Computational Fluid Dynamics Analysis of A Workroom Design

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Abstract

Diketahui bahwa masyarakat Jakarta menghabiskan biaya sebanyak 38,5 trilyun rupiah untuk kesehatan. Nilai ini cukup tinggi dibandingkan dengan APBN 2016 untuk kesehatan yang mencapai sekitar 67 trilyun rupiah. Enam puluh persen dari penyakit di Jakarta adalah penyakit pernapasan. Untuk kasus ruang gubernur Jakarta pada tahun 2005, diketahui bahwa jumlah partikel di kamar gubernur sekitar 45000 partikel per sentimeter kubik. Ada kemungkinan besar bahwa jumlah ini berhubungan erat dengan kualitas udara yang mengakibatkan gubernur mengalami gangguan pernafasan. Kualitas udara dipengaruhi oleh sirkulasi udara. Jadi, penting untuk merancang sebuah ruangan yang memiliki sirkulasi yang tepat dan memiliki kenyamanan termal. Sebuah model ruang kerja untuk kepala atau ketua telah dipilih sesuai dengan standar. Simulasi computational fluid dynamics (CFD) telah dilakukan untuk menentukan suhu udara masuk sehingga suhu di sekitar tempat pertemuan berada dalam keategori nyaman secara termal. Dari hasil simulasi diketahui bahwa kenyamanan termal tercapai ketika inlet suhu udara sekitar 19^{o}C.

Keywords: computational fluid dynamics, CFD, workroom, circulation, thermal comfort

Introduction

Jakarta is at the third position of the most polluted city in the world. One of the cause is there are many vehicles in Jakarta. Vehicle produces poisonous gases such as CO, Nox, Sox, HC, Pb and suspended particulate [1]. Poisonous gas can influence human health. It is the cause of respiration disease such as asthma, chronic obstructive pulmonary disease, pneumonia, bronchitis, and emphysema. Particulate in a room could also be the cause of respiration disease. It is our task to keep the amount of particulate below the standard.

From data gathering on 2010, it was known that people of Jakarta spend their money as much as Rp. 38,5 trillion for health. It was high enough compared to APBN 2016 for health which is just as much as Rp. 67 trillion. We know that APBN is for all of Indonesian. Sixty percent of the disease in Jakarta is respiration disease. This may connect us to the result of the study explained [2].

On 2005, there was an effort to measure amount of particulate in his room. It was known that there are 45000 particles in each 1 cm^3. This is above the standard. Knowing this fact that may be the one that cause the Jakarta's governor respiratory disease that was hard enough to be cured, Sutiyoso asked his subordinate to install a device to reduce the particles [2]

There was a research for knowing exposure of some people in Jakarta of their activities. It was to know how much poisonous gas around them. The method was to use a certain device to measure the poisonous gas. The sample was taken when the people used a certain vehicle in their activity. The vehicle were ac and non ac private vehicle and public transportation, and also motorcycle. It was conducted by accompanying the people 24 hours of his/her activity. The sample was from children until adult. The gas that has been measured are CO, PM2,5, Pb and some other gases. The result was compared with standard from WHO. The result shows that most of gas exposure is high when the people do the activity in vehicle. The value is very far from WHO's standard. In workroom the result also are greater than the standard. The amount of gas also high when the traffic jams. It is because when the vehicle moves, there is air circulation [2].

As mentioned above, circulation holds an important role of the amount of the particulate. The purpose of this task is to simulate circulation in a room using CFDSOF and to find the best way to reduce the particulate until below the standard. It's desired it can be a solution for particulate exposure in work room in many building in Jakarta. Finally, the purpose of this task is to design a healthy work room.

