Abdulhadi Mohsen Salman was born in Thi-Qar, Iraq. He received his degree in Mechanical Engineering B.Sc. in 2007 in Mechanical Engineering from the University of Basrah, College of Engineering.