Anbar Journal Of Engineering Science©Vol 7(2019) 349 – 361

Anbar Journal Of Engineering Science©
journal homepage: http:// http://www.uoanbar.edu.iq/Evaluate/

University of Anbar

Investigation of human thermal comfort and improvement in public places adapted to a hot climate in Iraq

Ahmed Ali Najeeb Alashaab, Mohammed Saeed Alamery

Mechanical Engineering Department, College of Engineering, University of Anbar, Iraq

PAPER INFO

Paper history:
Received 7/5/2018
Received in revised form … … …
Accepted … … …

Keywords:
Thermal comfort; hot-dry climate; air –condition public place; Iraq.

ABSTRACT

This study focuses on improving the thermal comfort in Mosques in Iraq. Omar bin Abdul Aziz Mosque in Baghdad is taken as a case study. In general, the weather in Baghdad is hot- dry climate during the summer. the study was conducted at the time of noon prayer on Friday where the maximum number of people can be obtained inside the Mosque about 500 worshipers and severe environmental conditions. Numerical methods (CFD) are used for the simulation utilizing the package of ANSYS (FLUENT V. 18). As the results depending on the number of elements, 4 millions elements are used for dividing the physical domain. Thermal comfort was assessed by finding the values of the predicted mean vote (PMV), predicted percentage of dissatisfied (PPD), and ASHRAE standard-55. The adaptive redistribution of the air conditioning device strategy at five cases is used to obtain the best thermal comfort. Moreover, changing the angle of air intake of space by changing the angle inclination of the access blade at three different angles of 0o, 7.5o and 15o degree, and studying its effect on the thermal comfort in breathing level. The four case is the best in terms of thermal comfort when the angle of intake air at 0o.when the PMV was 0.35 and PPD is 7.5, which is lower than the original state. The improving percentage of PPD is 10 % and PMV 14 %.

1. Introduction

Comfort thermal for humans is one of the most important goals for air conditioning (A/C) where is defined as "as the condition of mind which expresses satisfaction to the thermal environment" Fanger [1].

It is important to provide thermal comfort in public places, especially the mosques, which are the focus of research. People go to public places continuously in great numbers, which is also a challenge in providing the thermal comfort of the place. The mosque is considered important because it is a place of prayer and prayer for worshipers five times for the day. They spend 15 to 30 minutes each time, especially in Islamic countries. The research focuses on assessing the thermal comfort in Friday prayers at noon. , In July, where the highest temperature in Iraq to reach 50°C.

Many researchers studied the field of thermal comfort over the past century and were one of the most important researchers Fanger in the 1970's[1] and most of the research relies on it to calculate the level of thermal comfort of enclosed spaces. In their research, the researcher relied on practical surveys to calculate the thermal comfort of the occupants in the studied places. In the last few years, after the development of numerical simulation package, work began to evaluate thermal comfort numerically as is work in this research.

The research study in the hot - dry atmosphere is as follows: Khalil et al [2] investigation of the thermal comfort of the Nabiha Yukon mosque in Cairo, which is described as a dry- hot summer. a occupants body were simulated by parallel rectangles with dimensions (0.75 × 0.5 × 0.25) m^3. and assumed The skin temperature was 34 ºC at the metabolic level of 1.2 Met, found that was not achieving the thermal comfort in this building. AL–Ajmi [3] studied of the thermal comfort at six mosques in Kuwait in a hot- dry climate at a maximum temperature of 45 °C, all of which use central A/C to cool the place. The calculations started off the summer in April to the end of October and the poll was conducted for more than 140 people. The result of the survey was that the neutral temperature was 26.1°C at PMV = 23.3, and at AMV the neutral temperature was higher by 2.8°C. Thus contributing to the reduction of energy consumption. Hameed [4] studied the effect of building materials on the design of the mosque and effect the thickness of walls, ceilings and the transparent areas on the thermal comfort inside the mosque. He was found that the ideal thickness of the walls and ceiling at 36 cm and reduce the transparent areas to half improves the thermal comfort. Saeed [5] in this study was conducted a survey of the mosque in the city of Riyadh in King Saudi Arabia(KSA) was carried out in a hot-dry climate. to Assessment of the thermal comfort when the Clothes isolation of 0.4 - 0.6 clo. The poll results showed a good agreement with Fanger. Saeed [6] assessment of the thermal comfort in a classroom of KSA University in Riyadh. the practical survey of the classrooms, which was taken the data at the level of 0.9 m for the sitting and 1.2m for the standing. Hayatu et al., [7] investigation of the thermal comfort in the classrooms of the University of Bayrou Kano in hot- dry climate. using CFD of Numerical simulation by By the ANSYS – FLUENT package. The results were showed that 66% of the students voted for discomfort. Cena and Dear [8] studied the thermal comfort in the classroom at hot -dry climate in Australia . the clothes insulate value were between 0.5 clo in summer and 0.7 clo in winter and 0.1 clo insulated for chairs are added to them , At the rate of metabolization 1.3 met , the average length of persons 171 cm and rate of weight 75kg. The result shows that there was 3 °C between the neutral temperatures in summer and winter due to the difference insulate clothes. Khoukhi and Fezzioui [9] evaluated the thermal comfort in traditional houses in hot- dry climate in southern Algeria. used the CFD methods to numerical simulation .the result showed was the Traditional houses provided the thermal comfort for their occupants.but the Modern homes did not offer the thermal comfort of the occupants in extreme conditions except with the use of A/C. Jbara et al [10] The studied of thermal comfort in a mosque during the five prayers in a hot- dry climate in Egypt Cairo and the use of numerical simulation to calculate the temperature of the air and air velocity and relative humidity and the concentration of carbon dioxide and thermal radiation within the space. Assumption the average metabolite of 1.2 met and skin temperature at 34°C .it was recorded the data at breathing level of 1.7m above ground. There were four distributions of A/C device inside the mosque and choosing the best distribution that provides the thermal comfort. Budaiwi and Abdon [11] divided the space of the mosque into sections and studied the effect on the thermal comfort in a hot- dry climate of the mosque when using the appropriate A/C for each section according to need and the presence of occupants. The results proved a reduction of 23% of the energy used throughout the year. As well as a reduction of 30% when using the appropriate A/C. Compared the mosques isolated with the continuity of operation of the A/C and mosques isolated with the intermittent operation. the intermittent operation case was saving energy up to 46%. Hassan et al [12] investigation the thermal comfort in an office room in Iraq at a hot- dry climate.it was used the CFD of Numerical simulation by Ansys to calculated of the important factors such as air temperature, humidity, and air velocity. The k-ε model was used to represent the state of turbulent flow. It was found that the reduction of air ventilation and reduce the temperature for the air equipped to space improves the thermal comfort and that the presence of an exit air in the roof of the room did not affect at the thermal comfort of the occupants. Sallah et al [13] studied the thermal comfort in the hot- humid climate in Malaysia, especially affected the traditional clothing at level of the thermal comfort, which was that value of 0.528 clo during the five prayers. also conducted a field survey of the mosque occupants and found that the neutral temperature of thermal comfort was 30.44 °C at AMV and 25.88 °C at PMV. Bakhlah and Hassan [14] In the King Khalid Mosque in Malaysia in a hot- humid atmosphere verified the direction of the correct qibla at the mosque when the sun front-direction to him on 17th July 2010 and check the thermal comfort inside the mosque on this day and the day after and took the data at the level height of 0.9 m above the ground. Noman et al. [15], studied the thermal comfort at hot - humid climate of Malaysia, at the Jawhara Mosque, the simulation carried out of CFD methods by ANSYS - FLUENT. Using the strategy of redistributes of four air ventilators and choose the most suitable distribution to achieve thermal comfort for human recorded of the data at height 1.1 m at the breathing level of the occupants. Mushtaha & Helmy [16] assessment of thermal comfort of mosques in hot- humid weather in the United Arab Emirates. they studied the effect of the shape of the outer perimeter (rectangular, square, and octagonal) as well as shading devices on the thermal comfort inside the mosque. The results showed that the octagonal shape of the mosque is the best form as it and it reduces 10% of energy consumption. Akande and Adebamowo [17] evaluated of the thermal comfort using natural ventilation in a hot and humid climate in southern Nigeria Puja where a survey of 206 respondents was conducted for 68 buildings using natural ventilation to provide thermal comfort. The results revealed that the temperature of neutrality in the rain weather are 28.44°C and in the hot weather 25.04°C where it was higher than theoretical calculations 3.34°C in the heat and 2.64°C in the rain. Ibrahim et al., [18] studied the thermal comfort in hot-humid climate in Malaysia. Al-Homoud et al. [19], investigated thermal comfort in mosques at Friday prayers in the hot-humid climate in the city of Dammam in KSA, The result of the studied was referred to the lack of thermal comfort there because the large number of occupants, which increases the cooling load. The low level of air processing of the space where the level of cooling air intake should be 2m or higher. Budaiwi [20] studied the thermal comfort of the mosque In KSA in a hot- humid climate. in terms of finding the appropriate design of the mosque to reduce the load of cooling. the result showing reduced in the cooling load to 25% when compared the ideal thickness of wall with the wall isolated .and the recommended value for the insulator walls was U = 0.7 W/m²K and for the ceiling was U = 0.5 W/m²K. also can be reduced the power consume at using air ventilation less than 0.5 ACH and absorbance of the walls and ceilings are 0.5, 0.7, respectively.

There are also researchers who studied the thermal comfort of the cold weather. Some of them studied the effect of some factors that calculate the thermal comfort, such as clothing isolation and the rate of effectiveness of people (metabolic rate) varied areas of research in the rest of the subject of importance in the lives of humans and countries where the productivity of the individual when providing comfort Thermal has an average of 25%.

The objective of the study is to evaluate the thermal comfort of the mosques occupants at the Friday prayers. The improvement of thermal comfort is achieved through the re-distribution of the air conditioning system and changing the angle of inlet air from space, which provides the best thermal comfort inside the mosque.