Methodology

A simulation using CFD of a work room model of a building in Jakarta, especially for a leadership room, was done. The work room model and size was designed according to the standard. Those are some parameters may be considered beside the work room size: air circulation (flow, velocity, direction), work room temperature, and humidity.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommends ventilation rates for indoor environments in 1973. ASHRAE changed this standard in 1975 to specify the minimum value of 5 cubic feet per minute (CFM) of outdoor air per person be used in building design. The 62-1989 standard suggests a minimum of 15 CFM of outdoor air per person for offices (reception areas) and 20 CFM per person for general office space with a moderate amount of smoking. Sixty cubic feet per minute per person is suggested for smoking lounges with local mechanical exhaust ventilation and no air recirculation [3]. For thermal comfortness, temperature should be kept between 20-24^{o}C [4].

The "Government of Canada Workplace 2.0 Fit-up Standards" as published by Public Works and Government Services Canada (2012) made 4 worker profiles and corresponding work space based on the amount of time spent at the workstation [5]:

Leadership: 10 m² – maximum of 18.5 m². Examples: director, director general or higher.

Fixed: maximum of 4.5 m². Examples: policy analyst, administrative assistant, call/contact centre operator and translator.

Flexible: maximum of 3.0 m². Examples: account executive and auditor

Free Address: maximum of 1.5 m². Examples: consultants, remote workers, regional employees, full-time teleworkers. It should be remembered that the free address workstations are not for any specific employee.

Table 1 is a list of recommended workstation sizes for various job functions. It will promote efficient space planning and provides flexibility for future changes.

Table 1. Recommended workstation size [6]

Space Type	Functional Assignment	Space Allocation	
		m²	ft²
Enclosed Type A	Frequent meetings with up to four others and/or requiring confidentiality, security, visual and acoustical privacy. Typical assignment for Deputy Minister or equivalent.	22.5	240
Enclosed Type B	Frequent meetings with up to two others and/or requiring confidentiality, security, visual and acoustical privacy. Typical assignment for Assistant Deputy Minister, Director, senior position in charge of a regional or district office or equivalent.	13.9	150
Enclosed Type C	Frequent meetings with up to two others and/or requiring confidentiality, security, visual and acoustical privacy. Typical assignment for position involved with counseling, human resources management or other sensitive situations requiring ongoing visual and acoustical privacy.	9.3	100
Open Type D	Concentrated multi-source paperwork: compiling information, reading, writing, analyzing, calculating and referencing multiple sources of material; allows for manual and automated drafting functions. Typical assignment for managerial, professional or technical staff.	9.3	100
Open Type E	Multi-task paper intensive work: telephone work, keyboarding, filing, sorting documents, handling mail, editing, operating equipment, scheduling, receiving visitors. Typical assignment for secretary and administrative support staff.	6.5	70
Open Type F	Specific, task-oriented work, focusing on data input into electronic media. Typical assignment for clerical and data-entry staff.	4.5	50

According to the same reference, there are several types and layouts of the room, some of them are shown by Figure 1, 2, and 3.

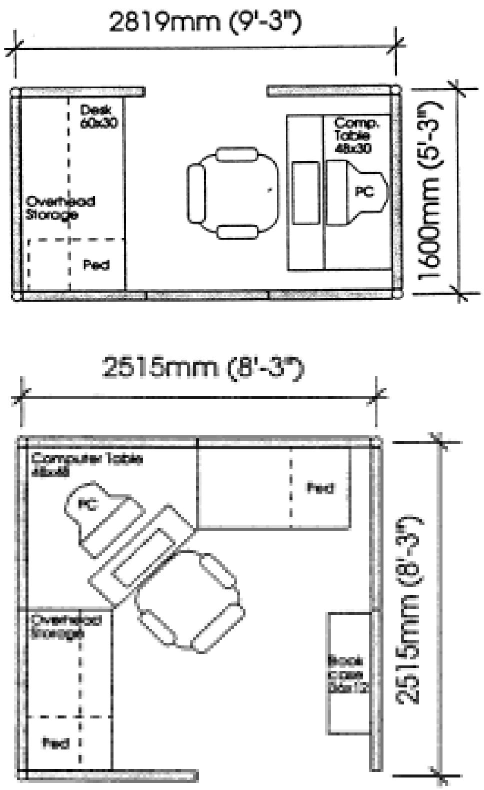
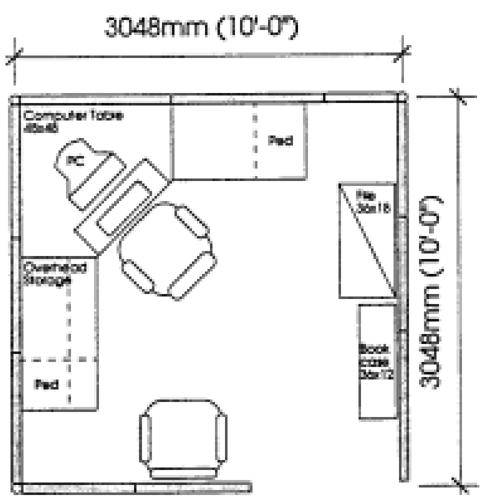


