

Airflow Analysis of Air Conditioning System for Lecture Hall: Study Case – Block G3, UTHM

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Abstract: Supply air from diffuser must be directed in such a way that the air reaches all the zones in the room without stagnant areas being present. Different arrangements of diffusers specifically using square ceiling type in a lecture room were studied. Three different arrangements of diffusers (existing, Design 2, Design 3) were simulated in computational fluid dynamics (CFD) using ANSYS FLUENT software to analyze the effect on airflow distribution. The CFD simulation was focused on the effect of airflow velocity and temperature distribution in a lecture room at occupied zone by different diffusers' arrangements. Existing diffusers arrangement has average airflow of 0.018 m/s and average temperature of 301.6 K distribution in occupied zone which is the most suitable arrangement. Design 2 diffusers arrangement has average airflow of 0.017 m/s and average temperature of 301.76 K distribution in occupied zone. Design 3 diffusers arrangement has average airflow of 0.014 m/s and average temperature of 302.84 K distribution in occupied zone. The existing arrangement of diffusers has achieved relatively more uniform air distribution than the other two arrangements in occupied zone; hence, it has suitable spread and better airflow behavior that can also save energy consumption.

Keywords: Airflow distribution, Air conditioning, CFD analysis, Square ceiling diffusers

1. Introduction

In order to maintain the comfortable level in a building, the airflow distribution of air conditioning must be efficient. Computational Fluid Dynamics (CFD) allows simulated distribution of airflow, temperature and more in the whole environment, which is extremely difficult to achieve from studies owing to the time and costs involved [1]. The advanced building design can be achieved by gathering information about the airflow behavior in the building's spaces as well as the rooms [2]. HVAC system is an important part of providing thermal comfort and healthy indoor air quality for residential buildings, apartment buildings, hotels, offices, hospitals, factories and so forth. A complete HVAC system consists of chiller, boiler, pump, refrigeration tower, air ducting, piping, exhaust air ventilator, fresh air ventilator, grill and diffuser. At the end of the ducting, diffuser is mounted to disperse cold or hot air through a given region [3]. It is usually installed in the places where the height of the ceiling is about 2 to 3 m high [4].

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2. Methodology

BKB1 (G3) lecture room model was sketched using SolidWorks 2019 software. There were 4 square ceiling diffusers and 2 grilles in total installed on the ceiling. Three design arrangements of diffusers are proposed as in Fig. 1.

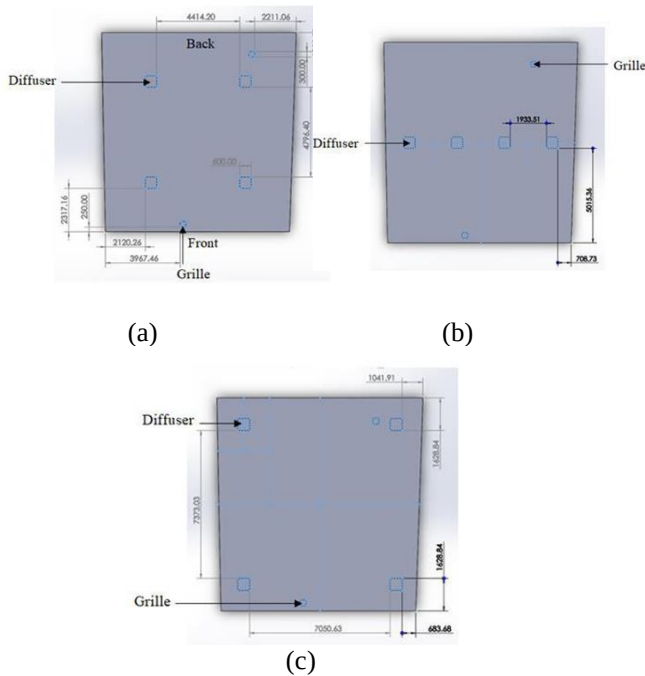


Fig. 1 - Arrangement of diffusers on ceiling layout plan of BKB1 lecture room (a) existing (b) design 2 (c) design 3

Fig. 2 shows the entire lecture room's airflow domain for geometry modeling. Design specifications are tabled in Table 1.

