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SIMULATING THE IMPACTS OF USING WALL AND UNDER-FLOOR AIR CONDITIONING ON CONTROLLING CARBON DIOXIDE CONCENTRATION IN ROOMS AND WAITING ROOMS TO REDUCE THE RISKS OF RESPIRATORY INFECTIONS.

J. ALZUBAIDY[1], M. FARHADI[2], HASANEN MOHAMMAD HUSSAIN[3]

[1,2] *Department of Mechanical Engineering, Babol Noshirvani University of Technology, Babol, Iran*

[3]*Department of Mechanical Engineering, University of Technology-Iraq, Baghdad, Iraq*

Abstract

The underfloor air distribution system is a type of air conditioning system that has recently received a lot of attention due to the reduction of energy consumption and the improvement of thermal comfort conditions in the residential area. The present study investigates the efficiency of these systems in terms of residents' thermal comfort, indoor air quality, and energy consumption using a combination of computational fluid dynamics and Taguchi's optimization algorithm. With regard to the need to study these goals at all times, optimization of this study has been performed with a multi-objective approach. First, the numerical simulation results have been validated by experimental data for a sample space equipped with an under-floor air distribution system. Then, considering the height of 2.7 meters for this space and placing the return valve, optimization has been done for the mentioned purposes. In another case, the effects of natural air conditioning on the interior of a room have been studied. The results show that the use of opening doors with the same row increases the air circulation and maintains the comfort temperature in such a way that compared to inconsistent doors, the average of air life increases by approximately 40%. The results also show that placing the valve at the height of 1.75 meters from the floor reduces the energy consumption by nearly 12%.

Keywords: UFAD, PMV, Thermal comfort, Air conditioning, Building

1. INTRODUCTION

Today, due to the increasing consumption of building energy and at the same time increasing the emission of carbon pollutants in the ecosystem, many researchers pay special attention to the energy consumption of buildings and air conditioning. During the hot and cold days of the year, large amounts of fossil fuels are mainly used to maintain a satisfactory temperature in the interior of homes and offices. This case raises environmental pollution and generally increases the global average temperature. To solve this problem, in addition to improving the design of buildings, researchers have recommended the use of air conditioning based on green fuels.

In recent years, there has been a growing awareness of indoor air quality and its interaction with the proper design of Air Conditioning and Mechanical Ventilation (ACMV). This is especially important in hospitals where airborne respiratory diseases are the second most common cause for patients, health care workers, and visitors. Therefore, the ACMV system in the hospital plays a more fundamental role in creating thermal comfort. In many cases, proper air conditioning is a factor in the treatment of patients and can even be the main treatment. The prevalence of respiratory infections, especially emerging respiratory diseases in recent years, has highlighted the importance of infection control. The global prevalence of Covid 19 disease, which is an acute respiratory disease, has increased the importance of proper air conditioning design in indoor places, and much research has been done in this area in recent years.

In a laboratory study, Berlanga *et al*. [1] examined thermal comfort, ventilation performance indicators, and exposure to airborne contaminants in an airborne infection isolation room equipped with a convective air distribution system. Three rates of air renewal have been tested to determine their effect on the studied variables. The results show that ventilation performance, pollutants, and general comfort indicators work well for both studied mannequins. In a review study, Sadrizadeh *et al.* [2] examined the systematic ventilation of a room. The purpose of this review study was to provide a good understanding of room air conditioners in terms of air quality and infection control using existing research and to provide multidimensional perspectives on the design and proper operation of the room air conditioning system. In a laboratory study, Kong *et al.* [3] investigated the effect of different air conditioning systems on indoor air quality. The results showed that air conditioning plays a vital role in eliminating the pollution caused by the virus. In a laboratory study, Tung *et al*. [4] used the isolated room's negative differential pressure and air conditioning rate to investigate the distribution of pollutants.

Lau and Chen [5]evaluated the performance of the under-floor air distribution system for a large workshop experimentally and numerically. The results of this study showed that the room air exchange rate, inlet velocity, and temperature, as well as the number of inlet valves, had the greatest effect on thermal comfort and air quality. Also, the partitions and the location of the outlet valve have a moderate effect on these parameters, and the distance of the inlet valves, the location of the occupants, and the arrangement of the furniture have the minimum impact on thermal comfort and air quality. Lin *et al*. [6] evaluated the effect of internal partitions on the performance of the under-floor ventilation system in terms of thermal comfort and air quality in an office. The results of their study showed that partitions might have a significant effect on airflow and the operation of the under-floor ventilation system. The presence of space above the partition causes air circulation in the upper area, and as a result, the air distribution in the room improves. Ho *et al*. [7] studied the effectiveness of these systems in a large, high-altitude space for different inlet air velocities and various locations for inlet valves at the same temperature for the air distributed to the room. In this study, in particular, the purposes of establishing thermal comfort conditions for residents and the practical application of these systems have been investigated. The results of their survey showed that under-floor systems could create fewer vertical temperature differences and create an environment with better thermal comfort than conventional ceiling air conditioning systems. Cheng *et al*. [8] Using a new method for calculating the cooling load of the coil in classified air distribution systems, the effect of separating the return and outlet valves on the thermal comfort of residents and energy consumption, experimentally and numerically examined in a model administratively. The results of this study show that by separating the location of the return and outlet valves, the potential for more energy savings for these systems will be provided. Also, lowering the height of the return valve will increase the temperature of the outlet valve and significantly reduce the cooling load of the coil. Heidarinejad *et al*. [9] examined the under-floor air conditioning system with return valve and non-compliant exit. In this survey, the appropriate angle for the rotary inlet valve, comparing the general thermal comfort conditions at three different inlet valve angles, was selected. Their results showed that increasing the distance of the valve from the floor of the hall reduces energy consumption. Fathollahzadeh *et al.* [10] investigated the possibility of using the under-floor system in a densely populated space concerning general and local thermal comfort conditions. In this study, different locations for inlet valves and various inlet velocities were investigated to determine the better performance of the under-floor ventilation system. The results of their study showed that when the inlet valves are located under the seats, higher temperatures are measured at relatively lower altitudes. Another way to control the temperature and maintain the comfortable temperature of the interior of the building is to use phase change materials (PCMs) [11, 12]. In a laboratory study, Li *et al.* [13] investigated the performance of wall insulation. In this study, they compared the wall with and without PCMs and found that the use of PCMs leads to a further decrease in internal temperature and gets closer to a satisfactory temperature range for human habitation. Javidan *et al*. [14], in a numerical study, investigated the presence of paraffinic PCMs RT21 and RT26. Their results show that increasing the thickness of the PCMs reduces the rate of thermal diffusivity into the interior of the building. In a numerical study and its comparison with laboratory results, Leang *et al*. [15] investigated the effect of PCMs on the thermal performance of a Trombe wall for temperature regulation. In this combined work, they examined a Trombe wall with a concrete cover as their experimental benchmark. Their results show that the Trombe wall containing PCMs increases the time to reach a peak about four times for the indoor temperature values. Balars *et al.* [16] provided an overview of the general design for acceptable indoor conditions for HAVC systems in hospital operating rooms. Data from 20 operating rooms in 10 hospitals were recorded, including a wide range of information on construction, ownership, type, and status of HAVC and assistive systems. Data related to environmental assessment were collected from 560 medical personnel at the workplace based on personnel questionnaires. The results of this study showed that these environments do not meet the minimum standards due to poor control of temperature conditions, improper placement of equipment, and its effect on the ventilation system performance. Mustakallio *et al*. [17] evaluated the method of convection and radiation heat transfer for cooling systems of offices in summer weather conditions. In this experimental work, they also investigated the thermal effects of the presence of individuals. Their results revealed that the heat flow pattern has a significant influence on the final performance of heating and air conditioning systems. Therefore, they stated that the method of irradiating cold air into the environment has a satisfactory result in cooling and maintaining a comfortable temperature. To study the thermal influences and maintain the comfortable temperature of offices, Espinosa and Glicksman [18] tried to measure the effects of using dividers. Their results showed that the arrangement and placement of partitions have a significant effect on the heat distribution and radiation. In such a way that, by arranging the partitions horizontally and creating a distance between people, the radiation effects of electronic devices are reduced, and the temperature gets satisfactorily close to the comfortable temperature. Lin *et al*. [19], about maintaining the comfortable temperature of offices, stated that humidity and heat inside the room have a great impact on the thermal performance of radiators.