Figure 1. Sample room layout type F (top) and E (bottom) [6]



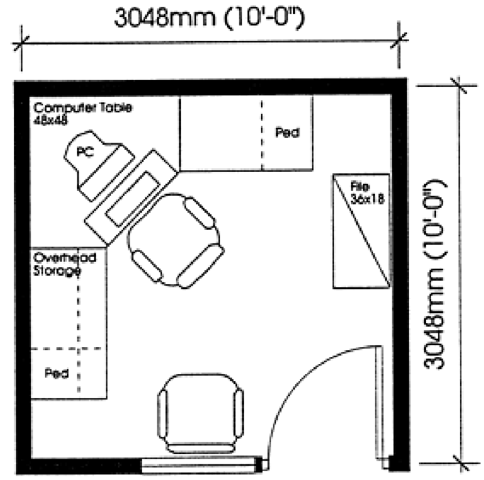


Figure 2. Sample room layout type D (top) and C (bottom) [6]

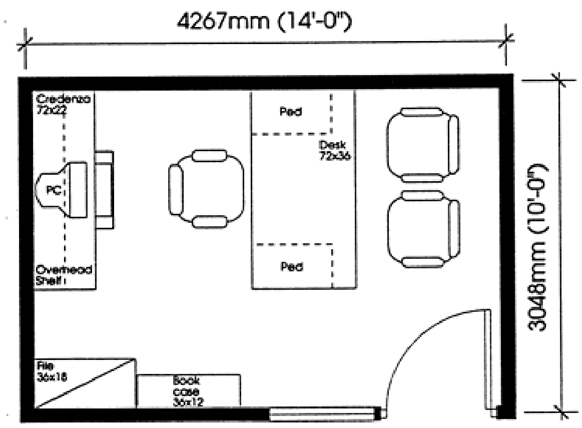


Figure 3. Sample room layout type B [6]

The standard is just the horizontal size of the requirement space, but the height is not defined yet. Minimum heights specified relate to different rooms in homes and other buildings are shown in the Table 2.

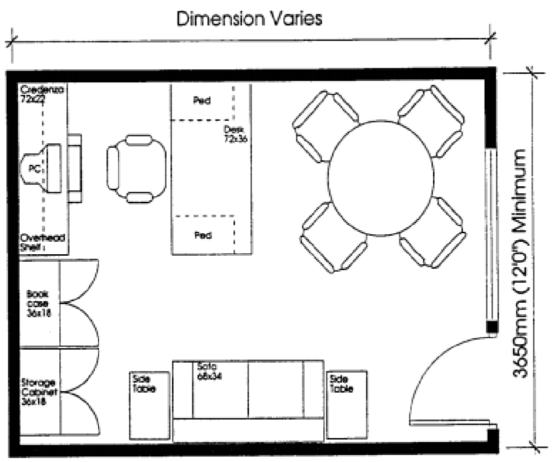


Figure 4. Sample room layout type A [6]