2. Mathematical model

To assessment thermal comfort, temperature, air velocity, and water vapor need to be calculated. These can be calculated by solving the system of coupled governing equations for the conservation of mass, momentum, and energy. Assume Steady-state, incompressible flow of air as a multi-component fluid which includes dry air and water vapor. The fluid properties are taken as constants. Assuming that there is no heat generation, energy fluxes due to inter-diffusion, and the equation is given by:

Conservation of mass equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (1)$$

Momentum equation (x-direction)

$$\rho g_x-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)= \rho(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}) \quad (2)$$

Momentum equation (y-direction)

$$\rho g_y-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)= \rho(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}) \quad (3)$$

Momentum equation (z-direction)

$$\rho g_z-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)= \rho(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}) \quad (4)$$

Energy equation

$$\rho cp\frac{dT}{dt}=k\nabla^2 T+\emptyset \quad (5)$$

$$\emptyset=\mu[2(\frac{\partial u}{\partial x})^2+2(\frac{\partial v}{\partial y})^2+2(\frac{\partial w}{\partial z})^2+(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y})^2+(\frac{\partial w}{\partial y}+\frac{\partial v}{\partial z})^2+(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x})^2] \quad (6)$$

Turbulence k-ϵ (RNG) model:

Kinetic energy equation.

$$\frac{DK}{Dt}=\frac{\partial}{\partial y}\left(\frac{v_t}{\sigma_k}\frac{\partial K}{\partial y}\right)+v_t\frac{\partial \bar{u}}{\partial y}\left(\frac{\partial \bar{u}}{\partial y}+\frac{\partial \bar{v}}{\partial x}\right)-\epsilon \quad (7)$$

Dissipation equation.

$$\frac{D\epsilon}{Dt}=\frac{\partial}{\partial y}\left(\frac{v_t}{\sigma_\epsilon}\frac{\partial \epsilon}{\partial y}\right)+C_1 v_t\frac{\partial \bar{u}}{\partial y}\left(\frac{\partial \bar{u}}{\partial y}+\frac{\partial \bar{v}}{\partial x}\right)-C_2\frac{\epsilon^2}{k} \quad (8)$$

$C1\epsilon = 1.24$, $C2\epsilon = 1.68$

Transport equation

The solution of the conservation equations for chemical species present in the domain of the CFD model, the CFD code should predict the local mass fraction of each species Yi in each control volume. This can be made by solving the convection-diffusion equation for the species i. The general differential form for the species at [2] is:

$$\frac{\partial}{\partial t}(\rho Y_i) + \nabla.(\rho \vec{v} Y_i) = -\nabla.\vec{J_i} + R_i + S_i \tag{9}$$

The PMV is based on the heat balance of the human body: in thermal balance, the internal heat production in the body is equal to the loss of heat to the environment. The PMV method combines four physical variables (air temperature, air velocity, mean radiant temperature, and relative humidity), and two personal variables (clothing insulation and activity level) into an index that can be used to predict the average thermal sensation of a large group of people in a space. At this, all equation defined in [2]:

Fanger's PMV and PPD method

$$\begin{aligned} \mathrm{PMV} = &\left(0.303\, \mathrm{e}^{(-0.036\cdot \mathrm{M})} + 0.028\right)\{ (\mathrm{M}-\mathrm{W}) - 3.05 * 10^{-3}\,[5733 - 6.99\,(\mathrm{M}-\mathrm{W}) - \mathrm{P_a}] - \\ &0.42[(\mathrm{M}-\mathrm{W}) - 58.15] - 1.7 * 10^{-5}\mathrm{M}\,(5867 - \mathrm{P_a}) - 0.0014\mathrm{M}\,(34 - \mathrm{t_a}) - 3.96 * \\ &10^{-8}\mathrm{f_{cl}}\,[(\mathrm{t_{cl}} + 273)^4 - (\mathrm{t_{MR}} + 273)^4] - \mathrm{f_{cl}} \cdot \mathrm{h}_c \cdot (\mathrm{t_{cl}} - \mathrm{t_a})\} \end{aligned} \tag{10}$$

$$\begin{aligned} t_{cl} = &35.7 - 0.0275(M-W) - R_{cl}\{(M-W) - 3.05[5.73 - 0.007(M-W)P_a] - \\ &0.42[(M-W) - 58.15] - 0.0173M(5.87 - P_a) + 0.0014M(34 - t_a)\} \end{aligned} \tag{11}$$

$$f_{cl} = \begin{cases} 1.0 + 0.2I_{cl} & I_{cl} < 0.5clo \\ 1.05 + 0.1I_{cl} & I_{cl} > 0.5clo \end{cases} \tag{12}$$

$$h_c = \begin{cases} 2.38(t_{cl} - t_a)^{0.25} & 2.38(t_{cl} - t_a)^{0.25} > 12.1\sqrt{V} \\ 12.1\sqrt{V} & 2.38(t_{cl} - t_a)^{0.25} < 12.1\sqrt{V} \end{cases} \tag{13}$$

$$PPD = 100 - 95 \cdot e^{\,(-0{,}03353\cdot PMV^4 - 0{,}2179\cdot PMV^2)} \tag{14}$$

3. Case study

The Mosque of Omar Ibn Abdul Aziz, located in Baghdad city of Dora in the case study investigates and improve the thermal comfort of the mosque. The Baghdad city located on the longitudinal line 44.4 and latitude 33.3. at above of sea level at 34 m.

The weather in Baghdad a hot- dry climate in the summer season. The summer months in Iraq generally extend from April to October, with temperatures reaching a peak of more than 50 ^{0}C in mid of July, shown asFigure 1. The dimension of physical domain of the mosque is 20×20m^2 from the area and high is 6.5m.

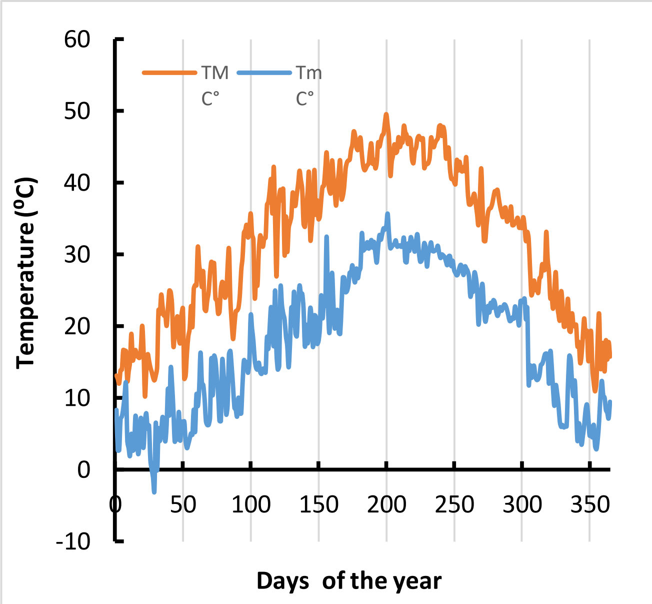

Figure 1. minimum and maximum temperatures in Baghdad weather in 2017.

4. Numerical model and simulation

The whole building of the mosque is designed modeled by using the package of Soildwork 2016. This representation includes worshipers, air conditioning units and ventilation openings. The area of the mosque is 400 m^2. The height of the walls is up to a roof of 6.5 m. A hemispherical dome is built at the center of the mosque of 10.5 m diameter. The walls on the eastern and western sides contain glass windows with a distance of 1.5m × 2m, with six windows on one side spread over two upper and lower rows. The effect of heat transfer from outside to inside the mosque will be transfer from the windows to the walls and windows. The A/C are installed over two sides with equal distances. The A/C include two pieces (indoor, and outdoor units). The indoor unit is ground-based. It is a rectangles with dimensions of 2.19 m high, 0.55 m width, and 0.34 m thickness. Also, it has an upper cold air intake slot with dimension of 0.26 × 0.45 m^2 and contains five blades for air steering.It while the lower air exit slot with a dimension of 0.45 × 0.5 m^2 as shown in Figure2 .The occupants are represented as a rectangle shape with dimensions of 1.7 × 0.5 × 0.25 m^3 per person [2, 10] as shown in Figure 3. The rows of prayers is represented in parallel rectangular with a height of 1.7 m and a thickness of 0.25m. The width of the rectangle is the number of persons multiplied by 0.5 m. In the prayer position, there is no gap between worshipers because of the type of the clothes that the worshiper wear in the Arab countries (Dishdasha), this representation is quite real [10]. There are two processes for human breathing; exhalation (entering the breathing air to the body) and inhalation (return charging the air outside). The source of these types are the mouth and nose. The mouth and nose are represented as a square shape with dimensions of $0.3 \times 0.3 m^2$. This is represented at a distance of 0.1m on the upper end of the parallel rectangles as shown

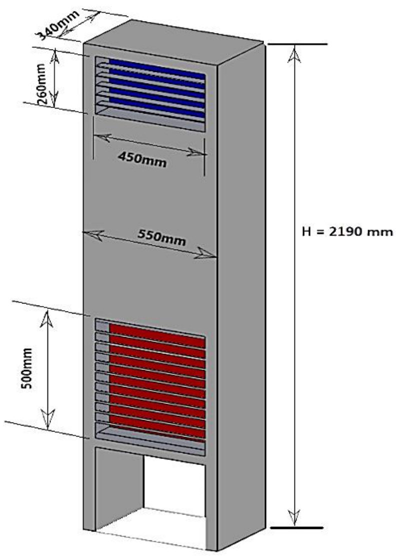

Figure 2. Scheme of air condition device

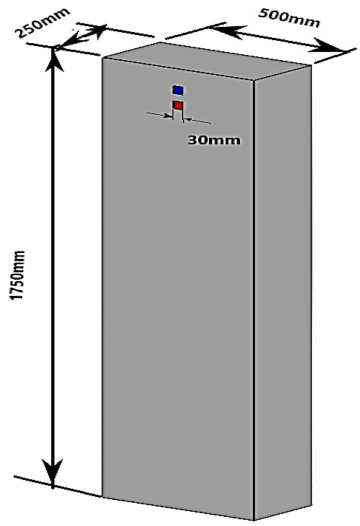

Figure 3. Scheme of worshiper

Now, it is going to choose a suitable type and an appropriate number of elements indoor to obtain precise. First, 440,000 elements are used. The mesh is then refined until a density of 1 million. To minimize the error value of the temperature at 2 m height. It is found that the best number of elements is 4 million which provides a negligible error as shown in the Figure 4 .the redistribution of the air conditioners inside the mosque and changing angles of the blades, four distributions are used in this study and each distribution includes three angles which are 0^0, 7.5^0, and 15^0 as shown in the Figure 5.