In the field of underfloor air distribution systems, previous studies have focused on different parameters and examined their impact on the goals of thermal comfort, air quality, and energy consumption in general. An important novelty in the present study, which has not been performed in previous studies, is the simultaneous analysis of the thermal comfort goals, air quality, and energy consumption to obtain optimal operating conditions for under-floor air distribution systems using multi-objective optimization. According to the parameters of the location of subsurface valves, the height of the return valve, room air exchange rate, inlet air temperature, and the angle of the inlet valves blades and considering several levels for each of them, the number of states resulting from different combinations of these parameters would increase. Therefore, considering these parameters and the demand to study the mentioned objectives to analyze the efficiency of underfloor air distribution systems, optimization is required for several purposes. In this work, using the Taguchi optimization algorithm, the optimization of underfloor air distribution systems has been done for small sample spaces and crowded spaces, respectively.

2. Government Equations and Boundary Conditions:

First, the governing equations, that is, the equations of continuity, momentum, and energy, are described. Each goal of thermal comfort, air quality, and energy consumption with the indicators required for their analysis are examined. Also, the governing equations in calculating each of these indicators are presented.

Flow governing equation [20, 21]:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u_i)}{\partial x_i}=0 \quad (1)$$

In this equation, ρ and u are fluid density and velocity. Given the steady solution to the problem and the assumption of flow incompressibility, this equation is simplified as follows:

$$\frac{\partial(u_i)}{\partial x_i}=0 \quad (2)$$

Momentum equation:

$$\frac{\partial(\rho u_i)}{\partial t}+\frac{\partial(\rho u_i u_j)}{\partial x_i}=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_i}\left[\mu\left(\frac{\partial(u_i)}{\partial x_i}+\frac{\partial(\rho u_j)}{\partial x_i}-\frac{2}{3}\,\delta_{ij}\frac{\partial(u_i)}{\partial x_i}\right)\right]+\frac{\partial}{\partial x_i}(-\rho\overline{u_i' u_j'}) \quad (3)$$

In this equation, p and μ are the pressure and viscosity of the fluid. Given the steady solution to the problem and the assumption of flow incompressibility, this equation is written as follows:

$$\frac{\partial(u_i u_j)}{\partial x_i} = -\frac{1}{p}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_i}\left[\nu(\frac{\partial(u_i)}{\partial x_i} + \frac{\partial(u_j)}{\partial x_i} - \frac{2}{3}\,\delta_{ij}\frac{\partial(u_i)}{\partial x_i})\right] + \frac{\partial}{\partial x_i}(-\overline{u_i' u_j'}) \tag{4}$$

Here the ν shows the kinematic viscosity. Based on Equations 3 and 4, the term $-\overline{u_i' u_j'}$ can be expressed as follows:

$$-\overline{u_i' u_j'} = \nu_t\left(\frac{\partial(u_i)}{\partial x_i} + \frac{\partial(u_j)}{\partial x_i}\right) - \frac{2}{3}\left(k + \nu_t\frac{\partial(u_j)}{\partial x_i}\right)\delta_{ij} \tag{5}$$

Here, the ν_t indicate the turbulent kinematic viscosity. In this work, the k-omega turbulence model is used to solve the problem.

$$\nu_t = 0 \cdot 003874\nu L \tag{6}$$

Here, V and L indicate the speed and distance from the nearest wall, respectively. The enthalpy can be used to express the energy equation:

$$\frac{\partial(\rho H)}{\partial t} + \nabla\cdot(\rho H\vec{v}) = \nabla\cdot[(k + k_t)\nabla T] + S_h \tag{7}$$

The following formula can be used to calculate the enthalpy:

$$H = \int_{Tref}^{T} C_p dT \tag{8}$$

Here T_{ref} represents the ambient temperature. And k and k_t represent the molecular conductivity and the conductivity due to turbulence, respectively.

One of the important parameters for comfort temperature is ratio of smaller is better to nominal the best [22].

$$\frac{S}{N} = -10\log_{10}(\frac{1}{n}\sum_{i=1}^{n}(Y_i - Y_o)^2) \tag{9}$$

Where Y_i and Y_o show results of simulation and the value of aim.

In the analysis of airflow in the room, one of the most significant indicators is to inspect the carbon dioxide concentration [23]:

$$C_{C_2O}(t) = C_0 + (C_{strart} - C_0)e^{-AER\,(t-t_{start})} \tag{10}$$

Here, AER is the standard limit of the air exchange rate, Where C_0 and C_{start} represent the carbon concentration of the outdoor space, and the initial carbon concentration of the room space, respectively.

3. Research objectives

Thermal comfort is a mental condition that expresses satisfaction with the thermal environment. Given that people are physiologically and psychologically different from each other, it is arduous to satisfy everyone in the same circumference. In other words, the environmental conditions required for comfort are not the same for everyone. Six main parameters are considered to define thermal comfort conditions. These parameters are metabolic rate, type of coating, air temperature, radiant temperature, air velocity, and humidity [24]. In this numerical work, the Predicted Mean Vote criterion has been used to evaluate the comfort conditions for the building shown in Figure 1.

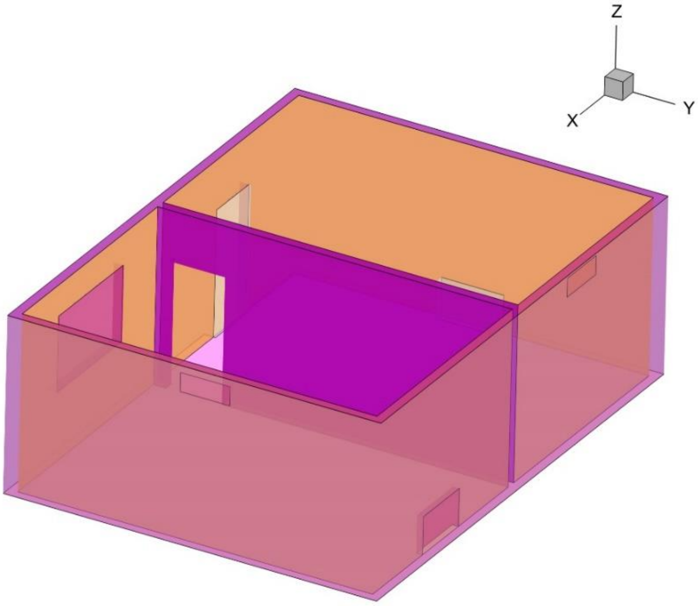
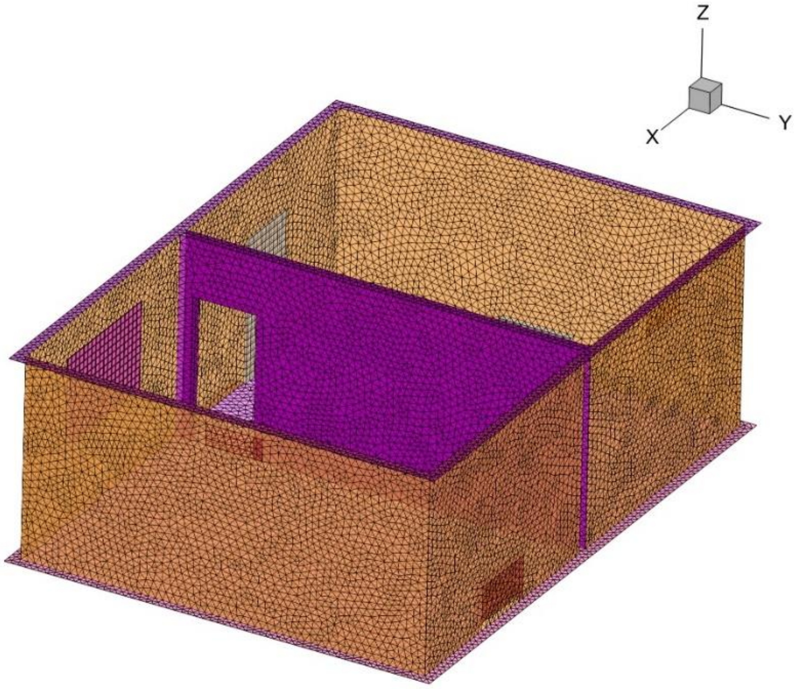