Table 2. Minimum height room according to standard [7]

Types	Size
Bedrooms.	2,4 m above a floor area of at least 6 sq m with a clear height of at least 1,8 m at any point that is more than 0,75 m from the edge of the floor space.
Any other habitable rooms in dwelling houses/units.	2,4 m above a minimum of 70% of the floor area, and not less than 2,1 m above the remaining floor area.
All other habitable rooms.	2,4 m.
Passages and entrance halls.	2,1 m.
Bathrooms, shower rooms, laundries and toilets.	2,1 m above any area where a person would normally stand upright.
Open mezzanine floor with an area no more than 25% of the area of floor immediately below it	2,1 m above and below the mezzanine floor.

A room has been designed with the existing standard and follows the indoor air quality (IAQ) standard. A computational analysis will be necessary to see the flow of the air and the amount of the air that enters to and exits from the room.

Room Size, Domain and Grid. The model will be like the type B layout i. e. for leadership room with height of 2,4 m. The layout is shown in the Figure 5.

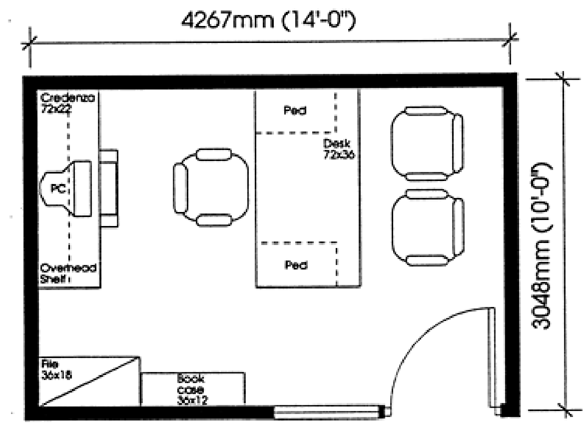


Figure 5. Layout Simulation Model

The computational domain is shown in the Figure 6.

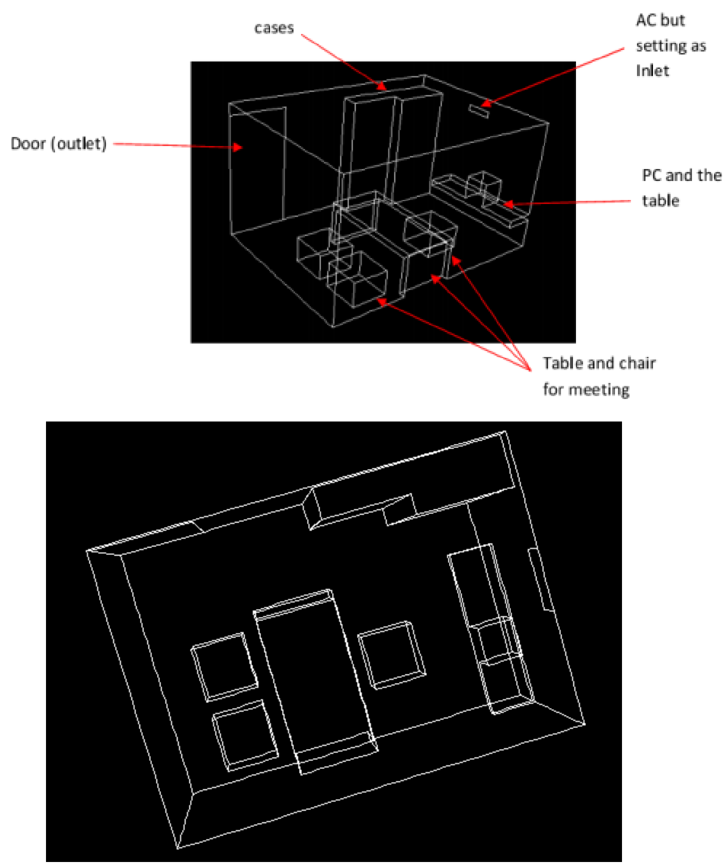


Figure 6. Domain of the room model

The grid is shown in Figure 7. The inlet and outlet are also shown in the Figure. The amount of cell was not more than 100.000 cells.