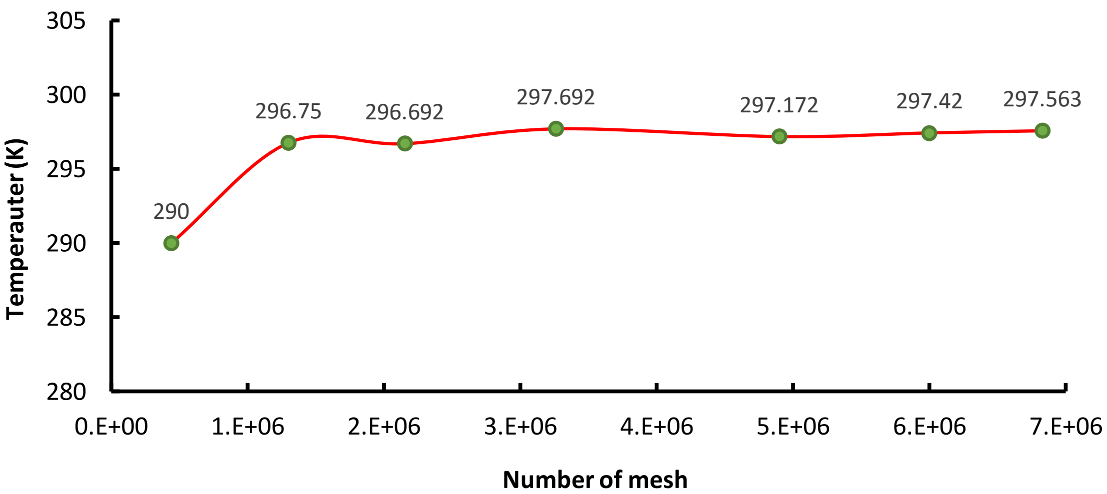

Figure 4. Mesh independent

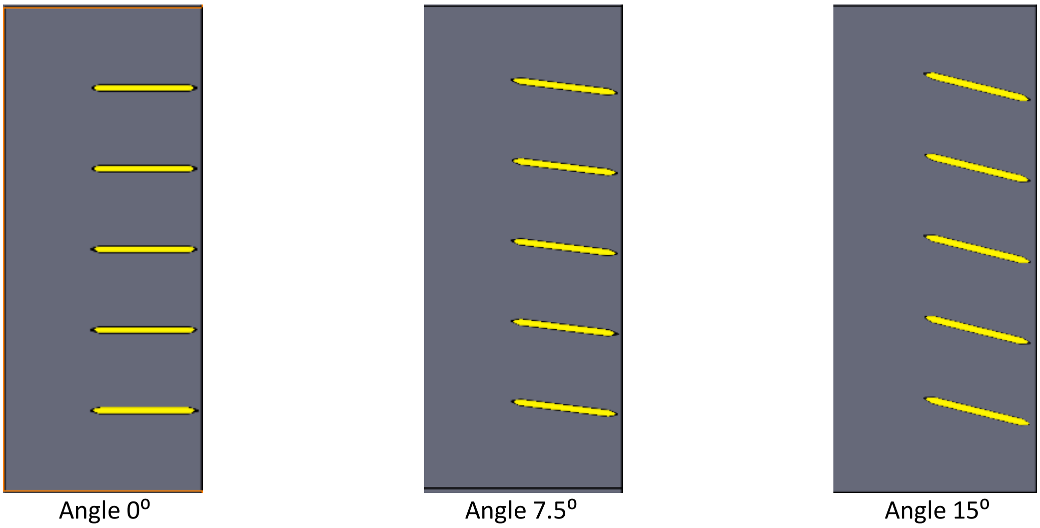

Figure 5. Scheme the inclination angles

The air velocity and temperature at the outlet from A/C are assumed is reported by the supplier in their catalog, present experimental tests, and previous studies that have the same conditions for the same A/C type. The assumption of the temperature of the body surface is taken depending on many studies focused on the effectiveness of the sitting state and rest of the person sitting at the same rate of metabolism described in ASHRAE-55 standard [21]. The temperature of the wall was measured based on the program of Hap 4.9 A/C loads for external conditions to the highest thermal load from mosque when is fill occupied during the year, which occurs on July 20 at 1 PM. Table 1. shows the values of input of the initial and boundary conditions of the mosque.

The temperature of the inner surface and the roof wall of the mosque were calculated by the Hap 4.9 program which design to calculate the thermal loads of the building. The outside conditions were described throughout the summer from April to October. The maximum external temperature of the program is at 50 ^{0}C according to the weather tables of the Iraqi forecast. The other information such as the layers of the wall and roof construction and the calculation of the value of thermal resistance (U). The detail of the mosque which include the dimensions of walls, roof, dome, windows and doors, and direction of the building are used to estimate the heat load.

The surface temperature of the human body skin is assumed 34 ^{0}C [10]. This value is derived from the level of the person's effectiveness and food metabolism. The effectiveness of the worshiper in the mosque is sitting and resting according to the ASHRAE standard -55 [21]. The metabolic rate (M) is 1.2 met or 70 w/m^2, by applying these values in the equation T_{sk}= 35.7 - 0.028× (M-W) to find the skin temperature ($T_{sk)}$.All the numerical studies of thermal comfort adopted this value as the temperature of the surface of the skin [16].

5. Scenario of Cases

Through this work, five different cases are discussed; the common between the five cases is he mosque occupied by worshipers to its full capacity limit. While the difference between the cases appears in the distribution of air – condition units in order to study the effect of varying their positions with respect to each other on worshipers' thermal comfort, see Figures 6-10.

Table 1. boundary condition

Boundary condition detail	Boundary condition value
Activity type	Standing, relaxed
Metabolic rate	1.2 met
Skin temperature	307 K
breathing rate	8 [L/min]
humidity from air breathing	0.042 [kgw/ kgd.a]
Temperature from air breathing	310 k
Air cooling rate	0.5664 m3/s
temperature of air cooling	286 k
Humidity of air cooling	0.0046 [kgw /kgd.a]
Walls temperature	303 k
Roof temperature	307 k
ventilated inlet air rate	0.3152 [m3 /s]
Humidity ventilated air	0.013 [kgw /kgd.a]
Temperature ventilated air	322 k
Clothing insulation	0.0775 [m2·K/w]
Initial air temperature	303