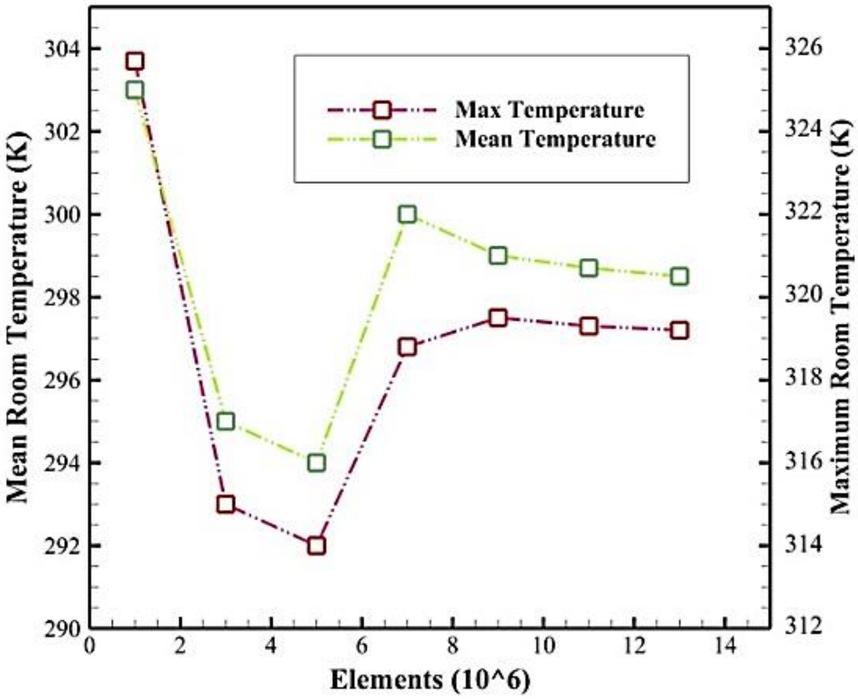
Figure 1. The building

4. Grid Independence

One of the most important parts of simulation based on meshing. Generally, increasing the number of mesh increments accuracy of results, but this can't guarantee forever. For this reason, tried to calculated the optimization number of meshing, Figure 2.



(a) Meshing

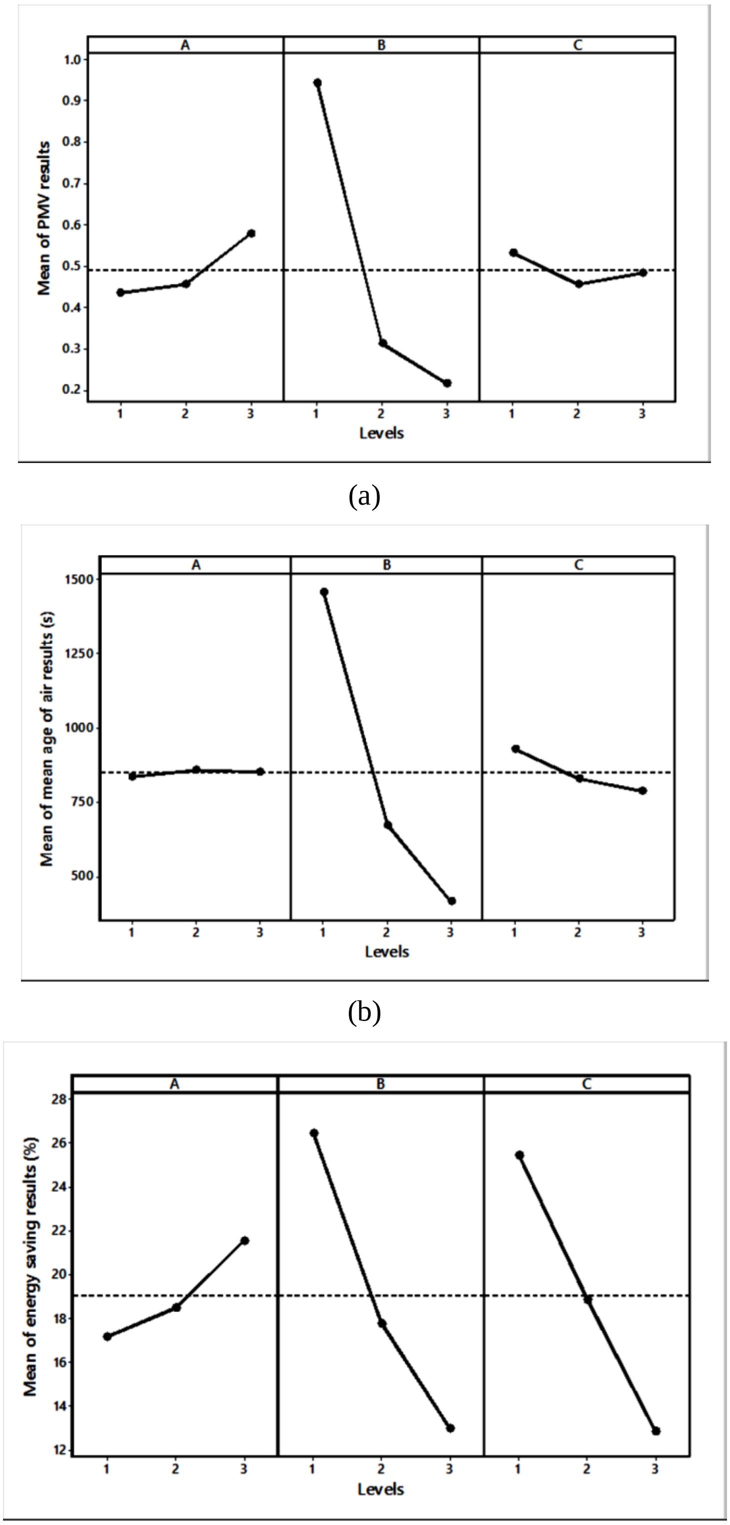


(b) Optimization

Figure 2. The optimization of meshing numbers

5. Results

The average results of the experiments show that with increasing inlet air temperature, the absolute value of PMV increases, and in the case of inlet air temperature between 17 and 19 degrees Celsius, thermal comfort is established. However, if the inlet air temperature is equal to 21 degrees Celsius, Thermal comfort conditions will not be established. Also, by increasing the inlet air temperature, the amount of energy consumption will increase. As can be seen, the room air exchange rate affects all three goals of thermal comfort, air quality, and energy-saving significantly. In addition, the graphs show that by decreasing the room air exchange rate, the absolute value of PMV increases, so that with the room air exchange rate equivalent to 2 times per hour, thermal comfort conditions will not be satisfied. Nevertheless, if the room air exchange rate is equal to 4 and 6 times per hour, thermal comfort will provide. Also, the average age of the air and the amount of energy savings decrease by increasing the room air exchange rate. As can be seen, the height parameter of the return valve has a great effect on the amount of energy savings as well as the goals of thermal comfort and air quality, (Figure 3).