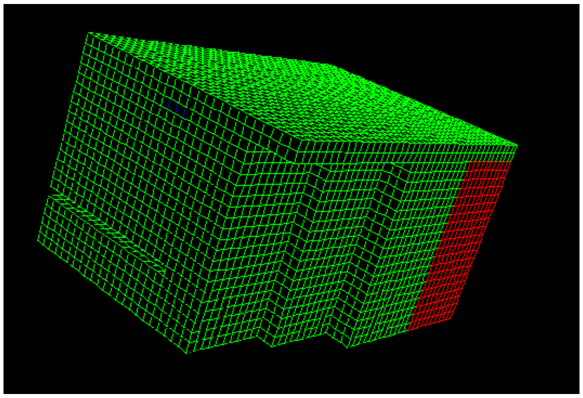


Figure 7. Grid of the model

Boundary Condition

Temperature. According to reference data in 2006, the mean temperature of Jakarta is 34,1°C by daylight and 23,5°C by night. So, the wall temperature will be the highest value, i.e. 34,1°C or 307,1 K.

Velocity of the Inlet Air, Inlet Area, and Temperature. For determining those parameters, a commercial air conditioner was chosen. It has 560 cubic meter per hours (CMH) when the air velocity is 9,9 m/s. From this we can determine the area is 0,015 m^2 or 15 cm x 10 cm. In this case, it was very hard to set the value like this. So, an area of 40 cm x 10 cm has been taken which gives 3,89 m/s value of air inlet velocity with the same amount of air, i.e. 560 CMH. For the temperature, it iss common to set the temperature of an AC with 24°C according to experience, but the effect of this setting would be seen. If it reaches the thermal comfort temperature it will be enough.

Density. The density was the ideal gas law which accordance to the equation (1).

$$\rho = P/RT \qquad (1)$$

where ρ, P, R, and T are gas density (kg/m^3), absolute pressure (Pa), spesific gas constant (J/kg.K) and gas temperature (K), respectively.

CFD Model

The CFD software used was a commercial one called CFDSOF®. In general, CFD analysis uses the general equation for airflow, energy transport, distribution of mass fraction and other related variables like turbulence as shown in equation (2) [8].

$$\rho\frac{\partial\phi}{\partial t}+\rho u\frac{\partial\phi}{\partial x}+\rho v\frac{\partial\phi}{\partial y}+\rho w\frac{\partial\phi}{\partial z}=\frac{\partial}{\partial x}\left(\Gamma_\phi\frac{\partial\phi}{\partial x}\right)+\frac{\partial}{\partial y}\left(\Gamma_\phi\frac{\partial\phi}{\partial y}\right)+\frac{\partial}{\partial z}\left(\Gamma_\phi\frac{\partial\phi}{\partial z}\right)+S_\phi \qquad (2)$$

where x, y, z are coordinates, u, v, w are velocities in the x, y and z directions, respectively. S_φ is a source term and Γ_φ is a turbulent diffusion coefficient. t is the time. φ is a fluid flow variable. When φ is equal to 1 and Γ_φ equal to zero, the equation (2) represents the continuity equation as shown in equation (3).

$$\frac{\partial\rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_j)=0 \qquad (3)$$

The equation (2) are the Navier-Stokes equations for φ equal to u, v, w respectively, as shown in equation (4).

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_j}(\rho u_i u_j)=\frac{\partial}{\partial x_i}\left[-\rho\delta_{ij}+\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)\right]+\rho g_i \qquad (4)$$

For φ equal to the temperature T, equation (2) represents the energy equation as shown in equation (5).

$$\frac{\partial}{\partial t}(\rho C_a T) + \frac{\partial}{\partial x_j}(\rho u_j C_a T) - \frac{\partial}{\partial x_j}\left(\lambda \frac{\partial T}{\partial x_j}\right) = S_T \qquad (5)$$

The equation (3), (4), and (5) are from Norton and Sun (2006) as stated in [9].

