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Computational Fluid Dynamics (CFD) Study on Air Flow of Air Diffuser in a Room

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Abstract: The objective of this study is to identify different types of air diffusers and evaluate the performance of 4-blades, 5-blades and proposed 7-blades round ceiling air diffusers and outlet position. Then compare the performance of each type of diffuser and outlet position in terms of airflow behaviour and temperature distribution. The scope of my study is that the models will be drafted, meshed, and simulated for their airflow behaviour and temperature distribution using ANSYS FLUENT. The expected result would be that the diffuser with more blades is expected to provide the room with a consistent airflow due to more blades mean more deflection of air. Also, a diffuser with more blades is expected to provide better thermal distribution to the room. An outlet near the ceiling of the wall could help achieve an optimal thermal comfort environment.

Keywords: Air Diffusers, Blades, Outlet, Airflow Behaviour, Velocity, Temperature Distribution.

1. Introduction

In some places like offices or malls, always use ceiling air diffusers to control the characteristics of airflow or temperature for air conditioning or ventilation purpose. This mechanical device will reduce the velocity of the supply air at the terminal to improve the mixing of the supply air and the surrounding air within the enclosure. It usually consists of a number of deflection blades or vanes which will direct the air in the desired direction. Currently, there are various types of ceiling air diffusers available on the market, in which the round ceiling air diffuser is one of the widely used diffusers.

On the other hand, computational fluid dynamics (CFD) applies numerical methods and algorithms to analyze and resolve issues regarding fluid flows in a laminar or turbulent approach for any geometry. It is one of the popular tools for modelling, simulating, predicting, and reporting flow characteristics or performance of air, gases and liquids, temperature, heat transfer, acoustic, and mass flow rate of static or dynamic bodies in simple or complex design.

Pre-processing, solving, and post-processing are the three stages involved in the CFD simulation. Pre-processing is mainly used to create and analyze the flow model using the computer-aided design (CAD) package such as ANSYS FLUENT, GAMBIT, COMSOL, etc., which constructs and forms

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acceptable computational mesh and inputs the properties of fluid materials and flow boundary conditions to produce suitable and fine mesh for the model with unique curvature and proximity features.

To supply and distribute air in any room or hall, ceiling air diffusers are commonly used. This is due to their ability to achieve the desired airflow at a competitive cost. However, the uneven air supply to the room always occurred in different air diffuser designs. For example 4-vane round ceiling air diffuser design. The situation will affect the thermal comfort of the room or create an unpleasant condition in which the room temperature underneath the air diffuser may be relatively low and the occupants around the air diffuser may feel uncomfortable. Therefore, a study of an effective air diffuser design and a good outlet position to provide better airflow and temperature distribution in a room is required. The objective of this research is to evaluate the performance of 4-blades, 5-blades and 7-blades, round ceiling air diffusers and compare the performance of each type of diffuser in terms of flow characteristics and temperature distribution.

Ceiling diffusers are one of the few visible parts of an air conditioning system. Typically mounted on the ceiling of a home or commercial building, their purpose is to evenly distribute conditioned air throughout the place. Diffusers are manufactured in a variety of shapes, sizes, colours and materials. The most common style of diffuser used in commercial installations is a round air diffuser due to competitive prices on the market.

A round ceiling diffuser is a diffuser with a round frame and cones constructed from high-quality aluminium sheets. This type of diffuser is designed mainly for any application that requires a high-performance diffuser. Because a round diffuser is capable of a high aspiration rate and handles a large amount of airflow rate at relatively low noise levels for supply and return air applications. This is useful to be installed in open spaces with high ceiling levels such as auditoriums, airport lobbies, hypermarkets, multi-purpose halls and factories.

The square ceiling diffuser was designed mainly to provide airflow patterns in horizontal, angled or vertical directions, unlike the round ceiling diffuser. Also, multidirectional airflow can be adjusted by arranging the orientation of the blades. A square ceiling diffuser is usually used in a space where the ceiling height is around 2 to 3 m high.

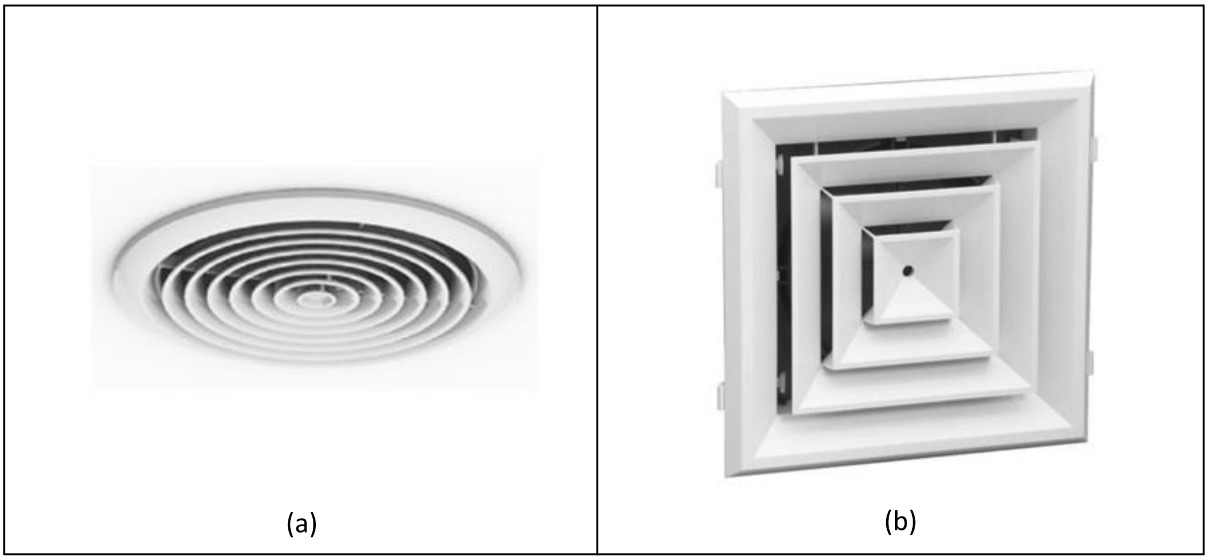

Figure 1: a) Round ceiling diffuser b) Square ceiling diffuser

The swirl air diffuser is designed to optimize air distribution effectiveness, where it has high air induction from the diffuser to extract stagnant room air, and a 360° swirl air throw pattern for a better Coanda effect to circulate the air masses for flushing the whole room to achieve quicker mixing of supply air and room air.