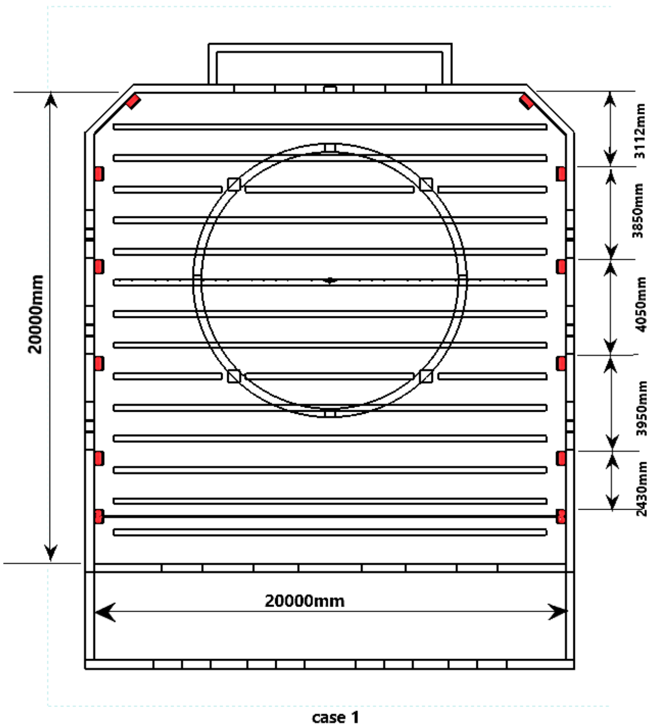

Figure 6. A/C distributed for case 1

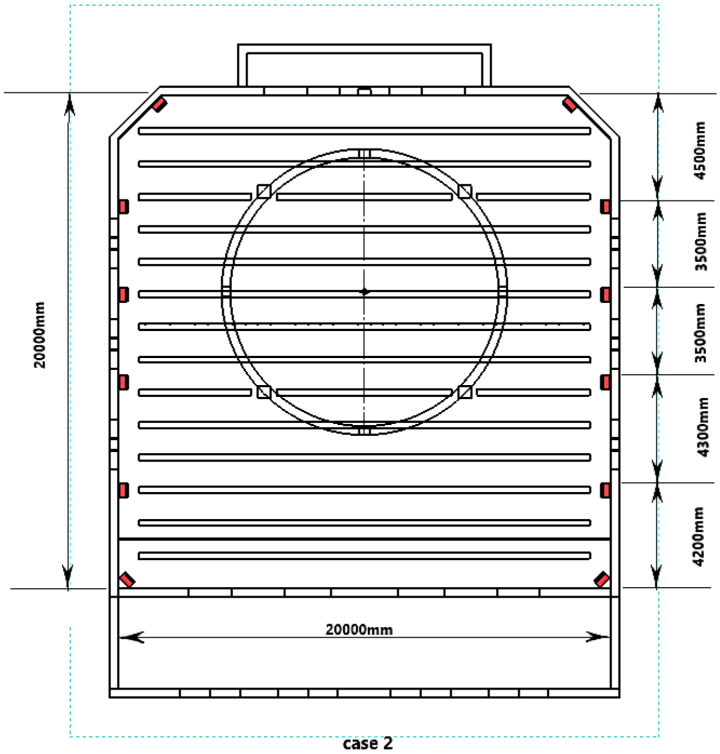

Figure 7. A/C distributed for case 2

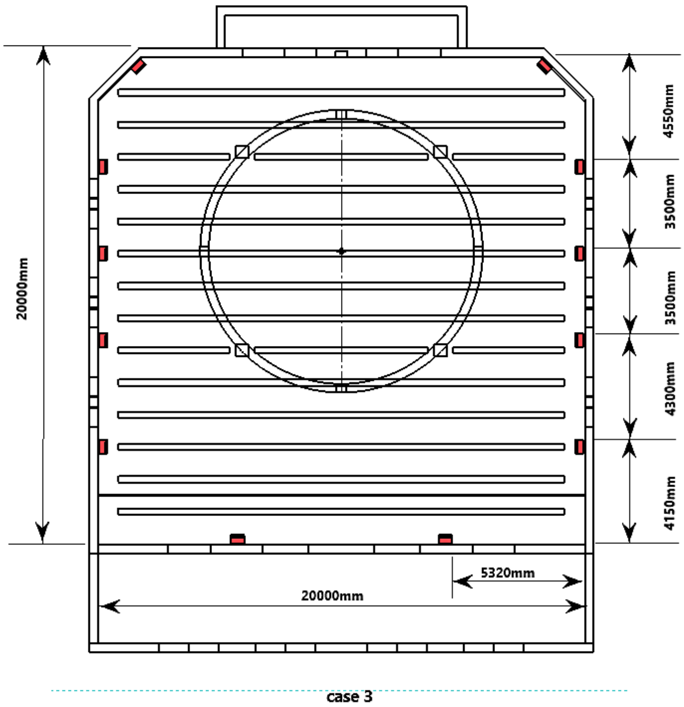

Figure 8. A/C distributed for case 3

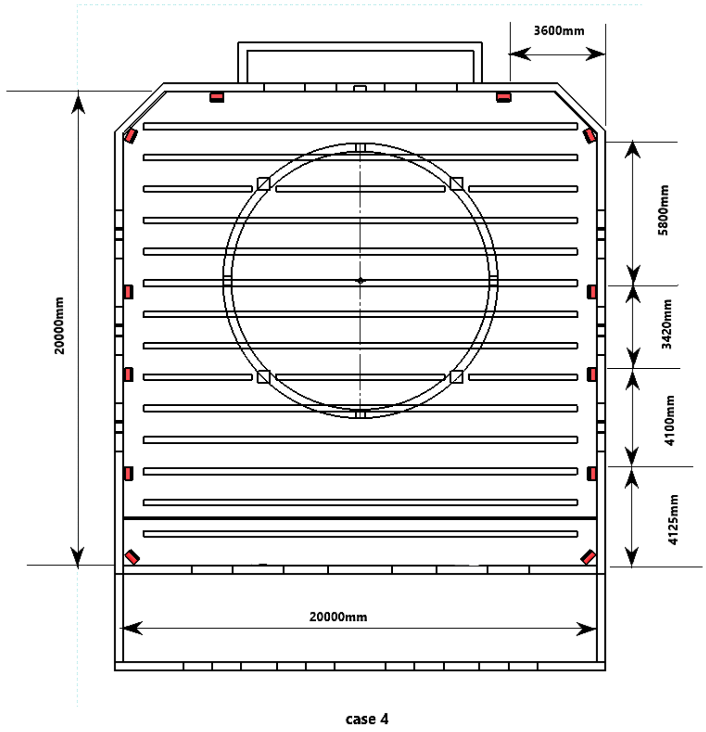

Figure 9. A/C distributed for case 4

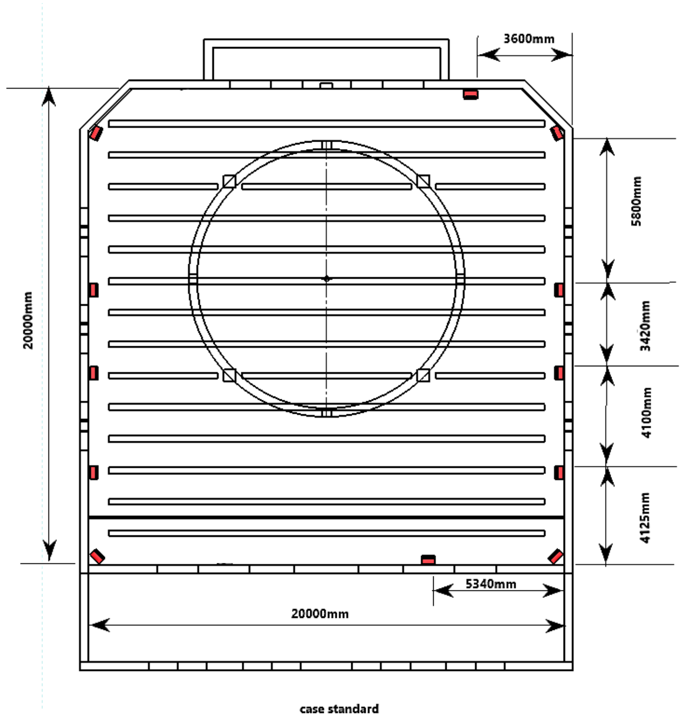

Figure 10. A/C distributed for standard case

6. Experimental and validation

A practical experiment was conducted to measure the temperature and relative humidity of the inside of the mosque in ten points along the middle of the mosque, 1.7 meters above the surface of the earth. Electronic devices such as the hygro thermometer used to measure the temperature of the air as well as to measure its humidity. The resolution of the device for measuring temperature is 0.1^{0}C, and 1 for measuring the relative humidity. The accuracy values of temperature and the relative humidity are ±1^{0}C and ±5%, respectively. And by the infrared thermometer, which is a device that utilizes laser reflection technology to measure the surfaces Temperature with 0.1^{0}C resolution and ±1.5^{0}C accuracy. The results were taken at 2:00 pm after turn the A/C on in the mosque for two hours to get the state of thermal stability. The comparison between experimental and numerical are shown in the in the Table 2.

A simulation of the mosque was performed within the surrounding conditions at which the experimental results were measured, the temperature of the space and its relative humidity were found. The results of the simulation were compared with the experimental results as shown in, Figure 11, and 12. The results were approximately error 0.05% in temperature and 10% in relative humidity between the results. And illustrated the location of instrument and dimension of point as shown in Figure 13.

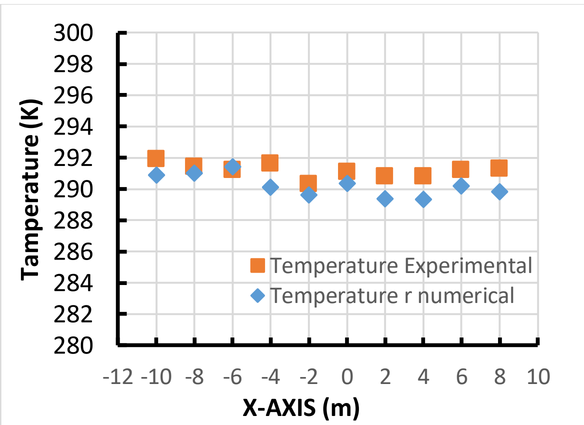

Figure 11. experimental and numerical temperatures

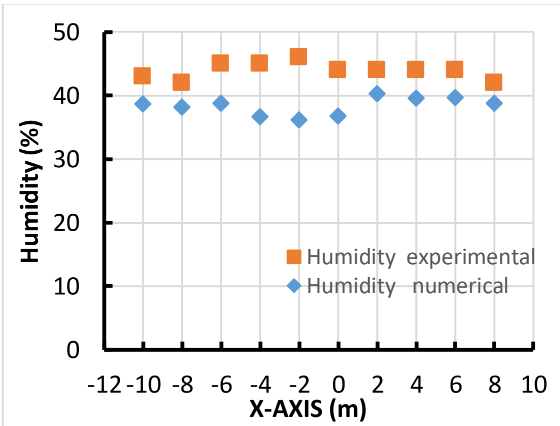

Figure 12. experimental and numerical humidity

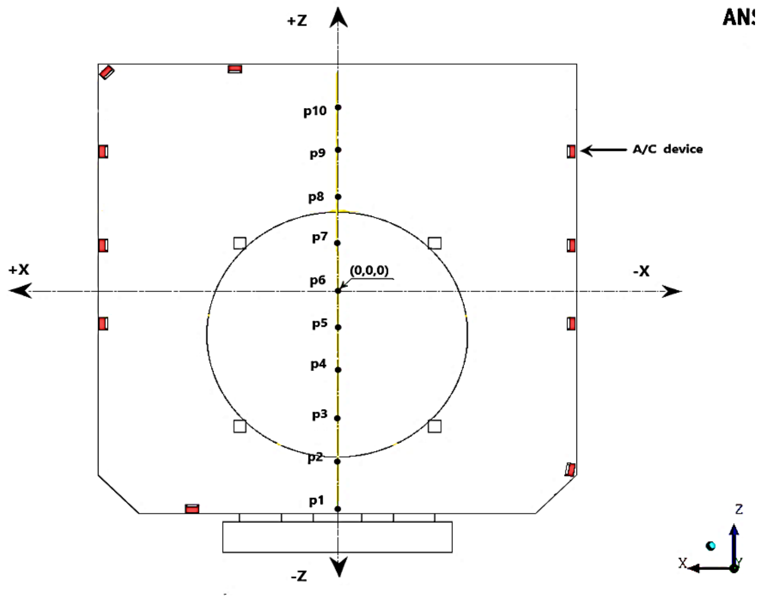

Figure 13 . location of instrument and orignal point (0,0,0)

Table 2 . data for experimental test

No. point	Location point At (x, y, z) (m)	Experimental Temperature (K)	Numerical Temperature (K)	Experimental Humidity (%)	Numerical Humidity (%)
Point 1	(0 ,1.7 , -10)	291.9	290.889	43	38.6492
Point 2	(0 ,1.7 , -8)	291.4	291.000	42	38.1905
Point 3	(0 ,1.7 , -6)	291.2	291.420	45	38.7446
Point 4	(0 ,1.7 , -4)	291.6	290.105	45	36.6936
Point 5	(0 ,1.7 ,-2)	290.3	289.596	46	36.1997
Point 6	(0 ,1.7 , 0)	291.1	290.361	44	36.7504
Point 7	(0 ,1.7 , 2)	290.8	289.346	44	40.292
Point 8	(0 ,1.7 , 4)	290.8	289.313	44	39.5803
Point 9	(0 ,1.7 , 6)	291.2	290.177	44	39.706
Point 10	(0 ,1.7 , 8)	291.3	289.798	42	38.7927

7. Result and discussion

This section presents the result of five different cases of re-distribution of air conditioners within the mosque, in each case, the angle of air entry was changed in three different angles of 0^0, 7.5^0 and 15^0 and numerically simulated by ANSYS-FLUENT v.18. The average air temperature, relative humidity, and airspeed in space at the breath level for humans at 1.7 m were also measured. The results of these factors will calculate the thermal comfort equations approved by (ASHRAE) the PMV and PPD equation.