In this study, the turbulent model used was k-epsilon RNG model. The simulation was done under steady state condition.

Results and Discussion

Case 1. For case 1, the w1, w2 and w3 are the same, i.e. 307,1 K for Jakarta outdoor temperature [10]. Where w1 is room wall, w2 is furniture in the room, w3 is the computer. From the input, this is the worst case of the temperature. Where for inlet temperature is 297 K or 24°C. The vector for temperature is shown in Figure 8.

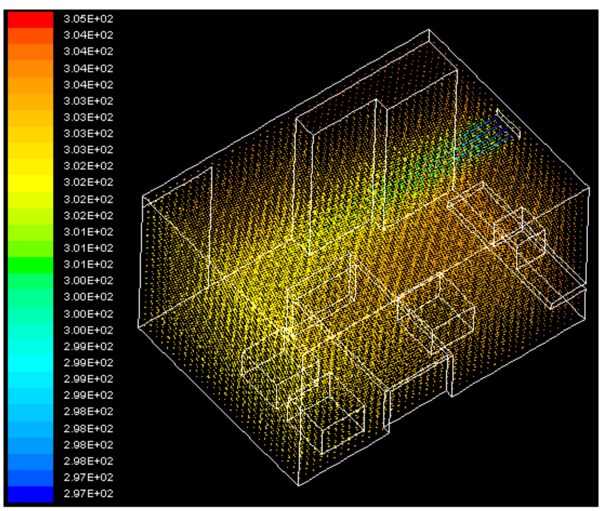


Figure 8. Temperature vector of case 1

The full contour of temperature for case 1 around the chairs and table is shown in the Figure 9.

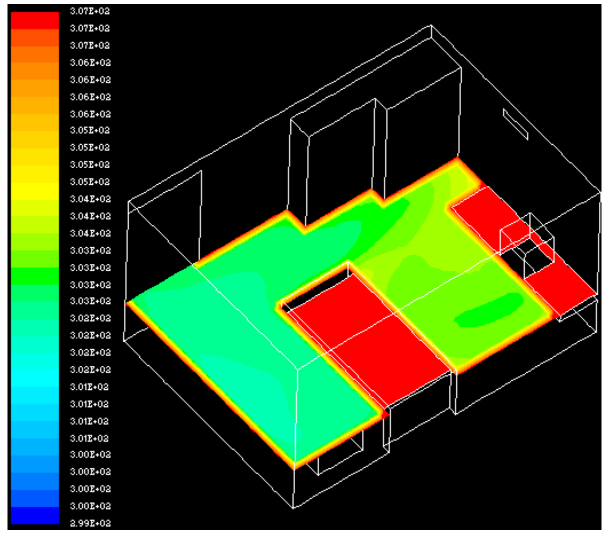


Figure 9. Full temperature contour around meeting area of case 1

From the result, it can be seen that the temperature near the chairs is shown by yellow color vector and light green and blue. It has been known that the light green and blue color have the value of 302 K or 29°C.

Case 2. For case 2, the w1, w2 and w3 are the same, i.e. 307,1 K. From the input, this is the worst case of the temperature. Where for inlet temperature is 290 K or 17°C. The result of temperature vector is shown in Figure 10.