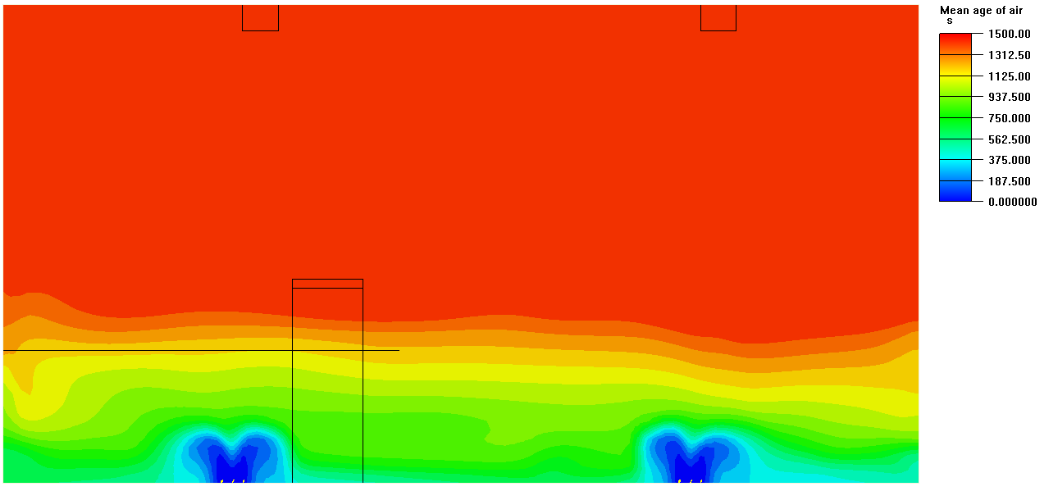
(a)

(b)

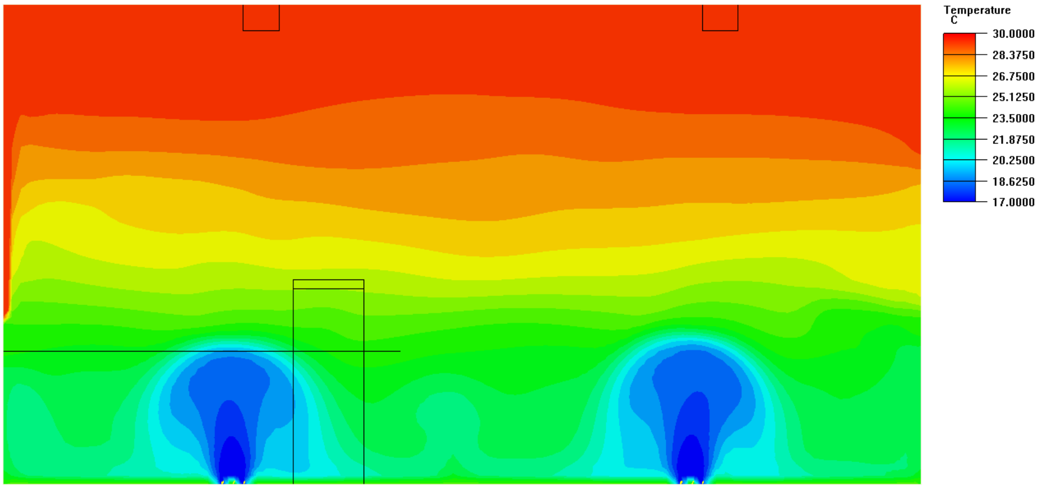
(c)

Figure 3. Graphs of average test results for all three goals of thermal comfort, air quality and energy reduction

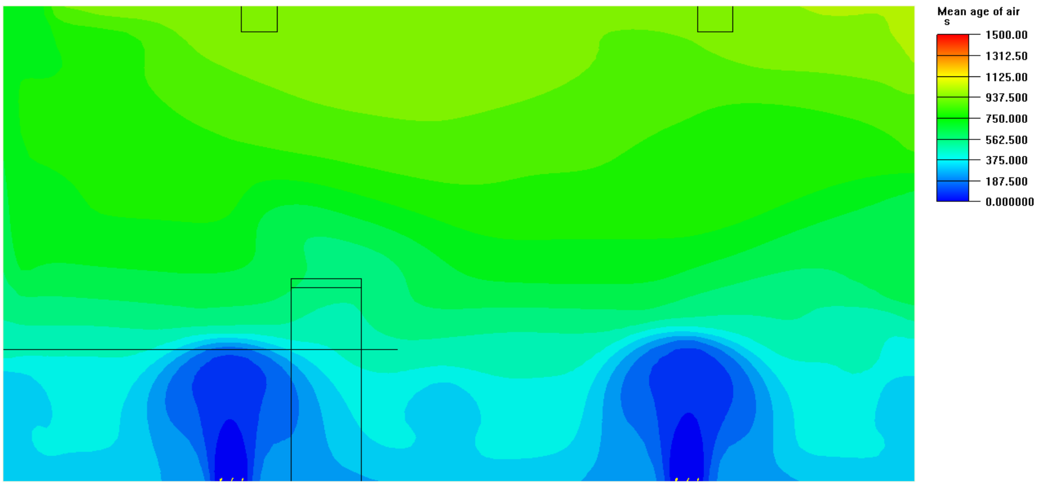
In Simulation No. 1, the inlet air temperature is 17 degrees Celsius, the room air exchange rate is 2 times per hour, and the return valve altitude is 1 meter above the ground. Considering that in this case, the air exchange rate and also the height of the return valve are low, and despite the low temperature of the inlet air, it is observed that in the head and neck areas of the person, the air temperature is high (Figure 4).


Mean age of air
s
1500.00
1312.50
1125.00
937.500
750.000
562.500
375.000
187.500
0.000000

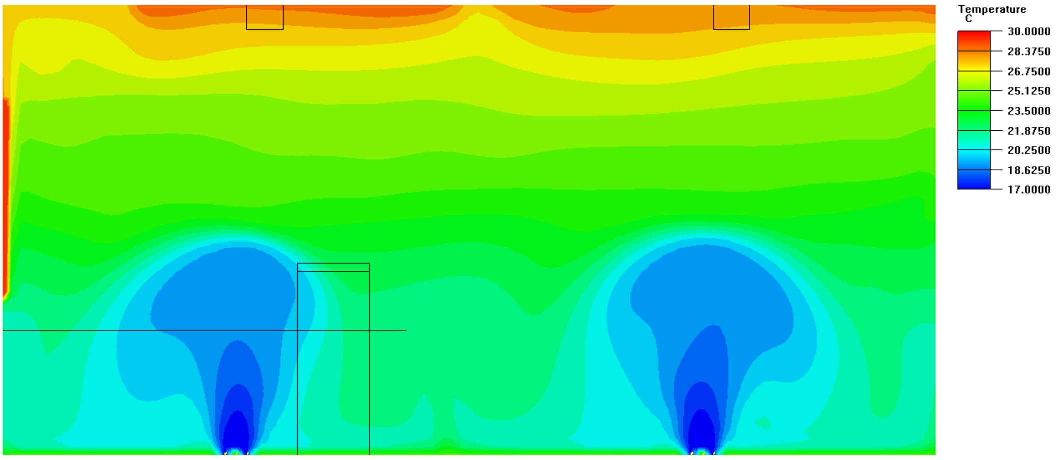
(a)


Temperature
C
30.0000
28.3750
26.7500
25.1250
23.5000
21.8750
20.2500
18.6250
17.0000

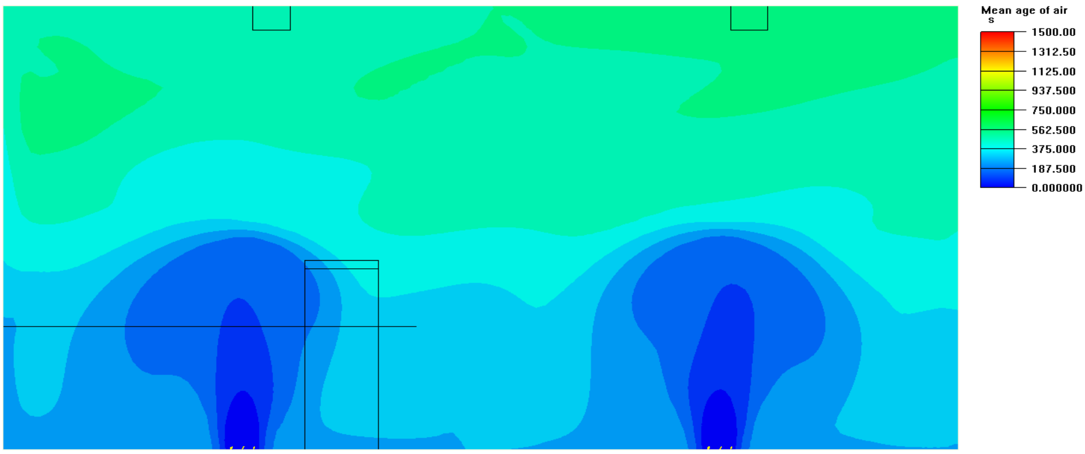
(b)