The results comprise the four and comparison between these cases and original case in terms of the three air intake angles of the space as shown in Table 3. The results are discussed and the best case is identified to be the case that provides the best thermal comfort for the worshipers. The strategy of re-distribution of air conditioners within the space is effective as they help improve the thermal comfort of the place with the same load of heat and without an increase in the number of electrical appliances required to condition the space, moreover, changing the angles of air entry by changing the angle of the tilt of air blades at the air in the air conditioner also effects the thermal comfort in the space.

It is observed a general behavior is reported to take place and this behavior applies to all five cases. The values of PMV and PPD are in their best values when the inclination angle is 0^0. At angles 7.5^0 and 15^0, the PMV and PPD values increase with the angular tilt of the horizontal position. As it observed in Figure 14,15 and 16 which represents the direction of the air flow to the space in the three cases of the inclination of the angles of entry, in the case of the horizontal angle 0^0 the direction of the air is horizontal for the longest distance until the next air current is met.

When the angle of inclination 7.5^0 the air stream guide to the bottom and meets with air stream was coming from the other side at close to the floor of the mosque. The resulting flow rises to the upper air layers. In the case of angle 15^0 the flow of air entering the space with the floor of the mosque was met about halfway with the ground before reaching the center area. Causes the eddies in the center of mosque, mixing the cold air with air in the down layer near the ground at the zone of high a above 2m, which may be used to improve some air properties at the breathing level. The airflow disturbance in two cases 7.5^0 and 15^0 improved the relative humidity values at the measured level at the breathing level 1.7m. But at the same time reduced the value of the average air temperature and its speed resulting in high values of PMV, PPD.

In the first case at the angle 0^0, the best value of PMV and PPD are 0.556, 11.49, respectively, for the same case at inclination angles 7.5^0 and 15^0, PMV to 0.643 at an angle 7.5^0 and 0.6786 at an angle 15^0 as shown in Table 3, due to low airspeed rate of breath level at these two angles. The effect of airspeed is great at the level of thermal comfort, which effects to increase the value of the coefficient of heat transfer (h_{conv}) and thus was increased the value of heat transferred from the outer surface of the body to the surrounding air. Note that the relative humidity is low because the upper layers have low relative humidity due to high air temperatures.

In the second case, the best value for PMV, PPD at the inclination angle 0^0 is 0.443 and 9.11 respectively. The value of PMV and PPD increases with an increase in the angle of inclination blade. It is 0.598 at the angle 7.5^0 and 0.611 at the angle 15^0 as shown Table 3. This is due to the high temperature of the air of the breath level due to the mixing of cold air with hot air in the upper layers.

In the third case, the air temperature is high at the angle of inclination 7.5^0 and 15^0 where it is 29.22 ^{0}C, 29.83 ^{0}C, respectively, as shown Table 3. PMV and PPD increased at these two angles due to higher air temperatures, in split of increased air velocity and lower relative humidity. Due to the fact that the location of the air conditioner in this distribution is close to the ventilation fan air location of the mosque, it caused mixing between air conditioning and ventilation air, which is approximately 50 ^{0}C temperature. While the best value for PMV, PPD were obtained at the angle 0^0 when the air is less.

In the fourth case there is also a rise in air temperature and a decrease in the air velocity rate, leading to a decrease in the value of PMV and PPD. At the angle of inclination 7.5^0 the value are 0.526, 10.8 and at 15^0 angles they are 0.579, 12.03

respectively. The best value are at the inclination angle 0^0 at PMV and PPD are 0.35, 7.55, respectively, as shown Table 3.

In the original case of air conditioning distribution, the best value of PMV and PPD at an angle 0^0 were the same as the behavior in all previous cases show in Figure 14. As for ASHRAE, standards the thermal comfort required to be provided at PMV range between the values (0.5 to -0.5) and percentage value of PPD should be allowed 20% to provide the thermal comfort. The second, third and fourth cases at the horizontal tilt angle provide this range of PMV values. The best case is in the fourth case.

Where PMV and PPD is 0.35, 7.55 respectively, as shown Table 3. And shown the contour of PPD at the five cases illustrated the best case as in Figure 19-22. So it is possible to depend on the best distribution of air conditioning inside the mosque with the tilt angle 0^0 as the best angle to intake air conditioning. The best results that provide an improvement in the thermal comfort conditions inside the mosque are in the fourth case when angle inclination 0 where the improvement rate in the value of PMV is 14%, and the percentage improvement in the value of PPD is 10.8% as shown in Figure 17 and 18.

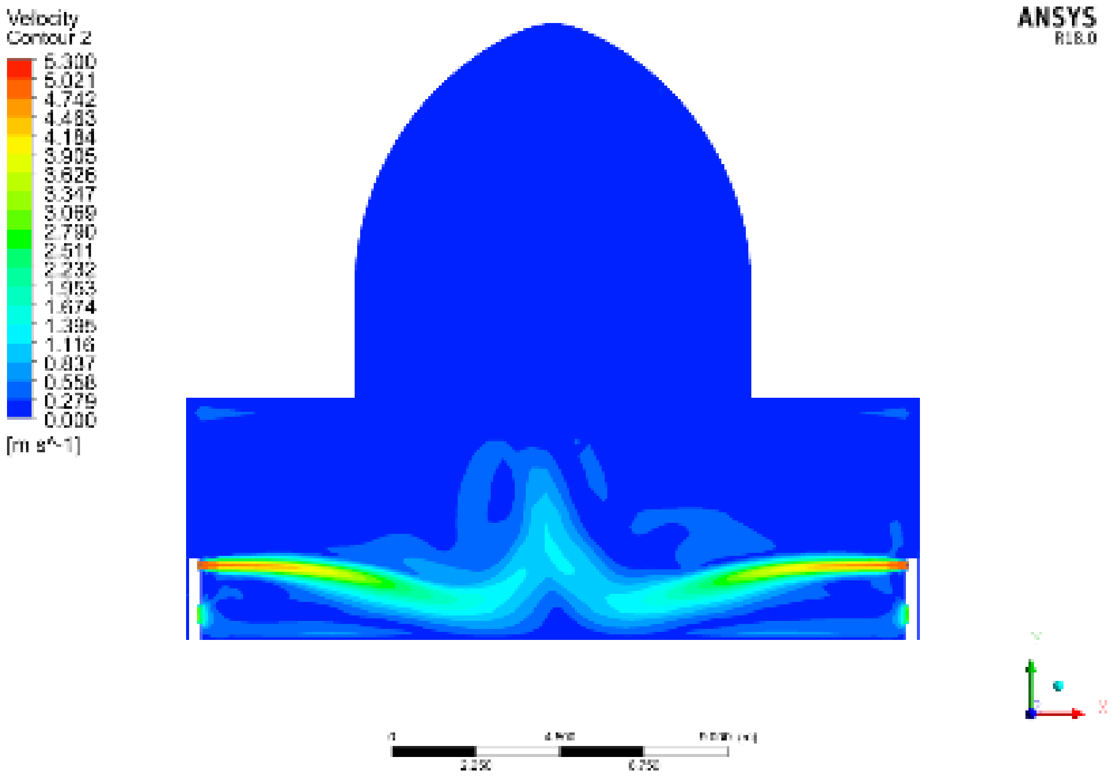

Figure 14. Air stream behavior inside the space from air conditioning intake of angle 0°
(vertical section at center of the mosque)

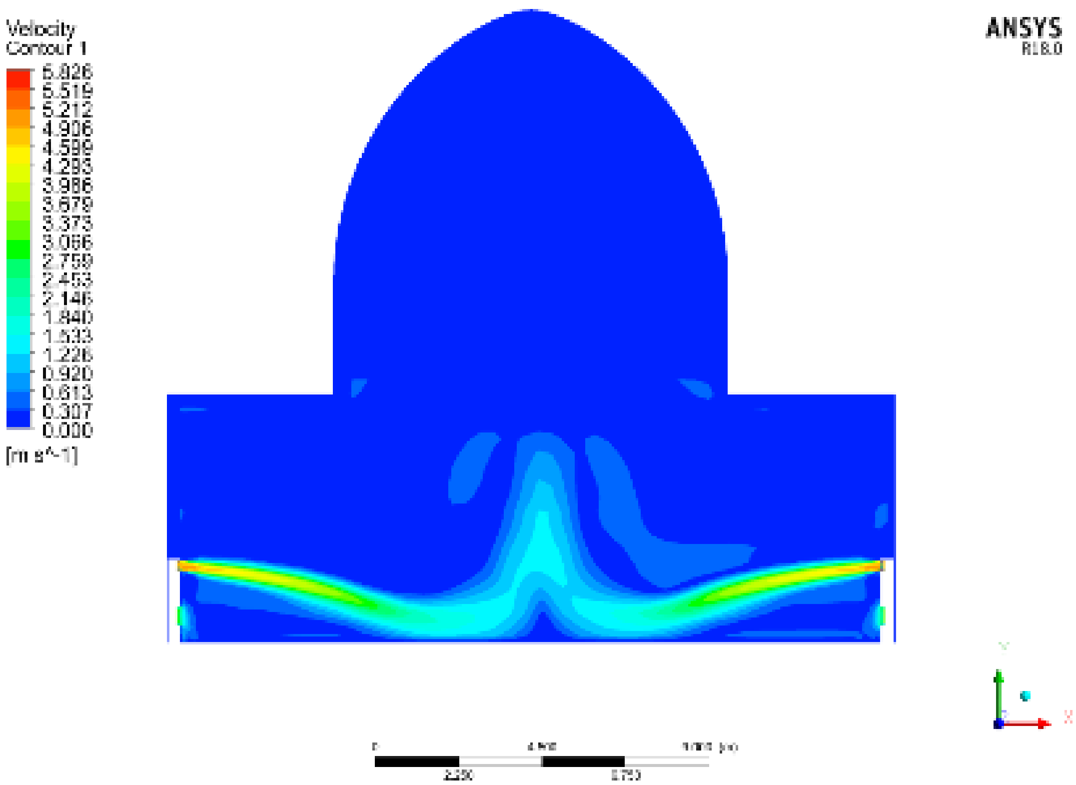

Figure 15. Air stream behavior inside the space from air conditioning intake of angle 7.5°
(vertical section at center of the mosque)