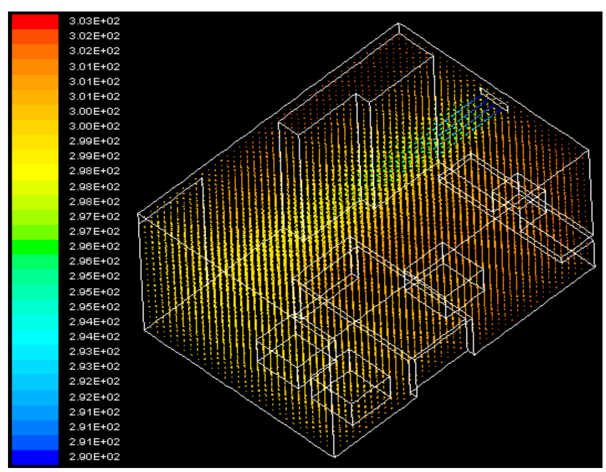


Figure 10. Temperature vector of case 2

The full contour of temperature for case 2 around the chairs and the table is shown in the Figure 11.

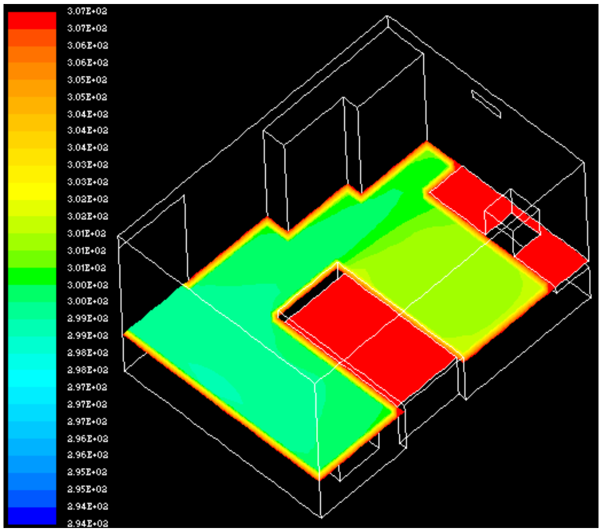


Figure 11. Full temperature contour around meeting area of case 2

From the result, it can be seen that the temperature near the chairs is shown by yellow color vector and light green and blue. It has been known that the light green and blue color have the value of 300 K or 27^{o}C.

Case 3. For case 3, the w1, w2 and w3 is the same, i.e. 301,8 K. Where for inlet temperature is 293 K or 20^{o}C. Here are the result of simulation. The result of temperature vector is shown in Figure 12.

The full contour of temperature for case 3 around the chairs and the table is shown in the Figure 13.

From the result, it can be seen that the temperature near the chairs is shown by yellow color vector and light green and blue. It has been known that the light green and blue color have the value of 298 K or 25^{o}C.

Case 4. For case 4, the w1, w2 and w3 is the same, i. e. 301,8 K. Where for inlet temperature is 292 K or 19^{o}C. The result of temperature vector is shown in Figure 14.

The full contour of temperature for case 4 around the chairs and the table is shown in the Figure 15.

From the result, it can be seen that the temperature near the chairs is shown by yellow color vector and light green and blue. It has been known that the light green and blue color have the value of 298 K or 25^{o}C. This value is still acceptable according to ASHRAE Standard 55 in [11] for thermal comfort of a room with natural convection.