Mean age of air
s
1500.00
1312.50
1125.00
937.500
750.000
562.500
375.000
187.500
0.000000

(c)



(d)

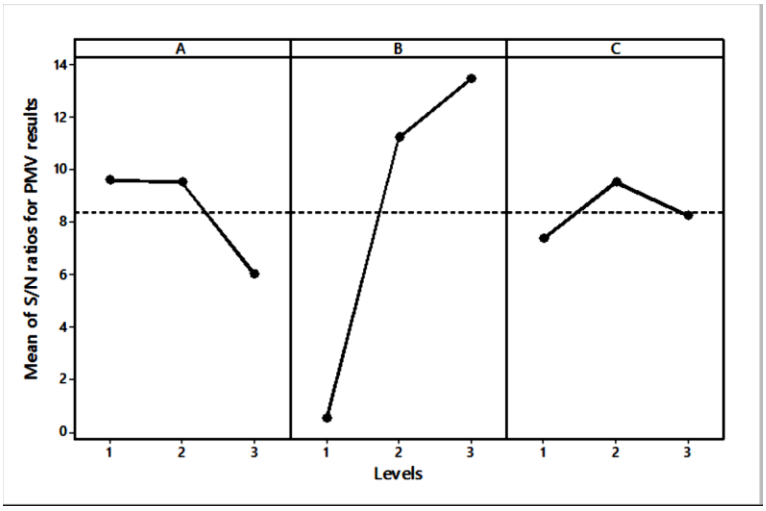


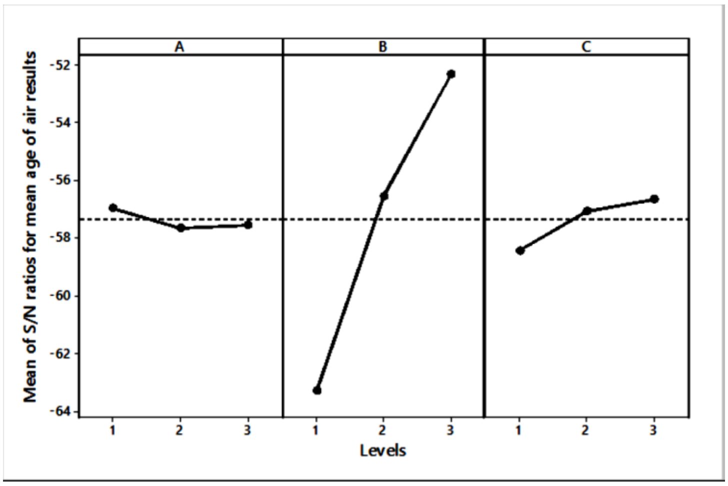
(e)

Figure 4. Temperature and average air age counters for experiments (a) No.1 (b) No.2 (c) No.3 (d) No.4 (e) No.5 at (height=1.8 meters)

Also, due to the high average age of the air in the inhalation area, the air quality in this area is not good. In Simulation No. 2, the inlet air temperature is 17 degrees Celsius, the room air exchange rate is 4 times per hour, and the return valve height is 1.75 meters above the ground. At this point, considering that the return valve is higher than the inhalation area and also the air exchange rate is average, Figure 4.a, despite the low inlet air temperature, the air temperature in the residential area is appropriate, and also the air quality in the inhalation area is relatively desirable. In Simulation No. 3, the inlet air temperature is 17 degrees Celsius, the room air exchange rate is 6 times per hour, and the return valve height is 2.5 meters above the ground. Regarding that, in this case, the inlet air temperature is low, and the air exchange rate is high, Figure 4.2, the temperature in the residential area is low, and also due to the high air exchange rate and the location of the return valve at high altitude, air quality in the inhalation area is desirable. In the optimal state, the inlet air temperature is 19 degrees Celsius, the room air exchange rate is 6 times per hour, and the return valve height is 1.75 meters above the ground. Supposing that, in this case, the inlet air temperature and the air exchange rate are appropriate and the return valve is located above the inhalation space, it was finally revealed that the living area is very suitable, and the air quality in the inhalation area is desirable.

According to the goals of minimum PMV absolute value, minimum average air age, and maximum energy saving, a diagram of the average S / N parameter for each of the inlet air temperature criteria, room air exchange rate, and return valve height for each the goals of thermal comfort, air quality, and energy consumption reduction are shown in Figure 5.





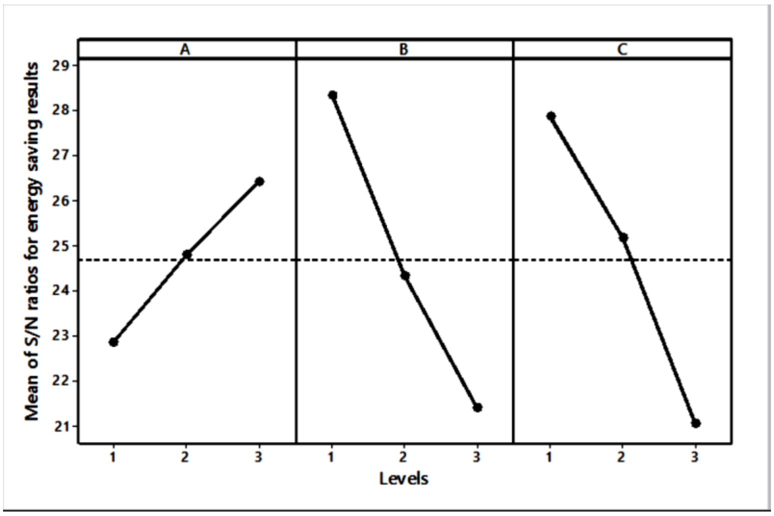
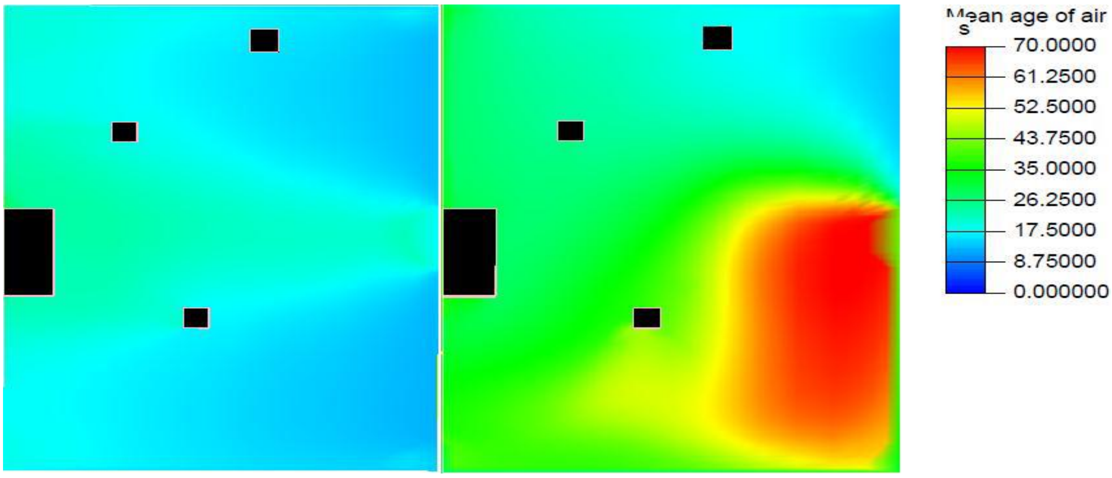