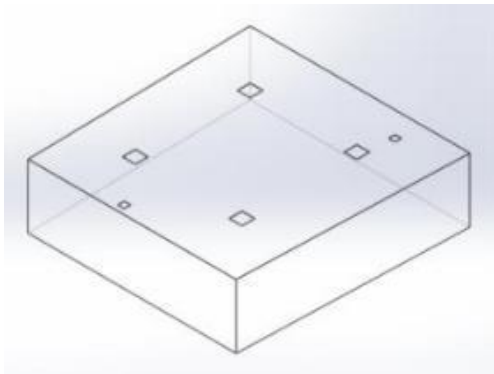


Fig. 2 - The geometry model of lecture room

Table 1 - Model specifications

Item	Name	Dimensions (L x W x H)
1	Room sizes	10 m x 10 m x 3m
2	Diffuser (inlet)	0.6 m x 0.6 m
3	Grille (outlet)	0.3 m x 0.3 m

In this study, the lecture room is divided into 25 grids in which every gridlines that cross each other are marked as grid points 1 to 16 at sitting level of 0.59 m height as in Fig. 3 where grid points 1 to 12 are significant because at that point, the space there is occupied with students.

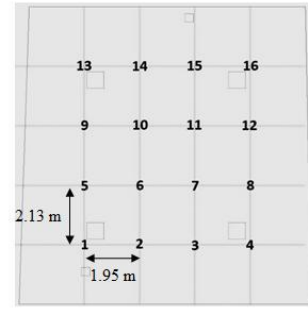


Fig. 3 - Location of grids at points 1 to 16

2.1 Meshing

The ANSYS 19.2 program was used in this analysis, and this edition has been updated to simplify meshing setup. The element order was linear for default settings, with an initial element size of 0.0574 m. In the present study, verification process and Grid Independence Test, element sizing in global mesh is adjusted until the mesh quality check is relevant. Fig. 4 shows the fine meshes from lecture room, ceiling diffusers and grilles created for air distribution model.

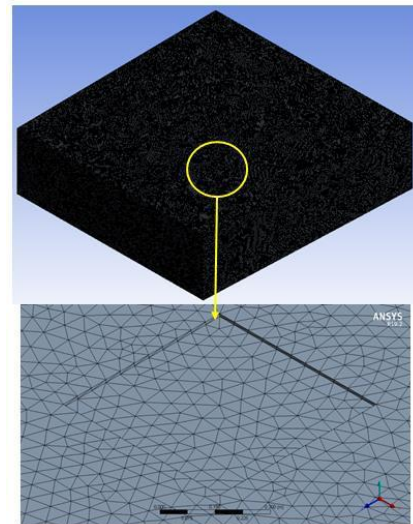


Fig. 4 - Fine mesh generated for lecture room model and zoomed view of square ceiling diffuser

2.2 Boundary conditions

Table 2 displays the operating boundary parameters used during the simulation.

Table 2 - Boundary operating conditions

Parameter Name	Value
Velocity inlet	0.19 m/s
Temperature inlet	291 K
Gauge pressure outlet	0 Pa
Backflow total temperature outlet	313 K
Wall heat transfer coefficient	5
Wall free stream temperature	313 K

2.3 Grid independence test

The temperature was chosen as a reference parameter to determine the independent mesh-convergence solution. Table 3 shows the results of GIT for the existing arrangement of diffusers. As seen in Figure 4, the temperature profile along the line drawn vertically at the center of the lecture room was plotted, with different element size for verification where the trend line for all the tests are seen to be significantly the same.

Table 3 - Mesh independency check for diffusers at existing arrangement

Diffuser arrangement	Test	Elements	Temp. (K)	Dev. (%)
Existing	Mesh 1	567710	302.95	-
	Mesh 2	578214	302.08	0.29
	Mesh 3	588221	302.79	0.24
	Mesh 4	598555	302.54	0.08
	Mesh 5	609952	302.40	0.05

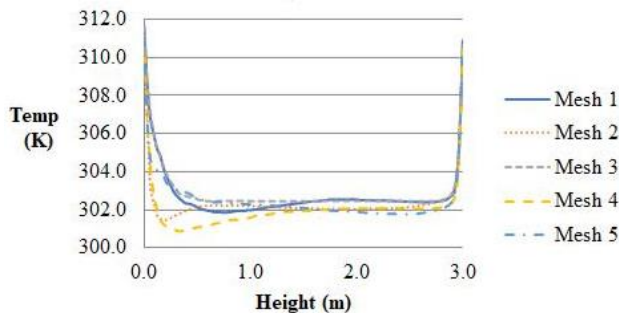


Fig. 5 - Temperature profile of different element size along vertical line at center of lecture room

3. Results and Discussion

3.1 Data verification

For verification purpose, the result of the journal [5] used to verify the new simulation is referred. In one of the analyzed rooms, which is Room 2, it indicated the minimum temperature. The outcome of the journal is contrasted with the data collected for verification. The minimum temperature value in the outcome of the verification simulation is 292.96 K while the minimum temperature value in journal simulation is 295.05 K. For both studies, the relative error is 0.71%. The simulation of verification is therefore accurate since the relative error in verification data is less than 10% [6].