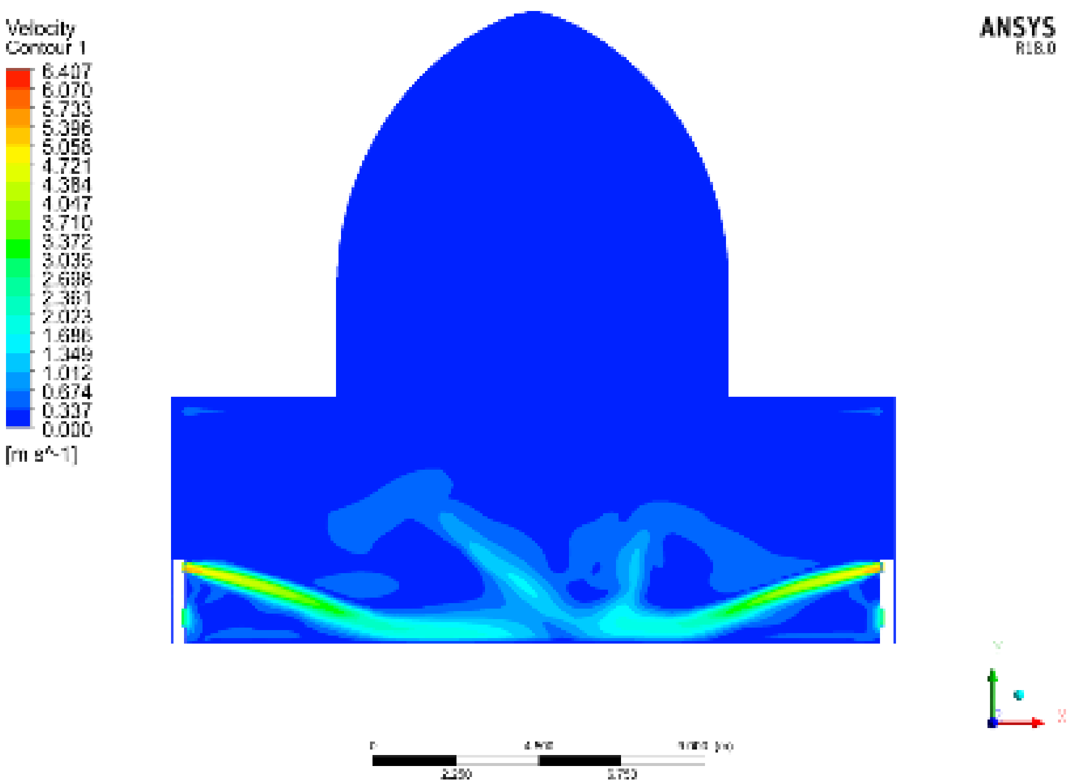

Figure 16. Air stream behavior inside the space from air conditioning intake of angle 15°

(vertical section at center of the mosque)

Table 3. Result of cases

Cases	Angle (degree)	PMV	PPD	Temperature (^oC)	Relative humidity (%)	Air velocity (m/s)
Case 1	0	0.556899	11.49375	24.28	30.97	0.473
	7.5	0.643587	13.69659	24.23	30.67	0.469
	15	0.678632	14.67963	24.08	30.41	0.425
Case 2	0	0.44387	9.110485	24.21	30.18	0.448
	7.5	0.598963	12.52192	24.51	30.19	0.464
	15	0.611678	12.84782	24.47	29.72	0.438
Case 3	0	0.413362	8.561582	23.98	31.15	0.41
	7.5	0.701051	15.33637	25.41	29.83	0.488
	15	0.917298	22.76997	25.9	29.22	0.42
Case 4	0	0.350148	7.550961	24.03	30.71	0.439
	7.5	0.526983	10.80922	24.3	30.52	0.433
	15	0.579358	12.03317	24.22	30.44	0.419
Case stand.	0	0.407942	8.468233	24.04	30.98	0.383
	7.5	0.530717	10.89254	24.29	30.71	0.441
	15	0.57073	11.82336	24.21	30.38	0.428

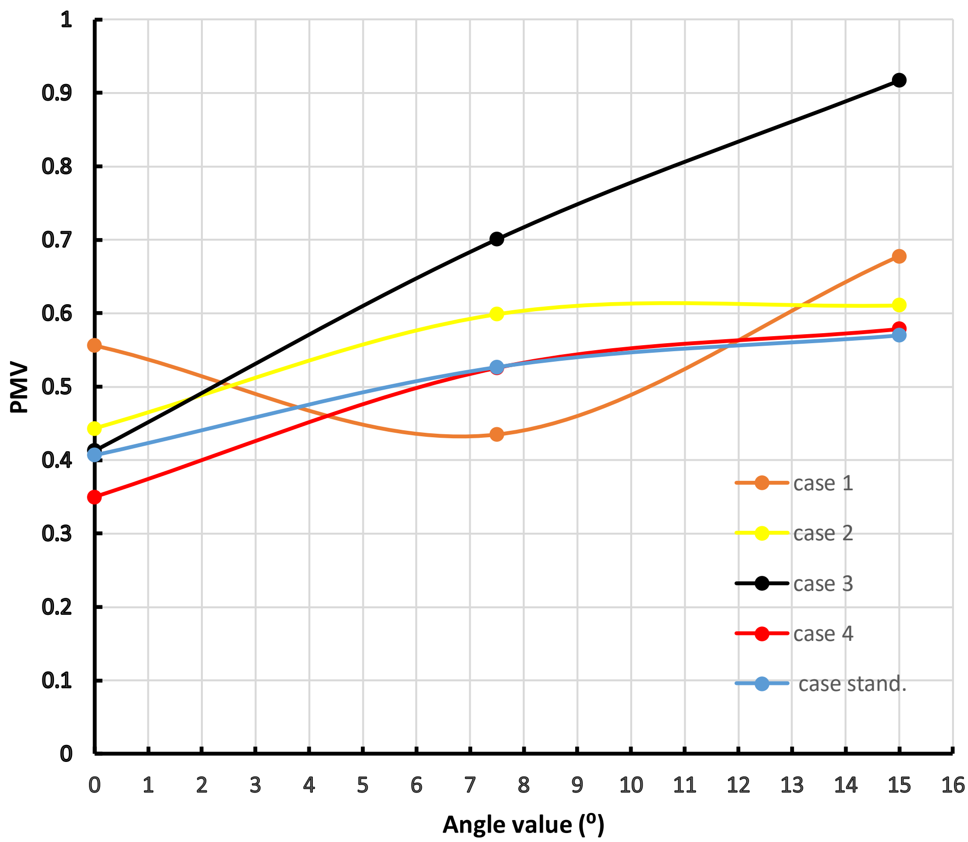

Figure 17. Comparison of PMV value for the five cases at the three angles 0°,7.5°, and 15°

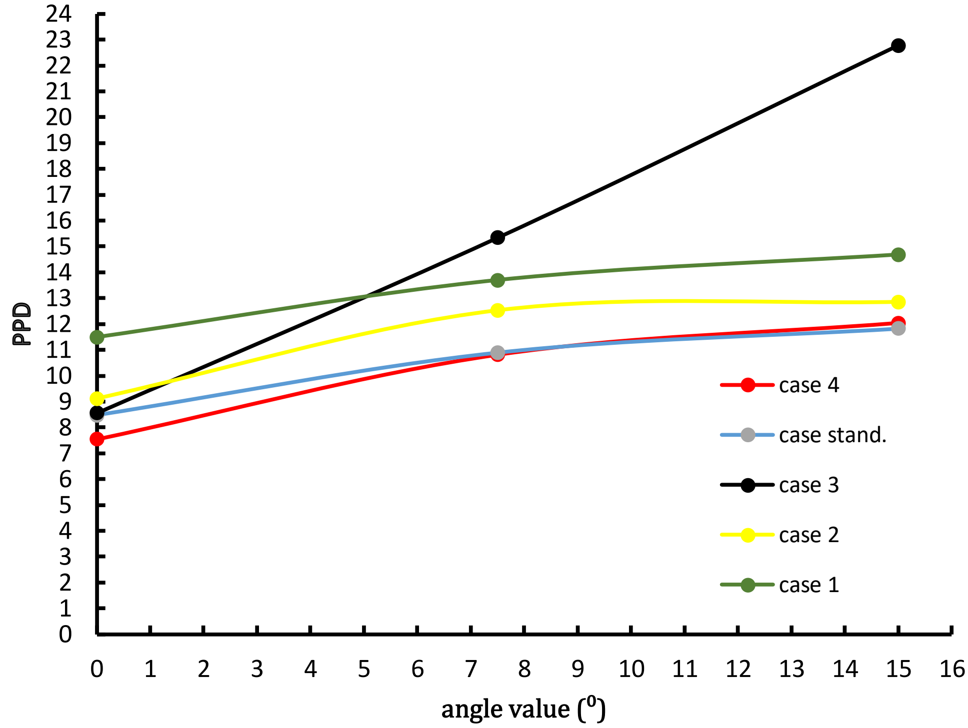

Figure 18.Comprision of PPD value for the five cases at the three angles 0°,7.5°, and 15°