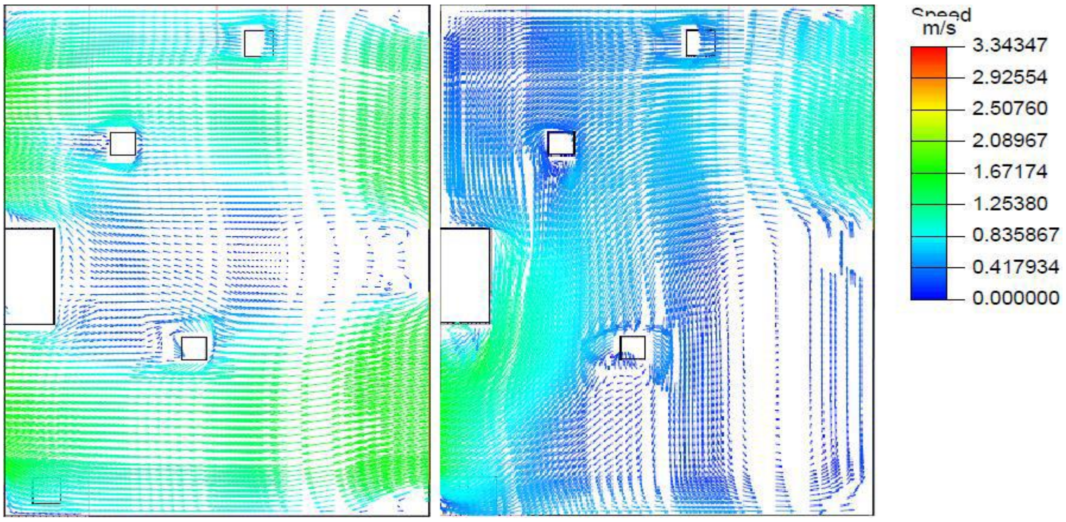
Figure 5. Graph of average parameter S/N for each of the goals of thermal comfort, air quality and energy consumption reduction

By considering the maximum value of the S/N parameter for each factor, the following combinations are considered the optimal state for each objective. If the purpose of this study was only to establish the thermal comfort of the inhabitants, the Taguchi algorithm presented the factor combination of levels A1, B3, and C2 as the optimal condition for this purpose. In other words, according to this algorithm, by selecting the inlet air temperature of 17 degrees Celsius at a distance of 19 meters from the ground, adjusting the air exchange rate of 6 times per hour, and also placing the return valve at the height of 7.2, the best conditions in terms of thermal comfort would be provided. As can be seen, the total S/N value in experiment No. 17 with the combination of factor levels A2, B3, and C2 is higher than in other tests, and therefore this test is selected as the optimal state. In other words, by selecting the inlet air temperature equivalent to 19 degrees Celsius, and air exchange rate equal to 6 times per hour, as well as placing the return valve at the height of 1.75 meters above the ground, would provide the best conditions in terms of thermal comfort, air quality, and energy savings. The simulation results for these conditions show that considering that the PMV value is equal to 0.04, the thermal comfort conditions for the residents in this area are well provided, thus reducing energy consumption by nearly 12%.

One of the salient parameters for determining the temperature of thermal comfort and air quality inside the room is the average of local thermal comfort. The average of local thermal comfort is considered as the average time when all air molecules are transferred from the air inlet to the expected point. Since natural ventilation is not as controllable as mechanical ventilation, the rate of air infiltration into the room depends on the position of the windows or opening doors. Therefore, an attempt has been made to examine the location of the opening doors. As shown in Figure 6,



(a)



(b)

Figure 6. The contour of (a) Local age mean (b) vectors of speed

A room with opening doors facing each other has a longer local thermal comfort. The reason for this is that inside a room whose doors are in the same direction, the speed of airflow is faster than in a room with non-aligned doors. Since the doors are not in the same direction, the air is trapped in a specific area of the room and prevents ventilation due to lack of flow. Therefore, it can be found that the use of transit ventilation, causes maintain the comfort temperature and quality.

In general, one of the major threats of spreading respiratory diseases is the presence of extreme carbon dioxide in the living room or any other roofed environment. In daily monitoring of the study environment, it was found that the hours of the presence of individuals are explicitly related to the amount of carbon dioxide in space. In this study, an attempt has been made to examine the attendance of individuals during the day (before noon). In this study, the room space has been examined by assuming that all people are present at the same time in the environment. Based on the results, it can be stated that the presence of people in the room is not the only factor in increasing the concentration of carbon dioxide. As can be seen from Figures 1 and 2, although room number 1, with ten people, has more individuals, its carbon dioxide concentration is lower than that of Room 2, where only six people are present. The reason for this difference is that room 1 has an air conditioner that is appropriate to the presence of people, has a good frequency, and is active at all times when people are in the room. Although room one has a good operating frequency, it has been discontinuously active, which has caused the concentration of carbon dioxide in the room to increase during idle hours. Room 3 and room 4 also have an equal audience of 6 people. Since the activity hours of room 3 have started before the audience enters, it has a much lower concentration of carbon dioxide. While both rooms have the same type of ventilation with the same working conditions (working frequency and working activity during the presence of people). Because ventilation has begun in Room 4 at the same time as the presence of people, the concentration of carbon dioxide is slightly higher due to the time-consuming (albeit low) ventilation, Figure 7.

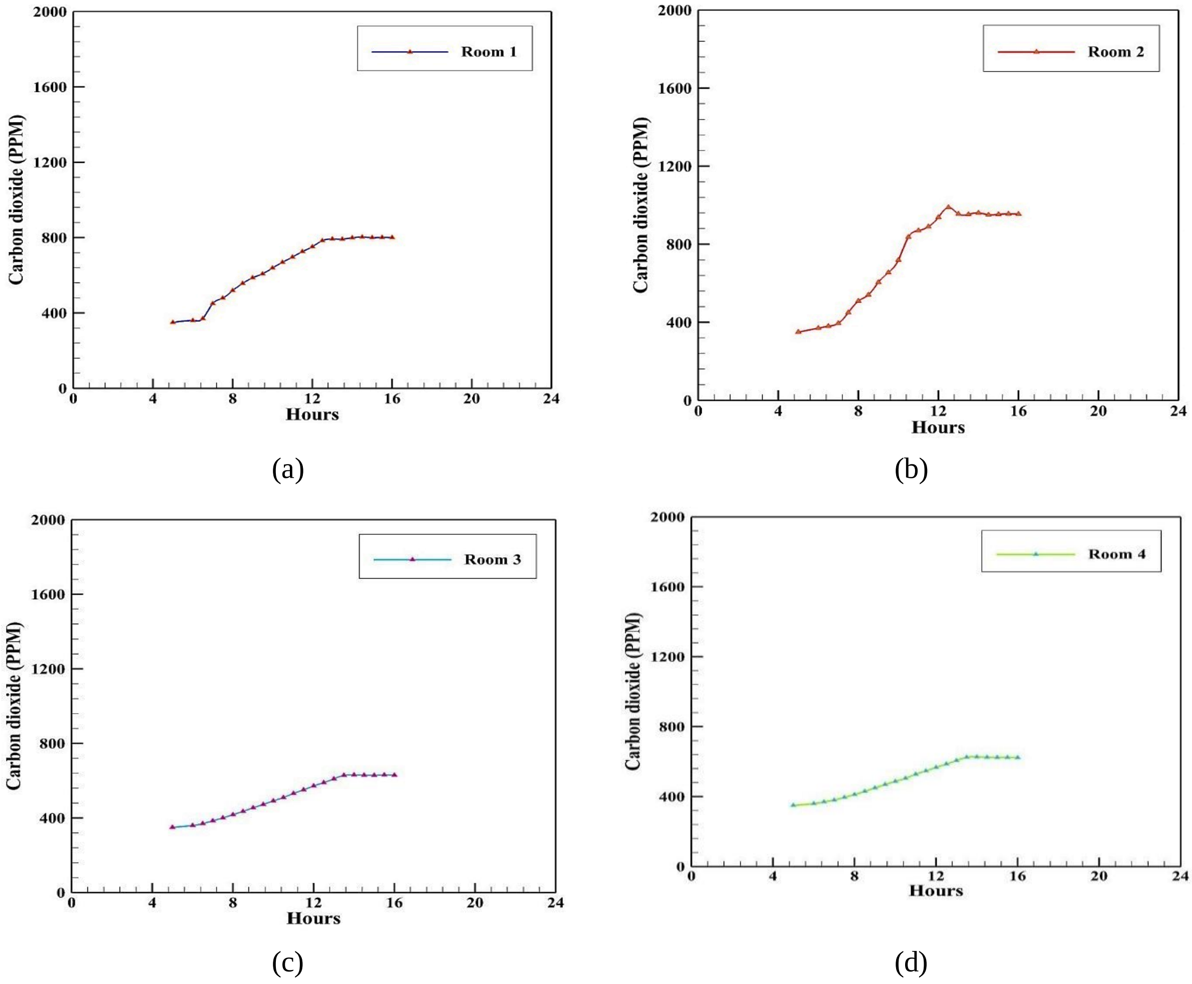


Fig 7. Examination of carbon dioxide concentration in waiting rooms (a) 10-person hall with air conditioning (b) 6-person hall without air conditioning (c) 6-person hall with air conditioning (active when people are present) (d) 6-person hall with air conditioning (activated before the presence of people)