Linear slot ceiling air diffusers with adjustable deflector blades can be used for horizontal and vertical flow in low noise and pressure loss operating conditions. It is mostly used in showrooms, hotel lobbies, conference rooms or spaces that required executive-level interior design plaster ceiling finishes due to its versatility and aesthetic, as it is available in highly customizable shapes. It can be detached individually for allowing cleaning of the terminal unit and ductwork.

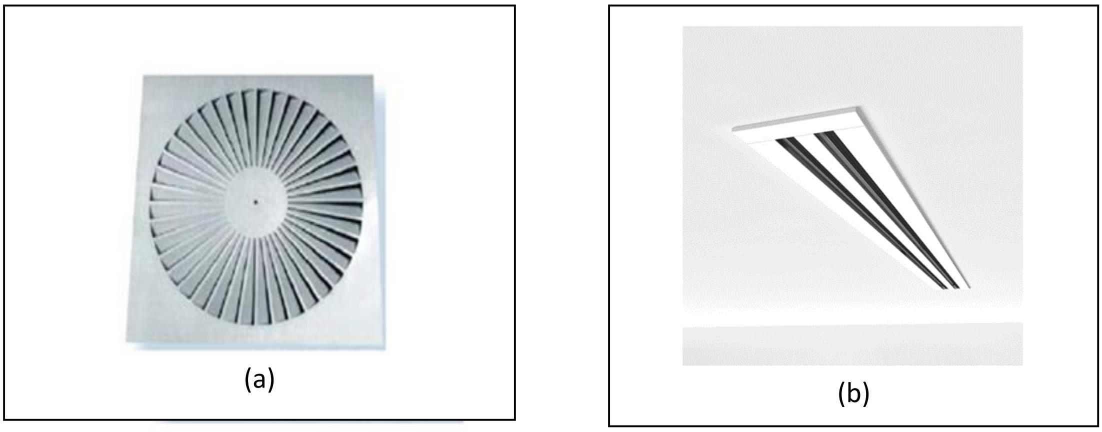

Figure 2: a) Swirl ceiling air diffuser b) Linear slot ceiling air diffuser

2. Methodology

2.1 Geometry of cases studies

A three-dimensional model of a room with either a bottom wall outlet or ceiling outlet duct and 3 different types of round ceiling air diffusers (4-bladess 5-bladess 7-bladess) are generated with Solidworks software. Therefore, there is a total of 6 geometries was studied. The geometry of the room is 4 $m(length)\times 3\ m(width)\times 3\ m(height)$.