3.2 Airflow distribution for different diffusers arrangement (Sitting level)

From Fig. 6, the contour of existing diffusers arrangement indicated that the airflow ($0 - 0.03$ m/s) was equally distributed by each diffuser at sitting level in the lecture room. There was a rapid airstream ($0.04 - 0.06$ m/s) concentrated along at the middle of the lecture room might be due to combination of four air patterns resulting in high volumetric downward draft.

The design 2 diffuser arrangement contour suggested that the airflow ($0 - 0.03$ m/s) was spread evenly at the sitting level in the lecture room on a long vertical lane. There was therefore a strong airstream ($0.04 - 0.06$ m/s) localized in each lane between the lecture room diffusers. In that case, the occupants at those lanes will feel discomfort due to a higher continuous airflow applied to their body. The contour of design 3 diffusers arrangement indicated that the airflow ($0 - 0.02$ m/s) was equally distributed from the edge by each diffuser at sitting level in the lecture room. The rise of the velocity peak ($0.04 - 0.06$ m/s) at that sitting level might be due to the development of huge mixing downward draft and swirling effect came from four counter flow and it happened because of the Coanda effect of air distribution at which the airflow clung to ceiling and approached to wall.

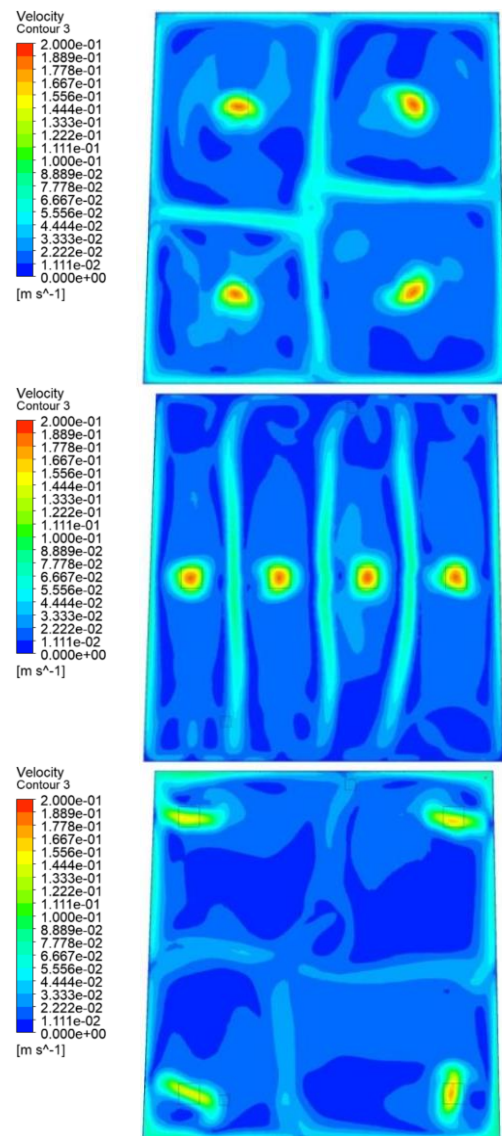


Fig. 6 - Top view of lecture room for velocity contour at sitting level

Fig. 7, the contour for existing diffusers arrangement indicated there was some portion of colder air (296.7 – 299.0 K) distributed in the region below one of the diffusers due to the airflow that tends to flow in the direction of the grille that is located at the back of the room at that region. The design 2 diffuser arrangement contour suggested that an even colder air (296.7 – 297.8 K) is distributed below one of the middle diffusers could be due to the tendency of the airflow to flow to the front grill direction. The contour for design 3 diffusers arrangement can be observed that the air temperature near the ceiling was colder compared to the middle region in the lecture room at which the cold air discharged from inlet through blade of diffusers had clung on ceiling then turn horizontally via wall.