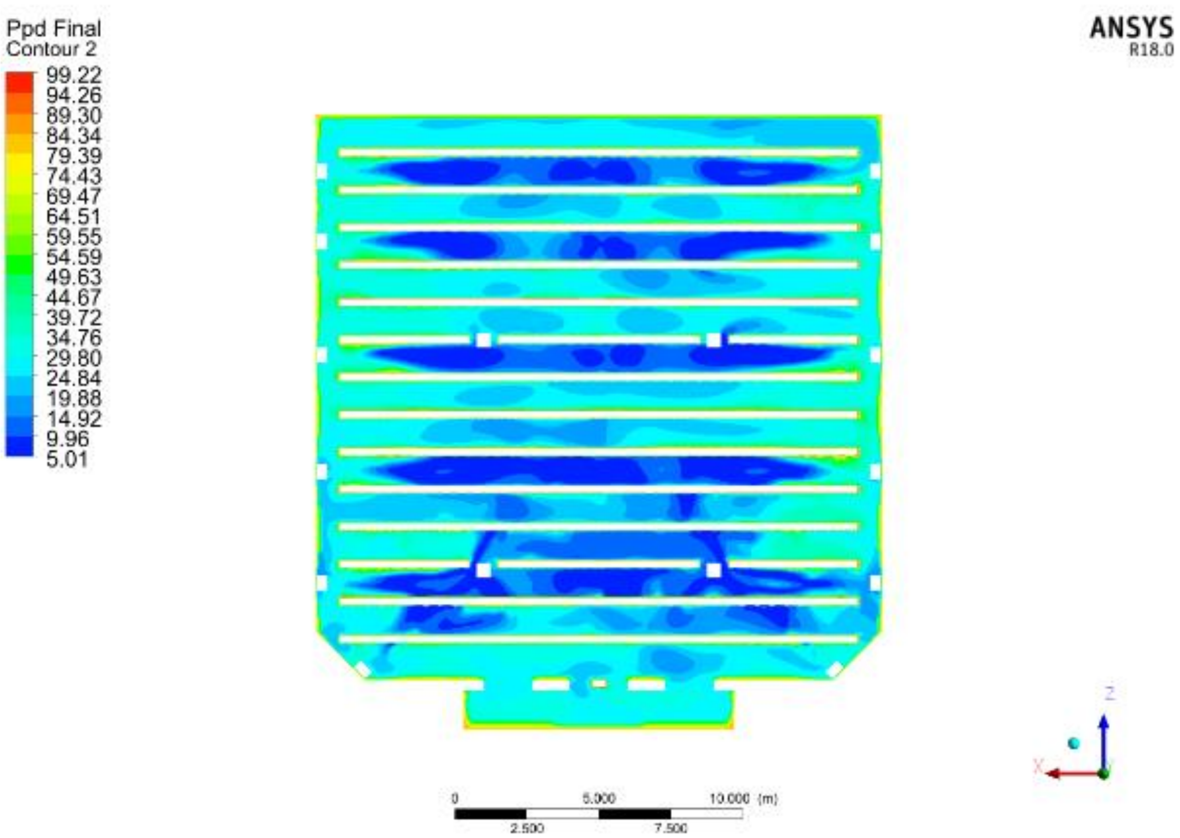

Figure 19. PPD contour at Case 1 angle 0° of the breathing level

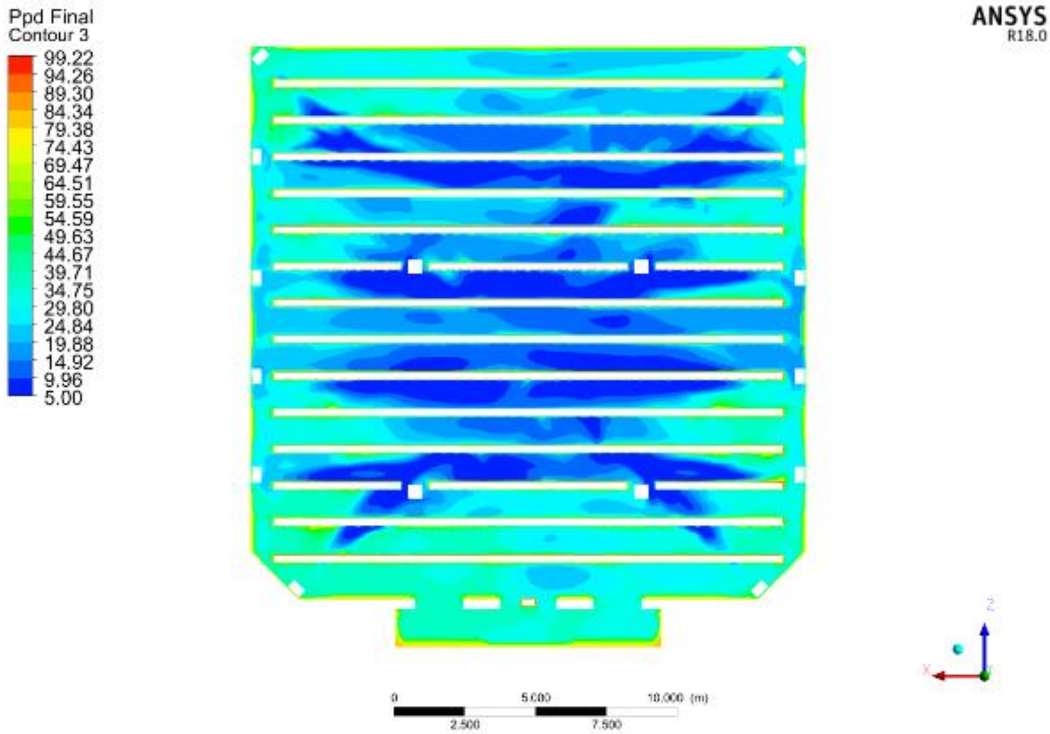

Figure 20. PPD contour at case 2 angle 0° of the breathing level

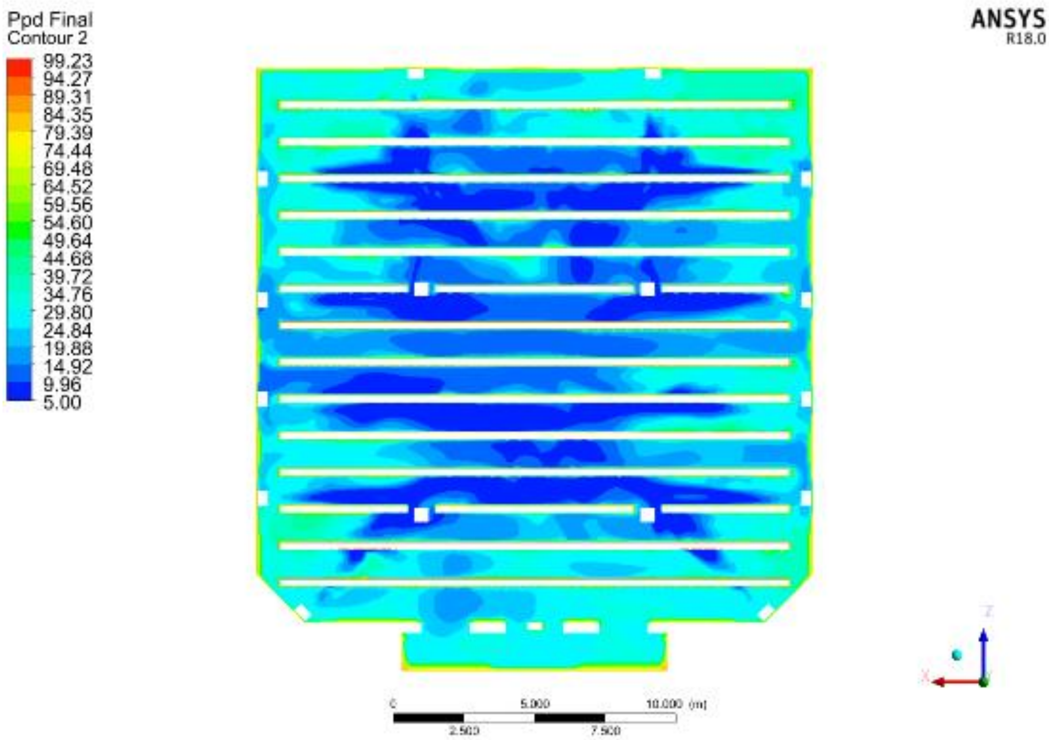

Figure 21. PPD contour at case 3 angle 0° of the breathing level

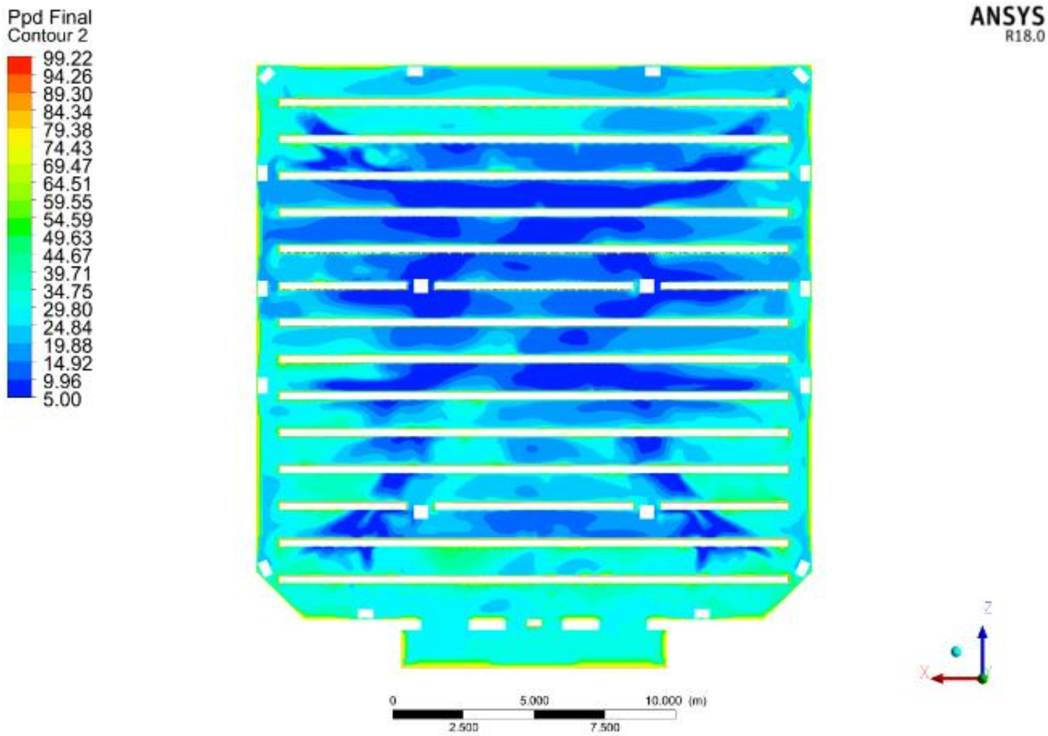

Figure 22. PPD contour at case 4 angle 0^o of the breathing level

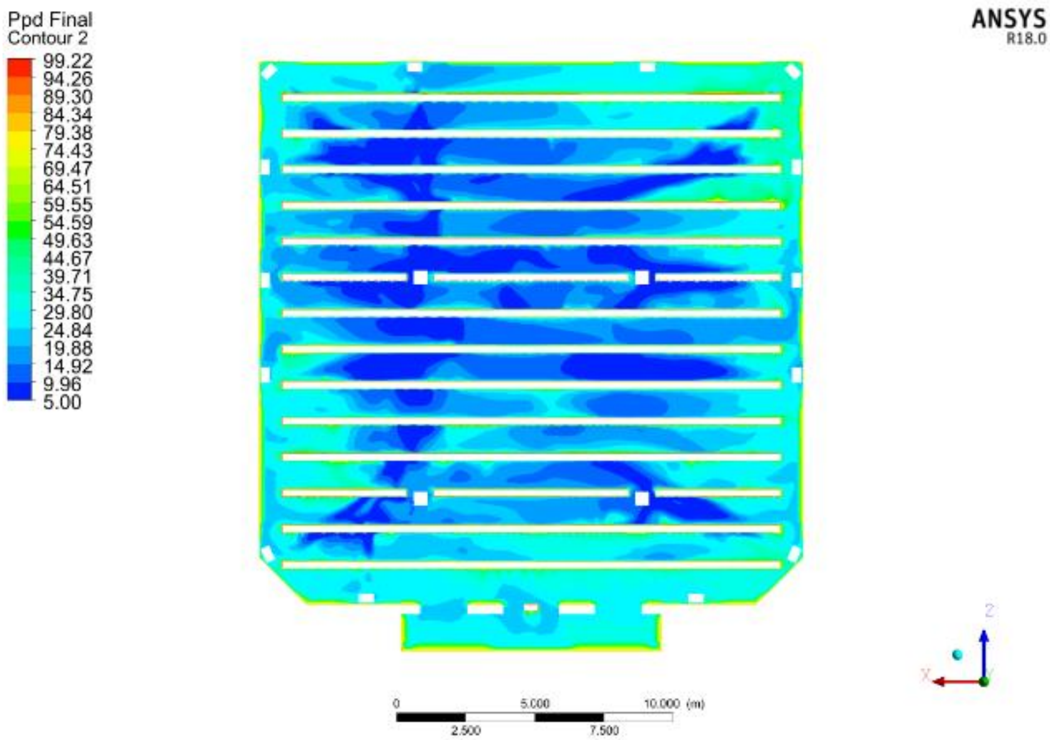

Figure 23. PPD contour at standard case angle 0^o of the breathing level

8. Conclusion

This study aims to verify and improve the thermal comfort conditions for worshipers inside the mosque in case the mosque is filled with worshipers, and on the hottest day of the year for the hot - dry climate in Iraq, which falls on July 20 at 1:00 pm at the time of Friday prayers. Numerical methods of solution were used by ANSYS – FLUENT V.18. The thermal comfort conditions inside the mosque is improved in a way that redistributes the air conditioners inside the mosque and three inclination angle 0^0, 7.5^0, and 15^0 to inlet air to provide the best air quality and thus the best distribution of temperature and relative humidity. There was an identical behavior for the flow of air flow circulation the space from the A/C, at the entry angle of 0^0, the direction of the current is parallel to the breathing level and almost horizontal. It caused an air velocity in the rate and decreasing the temperature at the breathing. It means that the angle 0^0 provides a low mixing of the air between the layers at the breathing level and the higher layers. This behavior was applicable to the five cases of air conditioning distribution. Due to this behavior, the values of PMV and PPD at angle of 0^0 are always lower than those at angles 7.5^0 and 15^0 for all cases. At the angle 7.5^0,15^0, the A/C current enters the space descending to the bottom of the floor of the mosque, and in the middle of the distance met the air current coming from the A/C in the opposite side. It made a unified current that ascended causing to greater mixing of air between the lower and upper air layers. This behavior can be utilized in the process of improving the level of thermal comfort in the upper layers of the breathing level. The relative humidity decreased whenever the inclination angle of the air enters the space increases, where the lower value is always at the angle of 15^0, because there is a greater mixing of the air between the upper and lower layers. Four cases of non-original air conditioning are carried out in the mosque. The results of PMV, PPD, for the original case at angle 0^0, are 0.407 and 8.46 respectively. PMV and PPD for the four case at angle 0^0 are 0.35, and 7.55, respectively. The best results that provide an improvement in the thermal comfort conditions inside the mosque are in the fourth case when angle inclination 0^0 where the improvement rate in the value of PMV is 14%, and the percentage improvement in the value of PPD is 10.8%.

Nomenclature

M	Metabolic rate, (W/m2)
W	effective mechanical power , (W/m2)
I_{cl}	clothing insulation, (m2·K/W)
f_{cl}	clothing surface area factor
Ta	air temperature, (°C)
T_{mr}	mean radiant temperature (°C)
T_{sk}	average skin temperature
Va	air velocity (m/s)
h_{conv}	convection heat transfer coefficient [W/(m2·K)
T_{cl}	clothing surface temperature (°C)
Clo	Clothing Insulation Unit [1 Clo = 0.155 m^2. °C/W]
met	metabolic rate (clo)
PMV	Predicted mean vote.
PPD	Predicted percentage of dissatisfied.
AMV	actual mean vote
Ø	Relative humidity (%)
ρ	density (kg/m^3)
τ	shear force (n/m^2)
C_p	air specific heat capacity (J/kg·K)
P	pressure (N)
g	Gravitational acceleration (m/s^2)
U	velocity in x- axis (m/s)
V	velocity in y- axis (m/s)

w	velocity in z- axis (m/s)
μ	viscosity (N/m²)
μ_t	turbulent dynamic viscosity (N/m²)
v_t	turbulent kinematic viscosity (m²/s)
Yi	mass fraction of each species *i*