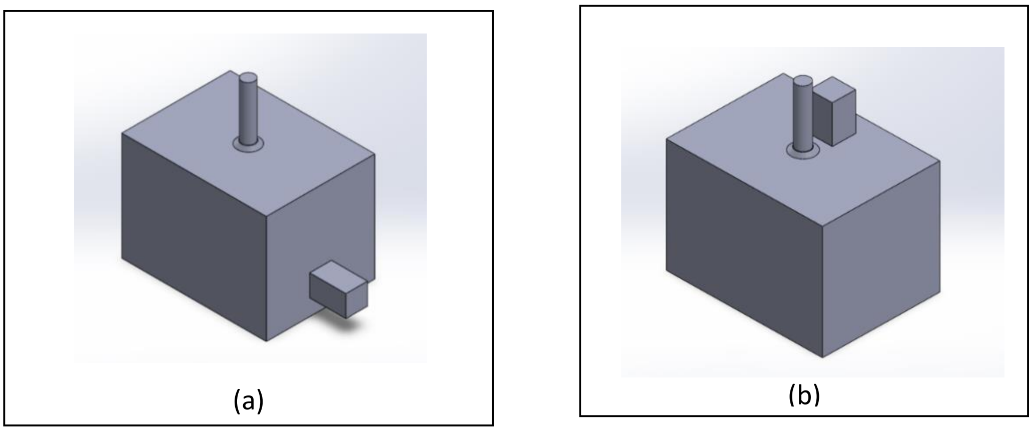

Figure 3: Room a) Bottom wall outlet b) Ceiling outlet

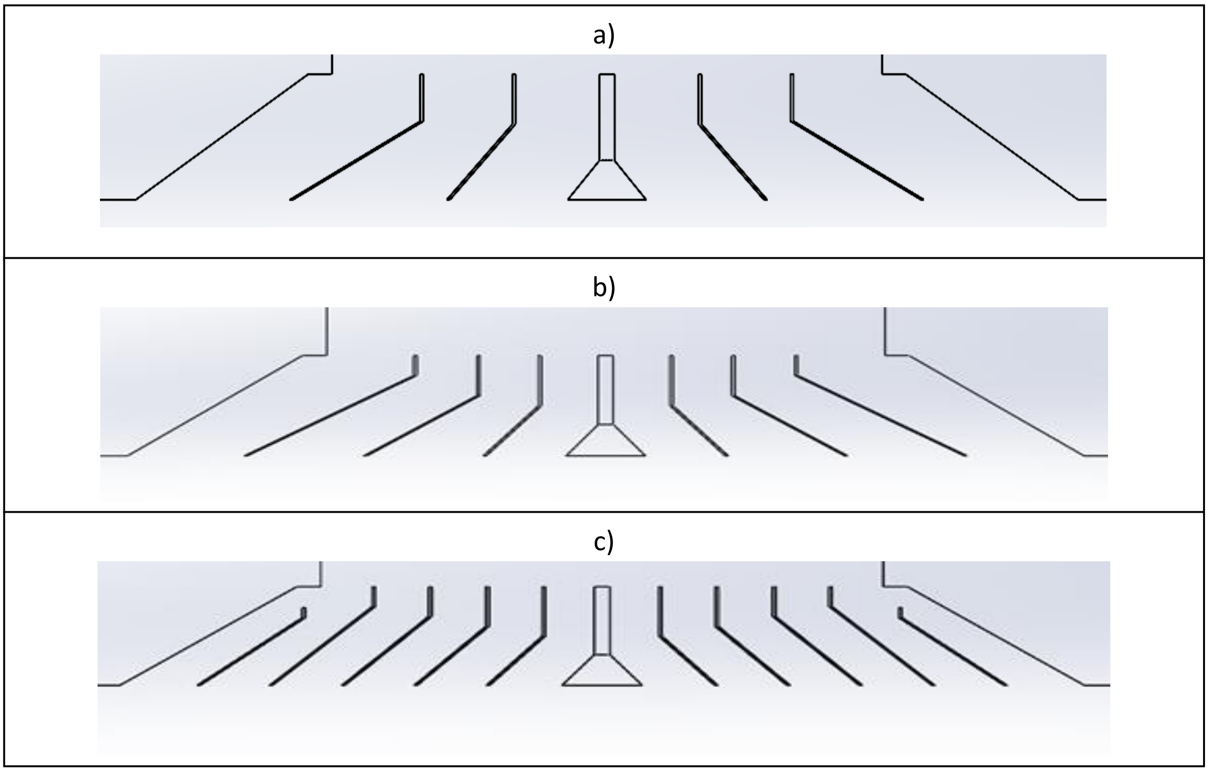

Figure 4: Round ceiling air diffuser a) 4-blades b) 5-blades c)7-blades

2.2 Governing Equations

One of the assumptions used in this study was the fluid is incompressible. For an incompressible fluid, density is constant, and the continuity equation reduces to the following condition [10,11]:

$$\nabla . V = 0 \qquad Eq.1$$

While the momentum equation is a mathematical formulation of the law of conservation of momentum. It states that the rate of change in linear momentum of a volume moving with a fluid is equal to the surface forces and the body forces acting on a fluid [15,16].

$$\frac{Du}{Dt} = \frac{\delta u}{\delta t} + V . \nabla u \qquad Eq.\ 2$$

2.3 Discretization of Model

For a room of the bottom wall outlet with a 4-blades round ceiling diffuser, the type of mesh generated was tetrahedrons. The number of grid nodes was 646894, while the number of the grid element was 3618517. For a room of the bottom wall outlet with a 5-blades round ceiling diffuser, the type of mesh also generated was tetrahedrons. The number of grid nodes was 760831, while the number of the grid element was 4244124. For a room of the bottom wall outlet with a 7-blades round ceiling diffuser, the type of mesh generated was tetrahedrons. The number of grid nodes was 1142544, while the number of the grid element was 6362619.

For a room of ceiling outlet with a 4-blades round ceiling diffuser, the type of mesh generated was tetrahedrons. The number of grid nodes was 706345, while the number of the grid element was 3949330. For a room of ceiling outlet with a 5-blades round ceiling diffuser, the type of mesh also generated was tetrahedrons. The number of grid nodes was 847556, while the number of the grid element was 4733739.

For a room of ceiling outlet with a 7-blades round ceiling diffuser, the type of mesh generated was tetrahedrons. The number of grid nodes was 1272864, while the number of the grid element was 7097764. Figure 5 shows the physical domain of the room model being meshed.

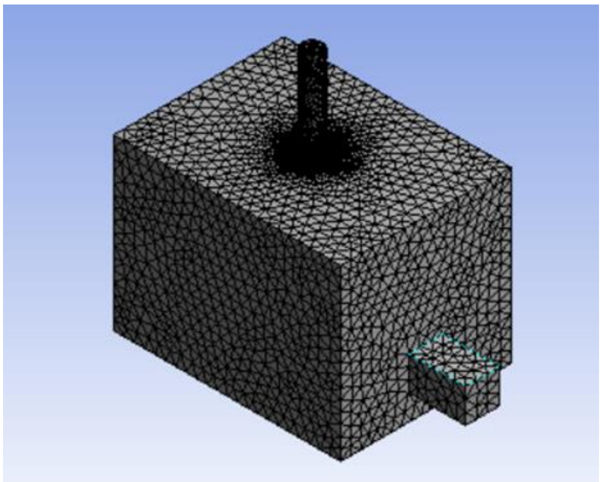

Figure 5: Physical domain of the room model is being meshed

2.4 Parameters and Boundary Conditions

Table 1: Assumptions and Parameter

Item	Parameter Name	Variable Value/Configuration	Unit or Dimension
1	Assumptions	Steady Flow Incompressible Flow Newtonian Fluid	
2	Room Dimensions	4 x 3 x 3	m
3	Inlet Velocity, V	1.0	m/s
4	Inlet Temperature, T_i	287 (14)	K (°)
5	Wall Temperature, T_a	298 (25)	K (°)
6	Density of Air, ρ	1.225	kg/m^3
7	Dynamic Viscosity, μ	1.7894 x 10^{-5}	kg/m-s
8	Specific Heat of Air, C_P	1006.43	J/kg K
9	Thermal conductivity of air, k	0.0242	W/m-K

The cool air from the inlet duct was set to 1m/s and 287K. While the wall temperature inside the room was set to 298K to simulate the normal temperature inside a room. Other parameters are set at default such as gravity, density, turbulent viscosity ratio and so on.

3. Results and Discussion

Figure 6 illustrated that the 4-blades round ceiling air diffuser does not provide a uniform airflow distribution to the room as most of the distributed air was concentrated around the central core of the room. This is due to the reason that of high volumetric flow from the air diffuser to the centre of the room, the air does not diverge much in different directions.