One of the important issues in examining the concentration of carbon in the room is air circulation. By and large, when space is confined, air rotation and circulation are very low, respectively. This accumulation eventually increases the carbon. In this study, three rooms with the following conditions have been examined: room one is without ventilation and is closed, room two is without ventilation and has cross-ventilation, and room three, which has a ventilation system, has been examined. The results show that with the presence of 5 people in each room, room number 1 has the highest amount of carbon dioxide, which is higher than the maximum standard. The condition in room number two is a bit better. In fact, due to the air flow and the entry of fresh air (at a constant speed), the concentration of carbon dioxide decreases. However, the concentration of carbon dioxide is still higher than the standard. The optimal conditions for Room 3 are entirely comprehensible, as with continuous air conditioning activity, the range of changes in carbon dioxide concentration is low and, most importantly, within the standard maximum and minimum range. It can be concluded that in addition to air circulation, lowering the temperature also has a significant effect on the concentration of carbon dioxide. Because room number two has a higher temperature than room number three (about 5 degrees more), this has caused the concentration of carbon dioxide to exceed the standard for room number two, Figure 8.

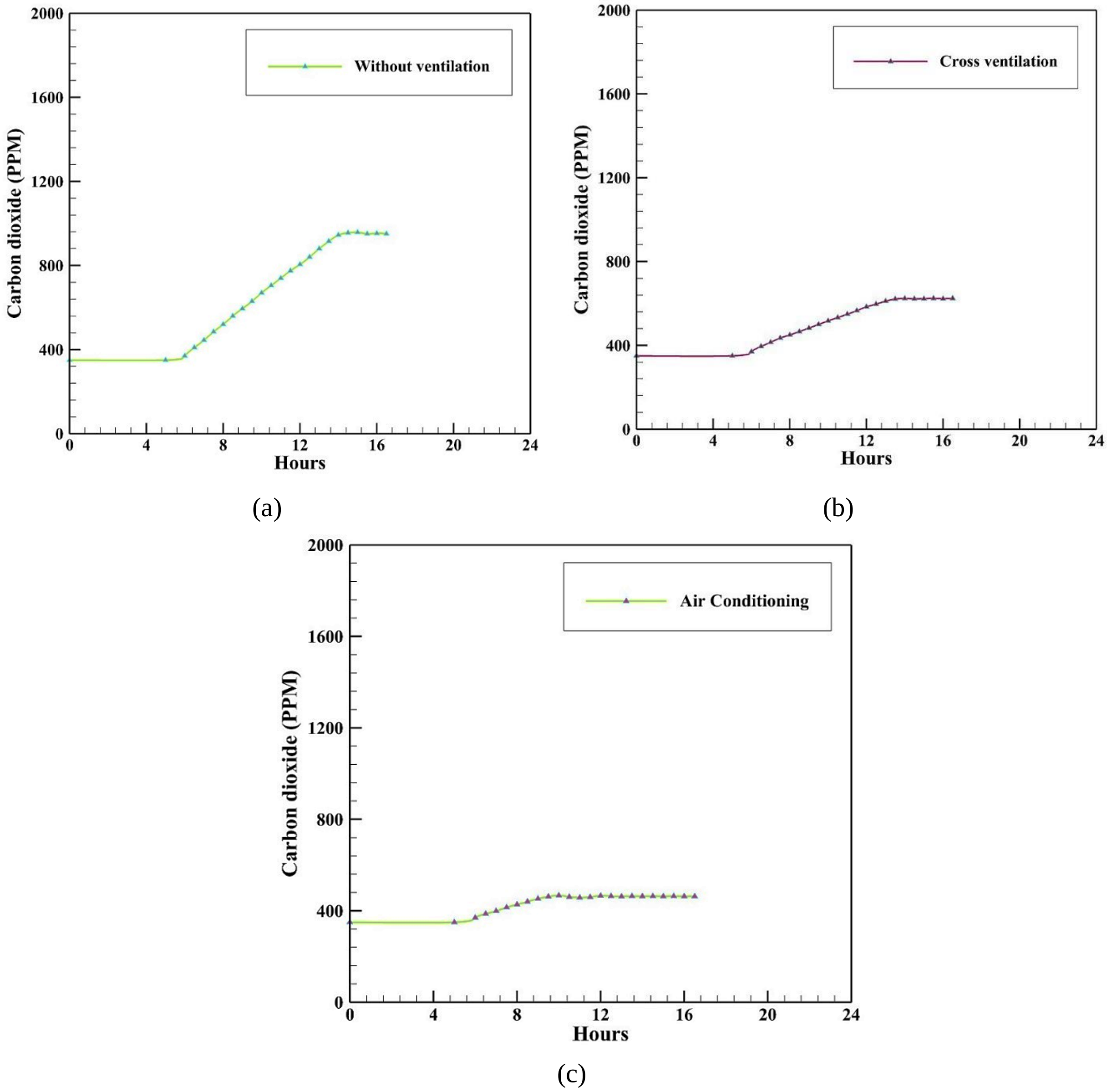
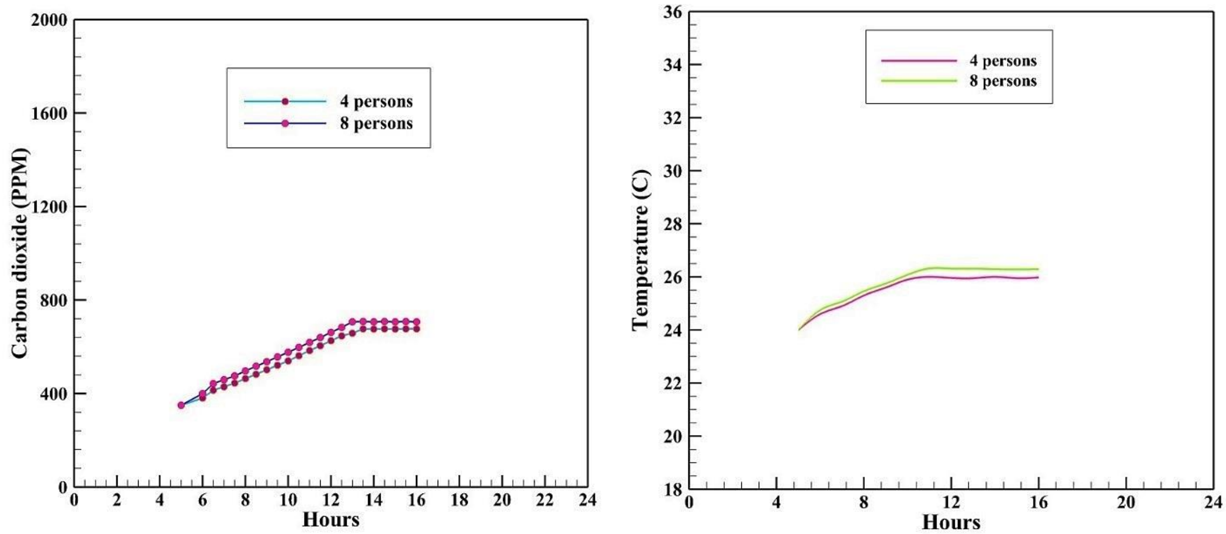
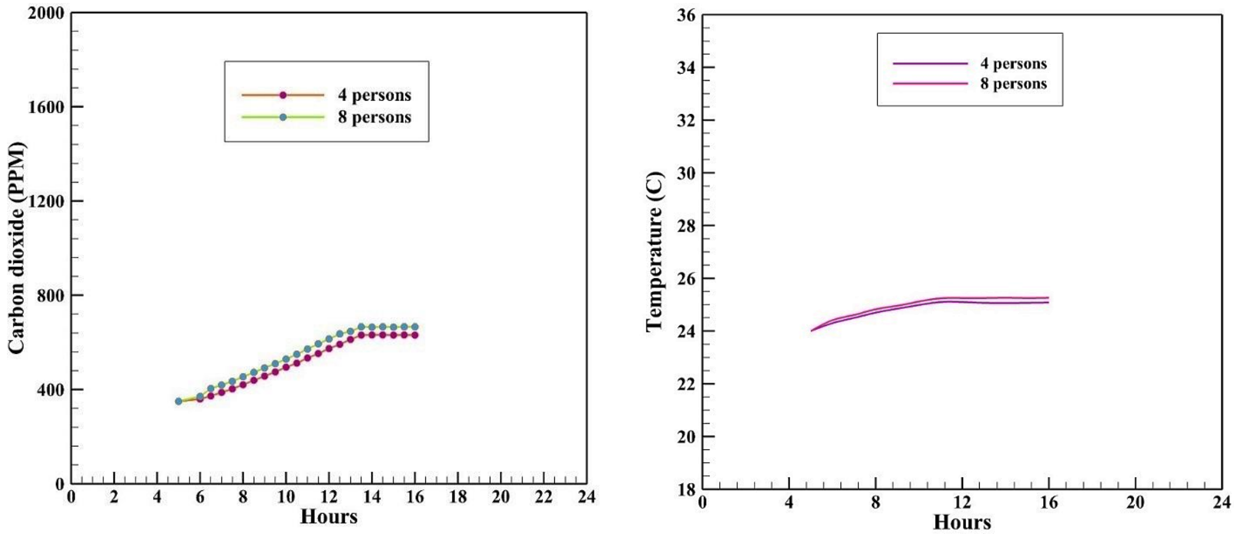