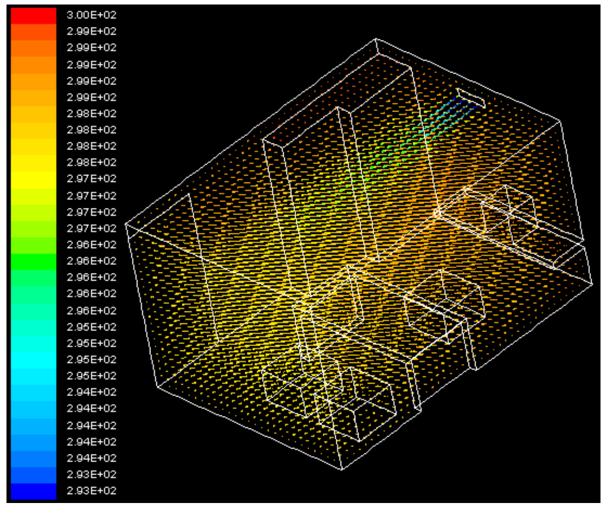


Figure 12. Temperature vector of case 3

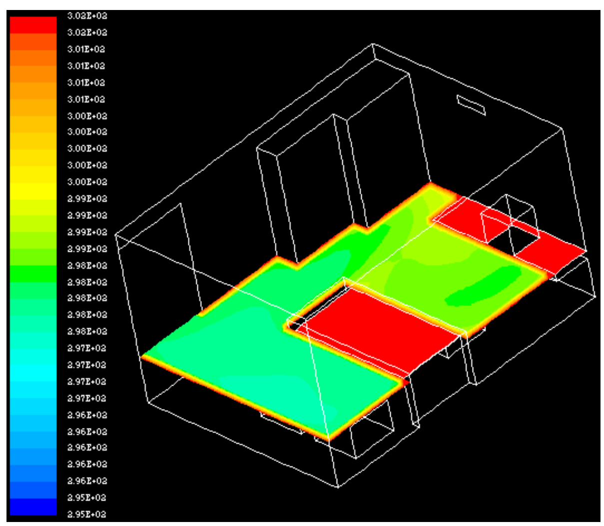


Figure 13. Full temperature contour around meeting area of case 3

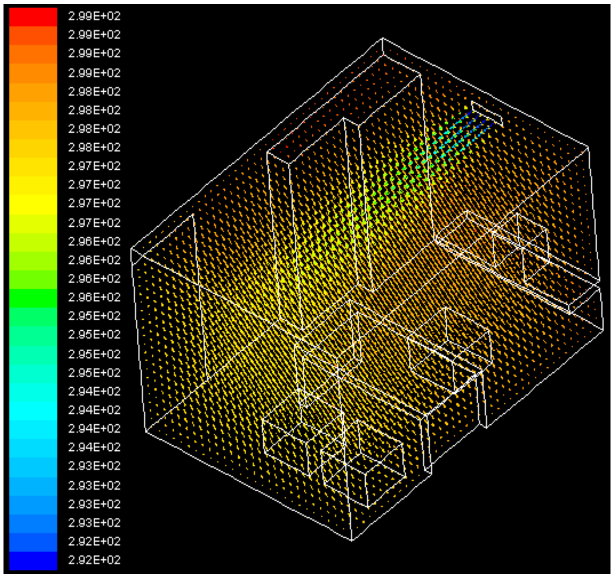


Figure 14. Temperature vector of case 4

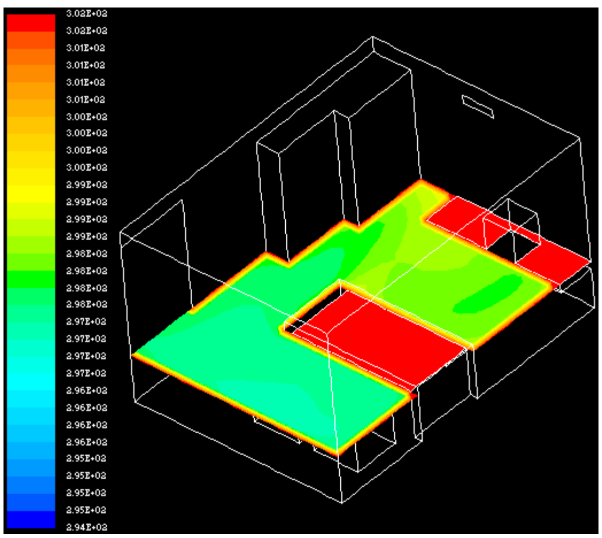


Figure 15. Full temperature contour around meeting area of case 4

Conclusion

According to the current study, air inlet temperature to reach acceptable thermal comfortness is 19°C. For high wall and furnitures temperature, it was very hard to gain a low temperature around the meeting area even using a relatively low inlet temperature. The design should be enough to supply the required amount of air in the leadership workroom. From calculation the total air is 0,93 m^3/min, while the standard only needs 0,56 m^3/min.

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