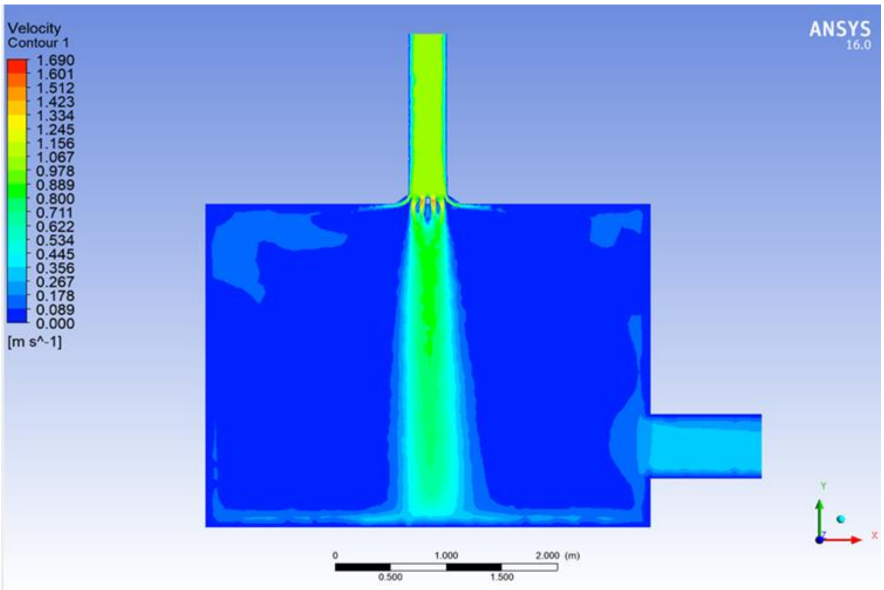

Figure 6: Contours of velocity in the room with 4-blades round ceiling air diffuser (bottom outlet)

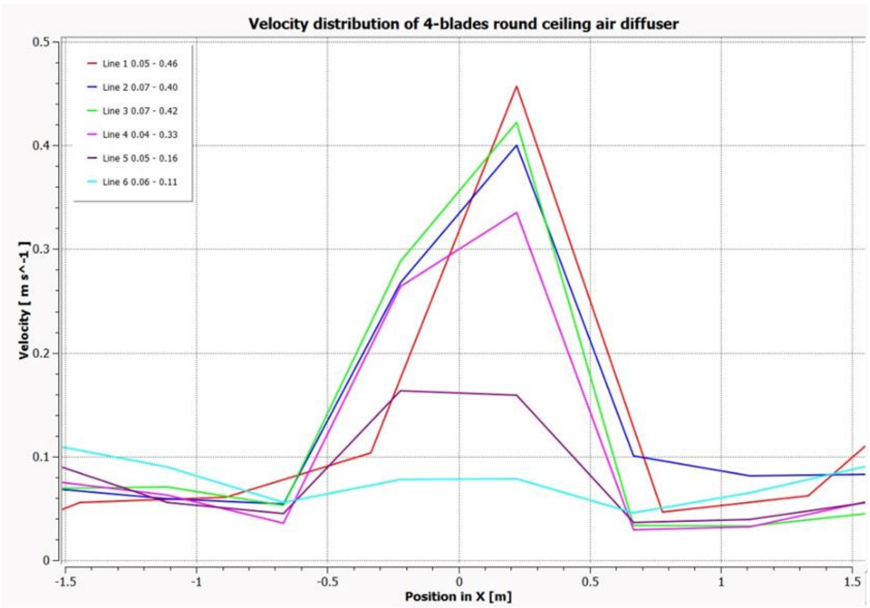

Figure 7: Velocity XY plot for 4-blades round ceiling air diffuser (bottom outlet)

The average velocity surge at the centre of the room (0 – 0.46 m/s) between -0.5 m to 0.5 m. The velocity profile within the room of lines 2 to 5 for the 4-blades air diffuser indicated air velocity was up to 0.42 m/s around the centre position due to uneven air distribution. Occupants standing nearby central might have physical discomfort due to strong airflow striking their bodies continuously. Therefore, a 4-blades round ceiling air diffuser is not suitable for a room with an outlet near the bottom wall.

The CFD velocity contour in Figure 8 shows that the airflow distribution from the 7-blades round ceiling air diffuser was evenly distributed throughout the room. There is no airflow concentration in the room central. By comparing the 5-blades air diffuser and 7-blades air diffuser, both of them are able to provide airflow evenly unlike the room with a 4-blades air diffuser in which most air is concentrated at the room central. Occupants might feel comfortable inside the room. Also, the Venturi effect was observed when air flowed through the air gap between the air diffuser blades, where air velocity was increased, and pressure was reduced.

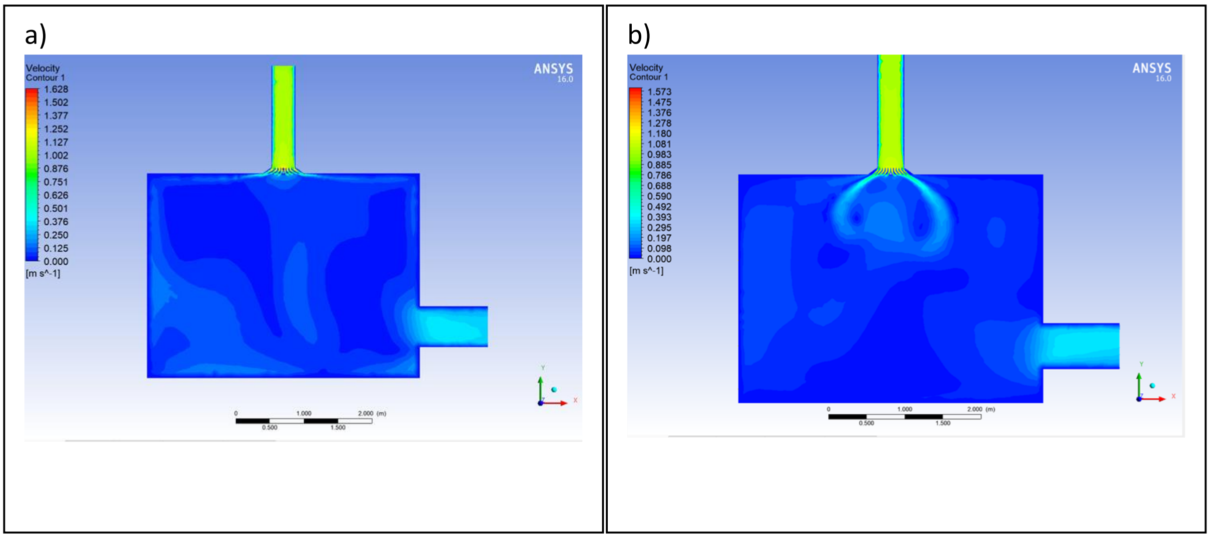

Figure 8: Contours of velocity in the room with a) 5-blades round ceiling air diffuser b) 7-blades round ceiling air diffuser

The CFD results of Figure 9 and Figure 10 for the 7-blades round ceiling air diffuser expressed that the airflow distribution (0 – 0.12 m/s) was slightly lower than that of those of the 5 blades round ceiling air diffusers (0 – 0.13 m/s) because round ceiling air diffuser with more blades tend to distribute the air in more angle and direction, therefore, the lower velocity observed is considered normal for this condition. The velocity profile within the room of lines 2 to 5 for 5 or 7-blades air diffuser reflected that the air velocity was within 0.1 m/s, while the velocity profile within the room of lines 2 to 5 for 4-blades air diffuser indicated air velocity was up to 0.46 m/s around centre position due to uneven air distribution. Therefore, a 7-blades round ceiling air diffuser does provide a uniform flow throughout the room as the velocities are average spread and no spike in velocity.