Fig 8. Investigating the influences of the existence and absence of air conditioning or the use of cross ventilation on the concentration of carbon dioxide in the room (a) room without air conditioning (b) room with cross-ventilation (c) room with air conditioning

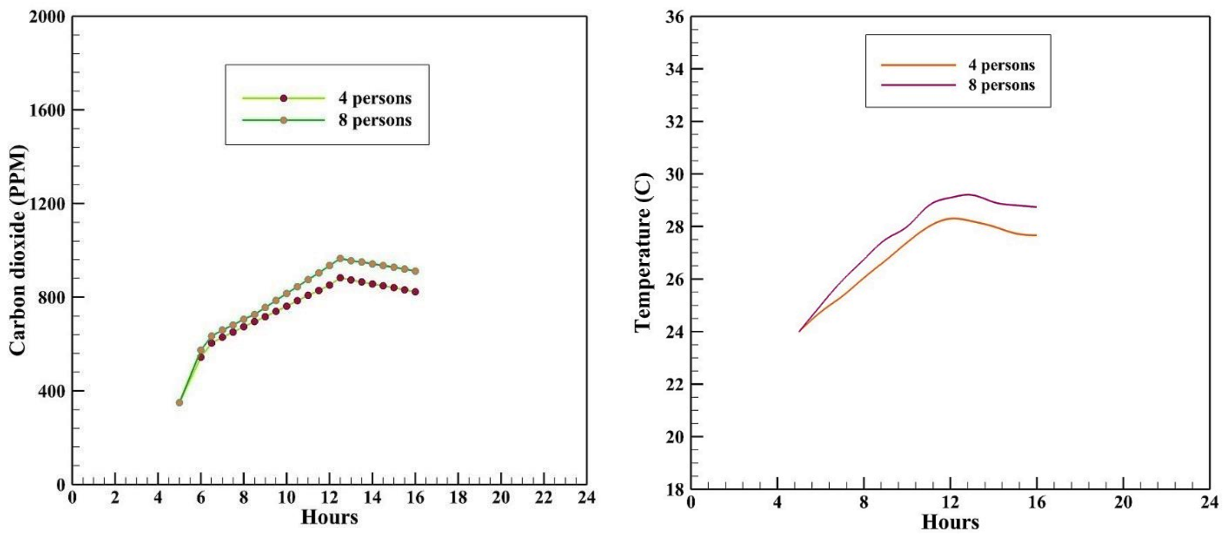
One of the main factors regarding the concentration of carbon dioxide is the study of room temperature. In this study, an attempt has been made to examine three rooms. Room No. 1 holds air conditioning without a valve (air circulation valve); Room No. 2 has air conditioning to adjust the temperature and, of course, contains an air circulation valve. Both rooms have the same temperature. Room No. 3 has no air conditioning, and the air is flowing through cross-ventilation. Room No. 3 has a much higher temperature compared to two rooms with air conditioning. This condition has also led to higher concentrations of carbon dioxide. Room No. 1 has a favorable situation compared to room No. 3, but with the increase in the number of people from 4 to 8, it does not have the desired conditions by the carbon concentration standard. The conditions of room No. 2 are absorbing due to the installation of air conditioning. Also, since the air circulation valve has been installed for this room, with the increase in the number of people from 4 to 8, the carbon concentration in the room is still within the standard range. This subject makes it clear that the two factors of temperature and air circulation have a significant effect on controlling carbon concentration, Figure 9.



(a)



(b)



(c)

Fig 9. Exploring the results of temperature and air circulation on carbon dioxide concentration in 8-person rooms (a) a room with air conditioning (b) a room with air conditioning and an air circulation vent (c) a room without air conditioning

The study of local thermal comfort is an important topic in the analysis of underfloor air distribution systems, so to investigate the conditions of thermal comfort in the optimal circumstances, the difference in vertical temperature between the head and feet and the average air velocity for both persons have been studied. According to Table 1

Table 1. The local thermal comfort conditions for the difference between head and foot.

Simulation	1	2
Temperature Differences (^{o}C)	**1.24**	**2.07**
Average Speed (m/s)	**0.074**	**0.092**

the vertical temperature difference between the head and feet is less than 2 degrees Celsius for both persons, and the local thermal comfort is provided in terms of the vertical temperature difference between the head and feet. Also, due to the average speed of the air in the front area of the persons, the percentage of dissatisfaction due to draught for both people is approximately equal to 9%, and the local thermal comfort is provided for both people according to the draught.

6. Conclusion

Ansys-Fluent software was used to simulate and solve the equations of mass conservation, momentum, and energy for a steady and turbulent flow. Numerical simulation has been done by the finite volume method. And the second-order method has been used to discretize the equations. A structured computational network has been used for numerical solutions, and a Simple algorithm has been employed to solve the coupling between pressure and velocity. In the outlet valve, the average static pressure is equal to atmospheric pressure, and the vertical gradient of other variables is equal to zero.

Air enters the space through 2 inlet valves, the room air exchange rate is equal to 4.4 times per hour, and the inlet temperature is 19 degrees Celsius. In this research, to simulate the circulating air flow distributed by the inlet valves, the subsurface valve is divided into three squares, and all the squares have different airflow directions. In this division, the middle zone is considered to have no airflow.

1. When the PMV value reaches the negative value of 0.01 in the residence area, the average age of the air reaches 88 seconds, which creates suitable conditions in the inhalation area.

2. When the PMV values run lower than zero, the highest energy consumption savings are achieved, as the energy consumption is reduced by nearly 20.1%.

3. The most suitable height for placing air circulation valves is standard dimensions of 1.7 meters to maintain a temperature of 20 degrees Celsius with a circulation rate of 15 times per hour for a room.

4. Using air conditioning systems reduces the concentration of carbon dioxide in the space of a 6-person room by nearly 43%.

5. The presence of an air circulation valve for a 4-person room with an air conditioning system causes the temperature to fall by 11%.

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Nomenclature

PMV	Perdicted Mean Vote
HVAC	Heating, ventilation, and air conditioning
UFAD	Under-Floor Air Conditioning
u	x-velocity [m/s]
v	y-velocity [m/s]
v_t	Turbulent kinematic viscosity
L	Distance from wall [m]
H	Enthalpy [j/kg]
P	pressure [pa]
S_h	Term of Source
K_t	conductivity due to turbulence [w/mk]

Greek Symbols

ρ	Density [kg/m^3]