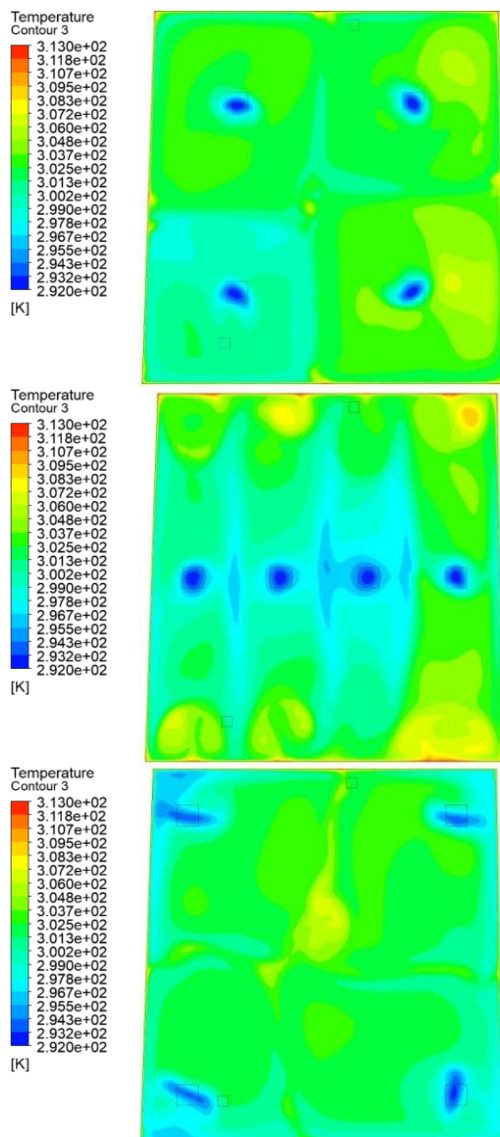


Fig. 7 - Top view of lecture room for static temperature contour at sitting level

3.3 Temperature difference at significant grid points

Based on Table 4, students sitting at grids 1 to 4 will feel the most comfortable with existing arrangement of diffusers, followed by design 3 and the least comfortable with design 2. This is because at these grids, existing diffusers arrangement has the fastest airflow (0.023 m/s) and coolest temperature (300.78 K) with even distribution of airflow and temperature. Because of diffusers arrangement at the edge of the lecture room, design 3 cools down mainly the edge of the room, so, the velocity of airflow decreases and so do temperature when it reaches the other regions. Design 2 is the least optimum because comfortable temperature does not reach these grids because of the arrangement of diffusers in the middle.

At grids 5 to 8 and grids 9 to 12, design 2 arrangement of diffusers has the fastest airflow (0.024 and 0.016 m/s respectively) and coolest temperature (300.08 and 300.2 K respectively). However, design 2 is not ergonomic as its arrangement of diffusers along the middle of the lecture room only allows air to flow efficiently at the middle region, causing the air to flow very slow and carry warm temperature once it reaches the adjacent regions. Cooled air that is mainly distributed at the center of the lecture room can cause discomfort to students sitting there.

At grids 13 to 16, students do not occupy these grids. Existing diffusers arrangement has the fastest airflow (0.02 m/s) and coolest temperature (301.88 K) with even distribution of airflow and temperature. Because of diffusers arrangement at the edge of the lecture room, design 3 cools down mainly the front edge of the room while design 2 comfortable temperature does not reach these grids.

Table 4 - Comparison of airflow distribution for different arrangement of diffusers at sitting level

Different arrangement of windows at sitting level						
Room		Average values				Sitting level plane
		Grids				
		1 - 4	5 - 8	9 - 12	13 - 16	
Vel. (m/s)	Existing	0.023	0.017	0.011	0.020	0.018
	Design 2	0.013	0.024	0.016	0.012	0.017
	Design 3	0.017	0.015	0.008	0.019	0.014
Temp (K)	Existing	300.7	301.4	302.3	301.8	301.6
	Design 2	303.7	300.1	300.2	303.1	301.8
	Design 3	302.4	303.3	302.8	303.1	302.8

4. Conclusion

In conclusion, the current arrangement of diffusers that is being used in lecture rooms at G3 is the best possible arrangement for fair airflow distribution compared to Design 2 and Design 3 as the existing arrangement of diffusers provides consistent air distribution in the lecture room where this arrangement has achieved relatively more uniform air distribution than the other two arrangements in occupied zone, hence, it has suitable spread and better airflow behavior that can also save energy consumption. Based on the suitable position of diffusers, this indicates that the installation and placing of diffusers in lecture rooms at G3 follow ACCA specifications for HVAC system.

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