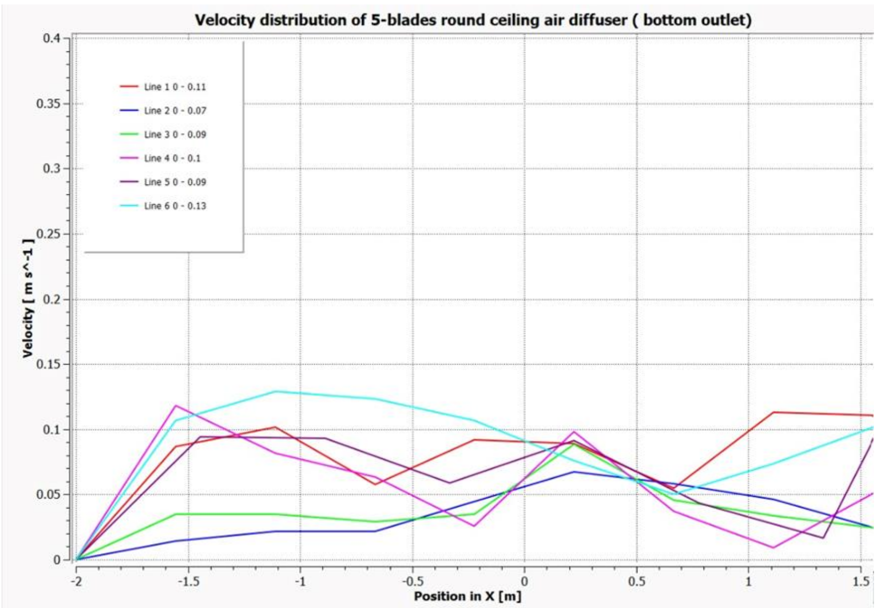

Figure 9: Velocity XY plot for 5-blades round ceiling air diffuser (bottom outlet)

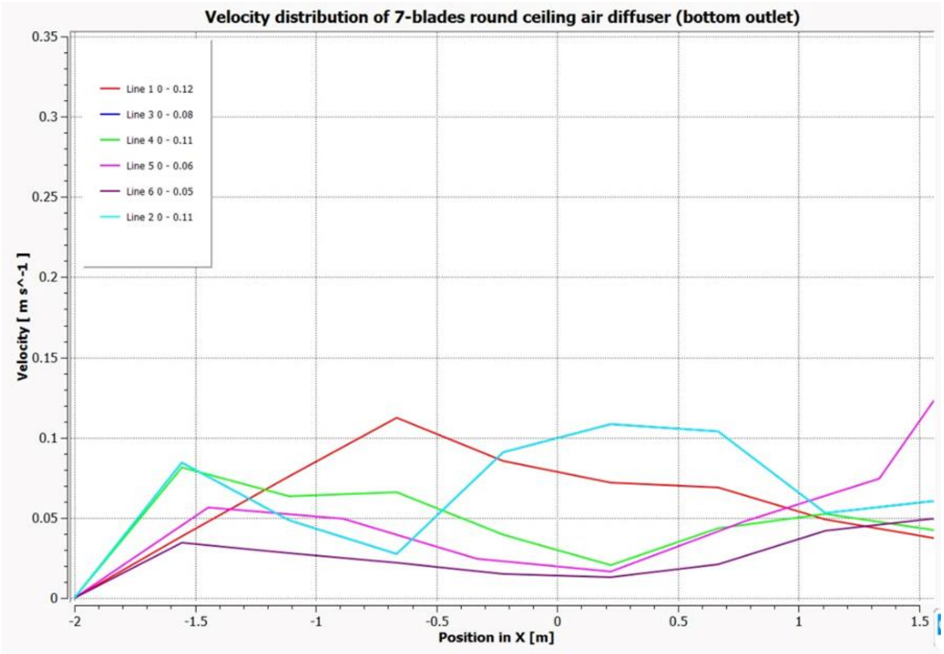

Figure 10: Velocity XY plot for 7-blades round ceiling air diffuser (bottom outlet)

Next, from Figure 11, the static temperature distribution contour illustrated most of the cold air is still focused on the central span of the room with a 4-blades round ceiling air diffuser due to reason as stated in the previous section. The occupants nearby the air diffuser might experience cooler conditions (288.74 - 291.05 K) due to aforesaid uneven air distribution.

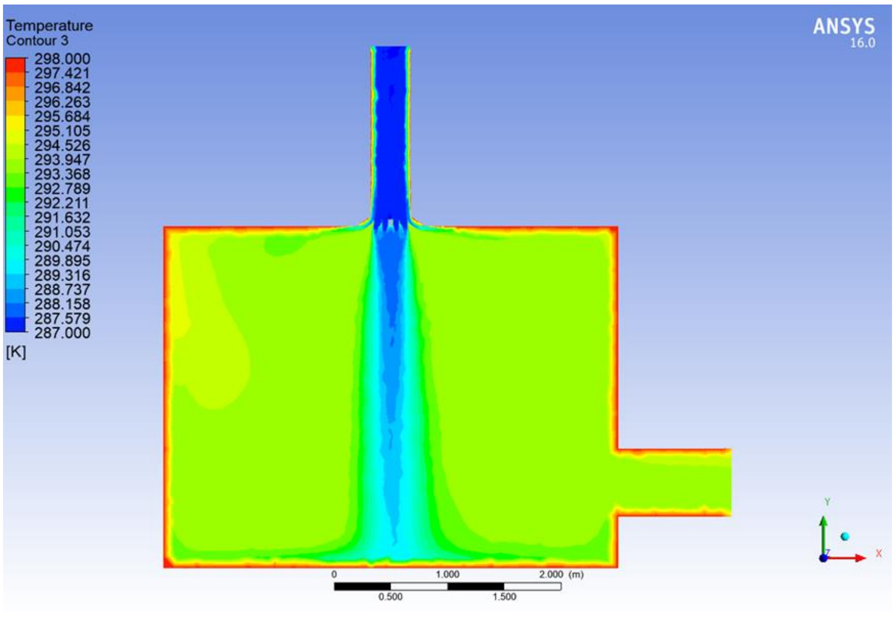

Figure 11: Temperature distribution of 4-blades air diffuser (bottom outlet)