R_i	species production net rate *i*
S_i	creation rate *i*
$\vec{J}_i$	species diffusion flux *i*
$D_{i,m}$	diffusion coefficient for species *i*
б	shear stress (kg/m.s²)
Q	heat energy (W)
q	heat flux (W/m²)

k	thermal conductivity (w/m.k)
i	victor in x –direction
j	victor in y –direction
k	victor in z –direction
Btu	British Thermal Unit
HAP	Hourly Analysis Program.
ISO	International Organization for Standardization in thermal comfort.
U	Over all heat resistance (W/m^{2}K)
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning.

Reference

[1] P. O. Fanger, "Thermal comfort: Analysis and applications in environmental engineering: Fanger, P.O. Danish Technical Press, Copenhagen, Denmark, 1970, 244 pp.: abstr. in World Textile Abstracts," *Appl. Ergon.*, vol. 3, no. 3, p. 181, 1972.

[2] E. E. Khalil and R. H. Ragab, "Air Flow in Places of Worship." Cairo University, journal.2013.

[3] F. F. Al-ajmi, "Thermal comfort in air-conditioned mosques in the dry desert climate," *Build. Environ.*, vol. 45, no. 11, pp. 2407–2413, 2010.

[4] A. Noori and A. Hameed, "Thermal Comfort Assessment to Building Envelope : A Case Study for New Mosque Design in Baghdad," vol. 2, no. 3, pp. 249–264, 2011.

[5] P. Taylor, "Thermal comfort requirements in hot dry regions with special reference to Riyadh Part 2 : For Friday prayer," no. July 2013, pp. 37–41, 2011.

[6] P. Taylor, "Thermal comfort requirements in hot dry regions with special reference to Riyadh, Part 1 : for," no. April 2015, pp. 37–41, 2011.

[7] I. Hayatu, I. Mukhtar, N. M. Mu, and J. S. Enaburekhan, "An Assessment of Thermal Comfort in Hot and Dry Season (A Case Study of 4 Theaters at Bayero University Kano)," vol. 3, pp. 1117–1121, 2015.

[8] K. Cena and R. De Dear, "Thermal comfort and behavioral strategies in office buildings located in a hot-arid climate," vol. 26, pp. 409–414, 2001.

[9] M. Khoukhi and N. Fezzioui, "Thermal comfort design of traditional houses in the hot dry region of Algeria," pp. 1–9, 2012.

[10] L. G. Jbara, E. E. Khalil, W. A. Abdelmaksoud, and E. M. El-bialy, "Comfort Analysis of the Effect of Solar Radiation on the Times of the Five Daily Prayers in Typical Mosques," no. Chen 2009, 2016.

[11] I. Budaiwi and A. Abdou, "HVAC system operational strategies for reduced energy consumption in buildings with Intermittent occupancy : The case of mosques," *Energy Convers. Manag.*, vol. 73, pp. 37–50, 2013.

[12] Q. H. Hassan, S. T. Ahmed, and A. Mahdi, "Numerical Simulation of Air Velocity and Temperature Distribution in an Office Room ventilated by Displacement Ventilation System," vol. 5, no. 4, pp. 32–42, 2014.

[13] A. Hussin, E. Salleh, H. Y. Chan, and S. Mat, "Thermal Comfort during daily prayer times in an Air-Conditioned Mosque in Malaysia," no. April, pp. 10–13, 2014.

[14] M. S. Bakhlah, "The Study of Air Temperature When the Sun Path Direction to Ka 'bah : with a Case Study of Al-Malik Khalid Mosque, Malaysia," vol. 3, no. 2, pp. 185–202, 2012.

[15] N. Kamsah *et al.*, "Improvement of thermal comfort inside a mosque building Jurnal Teknologi IMPROVEMENT OF THERMAL COMFORT INSIDE," no. December 2016.

[16] E. Mushtaha and O. Helmy, "Impact of building forms on thermal performance and thermal comfort conditions in religious buildings in hot climates : a case study in Sharjah city," vol. 6451, no. January 2016.

[17] O. K. Akande and M. A. Adebamowo, "Indoor Thermal Comfort for Residential Buildings in Hot-Dry Climate of Nigeria," no. April, pp. 9–11, 2010.
[18] O. Of, "INTERNATIONAL JOURNAL OF," vol. 5, no. 3, pp. 327–334, 2014.
[19] M. S. Al-homoud, "Envelope Thermal Design Optimization of Buildings with Intermittent Occupancy."
[20] P. Taylor and I. M. Budaiwi, "Journal of Building Performance Simulation Envelope thermal design for energy savings in mosques in hot-humid climate," no. April 2013, pp. 37–41, 2011.
[21] "ASHREA FUNDMENTAL NOTEBOOK 2013 _By Chiheb Sboui.".