The temperature distribution from the 5-blades round ceiling air diffuser was steadier (291.63 - 293.36 K) throughout the room than that of the 4 blades one in which most of the cold air was concentrated at the central span of the room. By comparing both temperature distribution contours, the 5-blades air diffuser does provide an environment with uniform temperature than the 4-blades diffuser. Those occupants in the room might feel comfortable as the air was evenly distributed throughout the room as there is no fast airflow around the room.

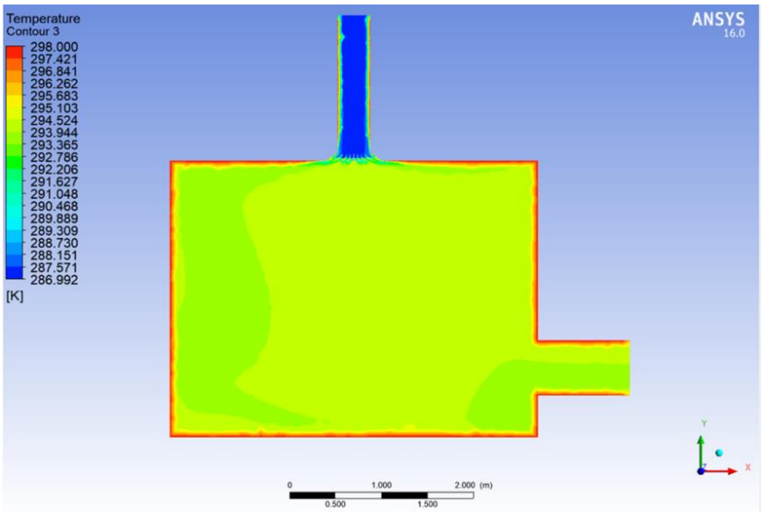

Figure 12: Temperature distribution of 5-blades air diffuser (bottom outlet)

Moreover, the temperature distribution for the 7-blades round ceiling air diffuser was (291.71 - 293.73 K) slightly higher than the room with a 4-blades and 5-blades round ceiling air diffuser. This might be due to the lower velocity in the room observed. Furthermore, no cold air was concentrated at the central span of the room. Those occupants in the room might feel comfortable as the air was evenly distributed throughout the room and no high flow concentration around the room.

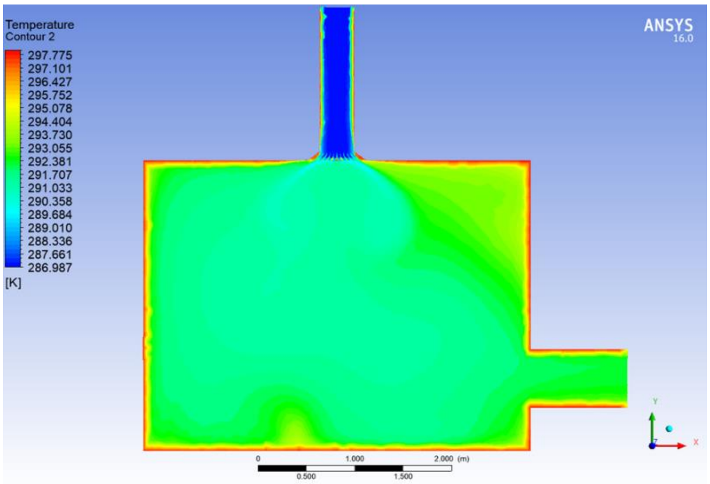

Figure 13: Temperature distribution of 7-blades air diffuser (bottom outlet)

3.1 Room with ceiling outlet

From Figure 14, the velocity contour of the room with a 4-blades round ceiling air diffuser reflected that the airflow was evenly distributed throughout the room. Most of the room space was covered with average velocity air which is much better than the 4-blades round ceiling air diffuser with the bottom wall outlet. It might be due to the pressure outlet being located at the ceiling and therefore high volumetric flow shown in Figure 6 (4-blades air diffuser with bottom outlet) is disrupted. The occupants in the room will feel comfortable because there is no strong airflow striking continuously from the air diffuser.

Furthermore, the velocity contour shows that the airflow distribution from the 5-blades round ceiling air diffuser was similar to the 4-blades round ceiling air diffuser. They did not display any concentration of air around the room and all the air was well distributed inside the room. Also, the Coanda effect was observed where the airflow approached the side wall and turned 90 degrees downward, which implied the throw of air could be longer. The Venturi effect was observed when air flowed through the air gap between the air diffuser blades, where air velocity was increased, and pressure was reduced.

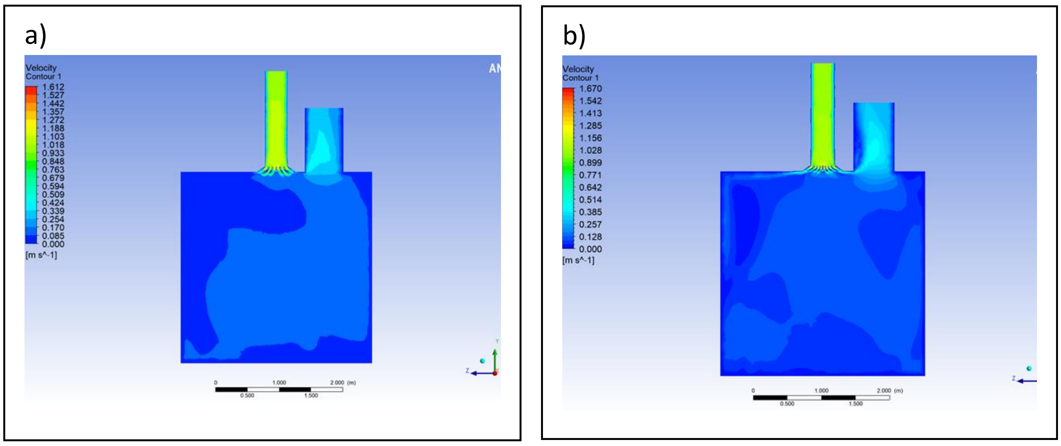

Figure 14: Contours of velocity in the room with a) 4-blades round ceiling air diffuser b) 5-blades round ceiling air diffuser

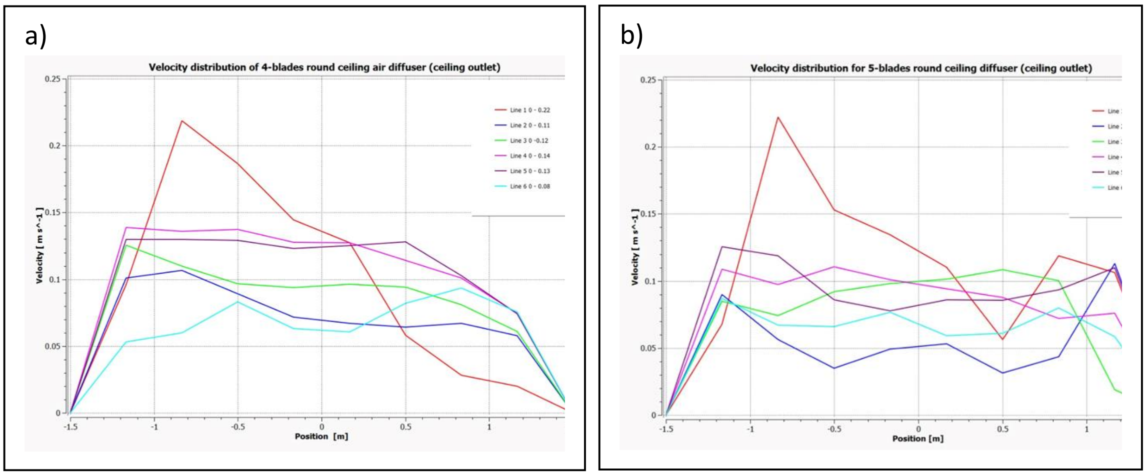

Figure 15: Velocity XY plot for a) 4-blades round ceiling air diffuser b) 5-blades round ceiling air diffuser (ceiling outlet)

The velocity chart shows that the airflow distribution from the 5-blades round ceiling air diffuser is highly similar to the 4-blades round ceiling air diffuser, both of the diffusers do provide a uniform flow throughout the room as there is no sudden surge in velocity flow. The average volume flowing in the room ranges from (0 – 0.22 m/s). For line 1, there is a velocity spike between -1 to -0.5 m position because this spot is near the ceiling air diffuser. For lines 2 to line 6, we can observe that the velocities are maintained at an average velocity between 0 m/s to 0.14 m/s and 0 m/s to 0.13 m/s for 4-blades and 5-blades round ceiling air diffusers respectively. Therefore, the airflow in the room was well distributed as well.

The temperature distribution for the 4-blades round ceiling air diffuser was consistent (291.4 - 293.6 K) throughout the room, while for 5-blades round ceiling air diffuser, the temperature was (292.1 -293.8 K) throughout the room. The average temperature is slightly higher than the 4-blades round ceiling air diffuser, and the air is distributed more uniformly. There is no region in the room spotted with abnormal temperature. Therefore, occupants in the room might feel relaxed as the temperature are relatively steady.

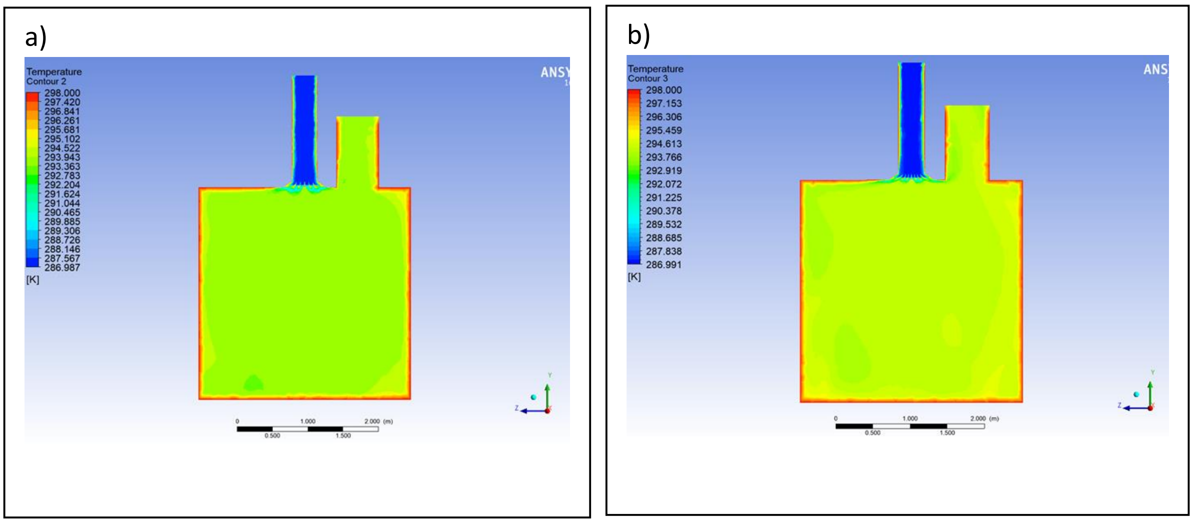

Figure 16: Temperature distribution in the room with a) 4-blades round ceiling air diffuser b) 5-blades round ceiling air diffuser

Figure 17, illustrated that the airflow distribution from the 7-blades round ceiling air diffuser was concentrated on the central and right sides, while there is less airflow on the left side of the room. Occupants standing near the left side of the room might not feel the cool air due to the unevenly distributed air. Moreover, the unevenly distributed air might be due to the deflection by the 7-blades round ceiling air diffuser plus the airflow was affected by the ceiling outlet. Furthermore, 7-blades air diffusers tend to distribute the air in more directions and so the velocity will become slower compared to 4-blades and 5-blades air diffusers. Therefore, the 7-blades air diffuser failed to distribute the air uniformly with the ceiling outlet duct room.

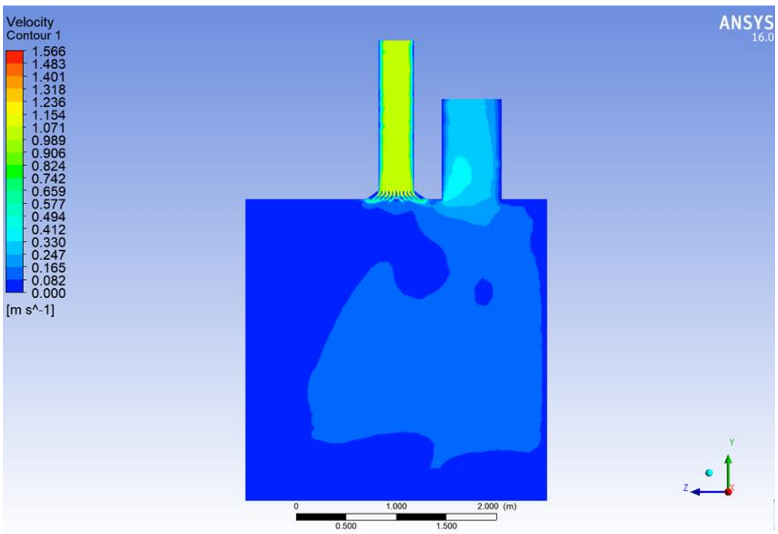

Figure 17: Contours of velocity in the room with 7-blades round ceiling air diffuser (ceiling outlet)

From Figure 18, the lower temperature distribution for the 7-blades round ceiling air diffuser was concentrated on the central and right side of the room (292.2 – 293.4 K). While on the left side of the room, the average temperature is between (293.4 – 295.1 K). This shows that the 7-blades round ceiling air diffuser unable to circulate the air uniformly in the room. Therefore, those occupants standing on the left side of the room might feel uneven temperature feeling.

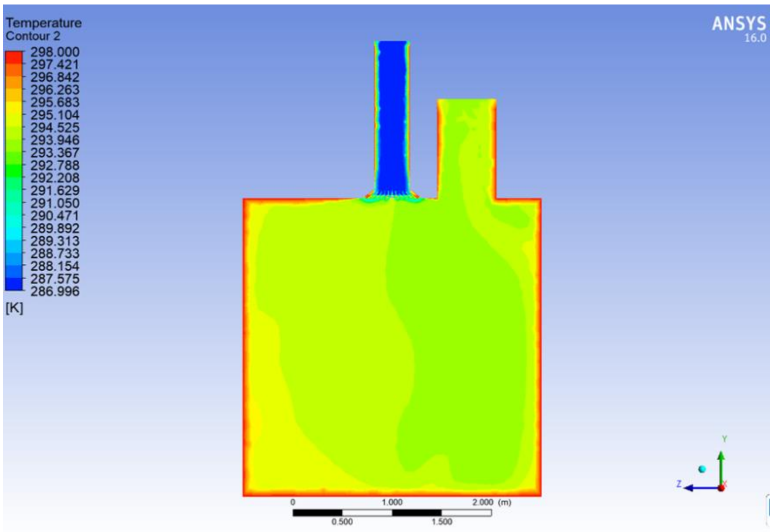

Figure 18: Temperature distribution of 7-blades air diffuser (ceiling outlet)

Table 2: Range of velocity magnitude, Y velocity and static temperature distribution within the room with the bottom wall outlet

Item	4-blades	5-blades	7-blades
Velocity Magnitude (m/s)	0 – 0.46	0 – 0.13	0 – 0.12
Y-Velocity (m/s)	-1.617 – 0.312	-1.617 – 0.317	-1.528 – 0.272
Static Temperature (K)	288.74 – 291.05	291.63 – 293.36	291.71 – 293.73

Table 3: Range of velocity magnitude, Y velocity and static temperature distribution within the room with ceiling outlet

Item	4-blades	5-blades	7-blades
Velocity Magnitude (m/s)	0 – 0.22	0 – 0.22	0 – 0.22
Y-Velocity (m/s)	-1.535 – 0.409	-1.629 – 0.395	-1.509 – 0.381
Static Temperature (K)	291.4 – 293.6	292.1 - 293.8	293.4 - 295.1

4. Conclusion

In a nutshell, the room with the bottom wall outlet and existing 4-blades round ceiling air diffuser shows the problem of uneven air distribution. Due to the fact that the 4-blades round ceiling air diffuser failed to distribute the air in multiple directions and angles. Therefore, high volumetric airflow at the central span of the room was observed and identified via CFD simulation. Subsequently, CFD simulation of 5-blades and 7-blades round ceiling air diffusers has reduced this problem significantly. The temperature and air distribution for both diffusers were well distributed in the room within a small range of average temperature.

A 7-blades round ceiling air diffuser would be the first choice since it can diversify the air in more directions. In reality, inlet velocity or temperature can be different due to external issues or settings, 7-blades round ceiling air diffuser could provide stable and uniform air flow distribution compared to a 5-blades round ceiling air diffuser.

For a room with a ceiling outlet duct, the 4-blades round ceiling air diffuser has a completely different result as there is no concentration of airflow in the central span identified during the CFD simulation. This may be due to the reason that the ceiling outlet duct has affected the airflow in the room. Furthermore, 4-blades and 5-blades round ceiling air diffusers show similar CFD results, with similar average velocity and temperature distribution. Whereas, a 7-blades round ceiling air diffuser is not suitable to install in a room with a ceiling outlet duct because most of the air was concentrated on the central and right sides of the room. There is very less airflow on the left side of the room. Therefore, those occupants standing on the left side of the room might feel uneven temperature feeling. In short, 4-blades and 5-blades round ceiling air diffusers are both suitable to be selected, while 7-blades round ceiling air diffuser performance is poorer.

Acknowledgement

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