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Investigation of combined ventilation in the comfort conditions of an isolated room

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ABSTRACT

An air conditioning system is characterized as a device that controls the air's temperature, flow, and humidity within a specific space. If an air conditioning system can guarantee that a room is comfortable, then it functions well. The influence of the ceiling ventilation air flow speed on the ventilation performance in a room with a mixed ventilation system will be researched in order to improve the indoor air quality and create a comfortable and healthy atmosphere. This investigation has assessed the properties of air dispersion and evaluated the factors and conditions outside the classroom. These variables include temperature, relative humidity, air speed, and CO_2 content. The average relative humidity of the air exhibits a similar pattern to that of the average CO_2 concentration, beginning to decline as air input via the valve increases. Furthermore, CO_2 content is a primary determinant of indoor air quality; numerical simulation results are used to assess its value in relation to people's mouths and noses. Because of its distance from the flow source, the air velocity distribution near the ground is minimal and falls within the advised thermal comfort range. The room's air temperature is managed by the existing ceiling air conditioner, which enters the space at a 45-degree angle. An excellent combination of appropriate room air quality conditions and energy conservation can be accomplished by utilizing the ceiling cooler and the ventilation system's airflow rate.

1. Introduction

People spend over half their lives indoors, with indoor air quality causing most illnesses. This concept has persisted since the 1850 health movement and the 1960s' shift towards outdoor environments. The situation is influenced by energy sources, permanent structures, and outdoor air quality, but evidence suggests serious illnesses are caused by inadequate indoor air [1]. Indoor air quality (IAQ) is crucial for human life as it impacts health conditions and the non-industrial environment. Improving IAQ can reduce the incidence of allergies, bronchitis, and lung cancer. The efficiency of ventilation systems in removing contaminants from the interior is essential. Poor IAQ can lead to

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low productivity, sick building syndrome, and lower academic performance, affecting occupants' comfort, health, and wellbeing [2]. The model suggests that most people are comfortable at temperatures around 24.2 °C, with variations depending on activity. It handles air velocities greater than 0.2 m/s, allowing 0.8 m/s without local control and 1.2 m/s with local management. This enhanced air movement raises the office space temperature in summer to 30 °C [3]. An inhabited space is defined as having an effective draft temperature between -1.5 and +1K and an air velocity less than 0.35 m/s. This is referred to as the ADPI [4]. The air change rate is the ratio of air introduced or evacuated from a space divided by its volume, determining the frequency of air changes per hour in a given area. The air change rate is the ratio of air in a space divided by its volume, calculated based on the number of times air is replenished per hour. The nominal time constant in a ventilated zone is determined by the ratio of space volume to air volume airflow rate, or the mass air content to air flow rate, and is equal to the air change rate [5]. Concentration measures the volume of gases like carbon dioxide, oxygen, or methane in the air, with popular units being parts per million and percent concentration. A 1,000 ppm concentration indicates 1,000 carbon dioxide molecules [6]. Carbon dioxide, a naturally occurring gas, is measured in ppm and is typically found in outdoor air. Indoor concentrations are typically higher in buildings due to human activity. The amount of ventilation required for schools and offices is typically specified by ASHRAE Standard 62, with classrooms and offices requiring 15 and 20 cfm of outside air per person, respectively. However, these rates may change due to ASHRAE Standard 62's ongoing changes [7]. Bamodu et al.'s study on thermal comfort in a 4-way cassette air conditioner-equipped office room found that efficient regulation of HVAC systems can lead to energy savings and increased occupant comfort, as buildings account for 40% of global energy consumption [8]. Lim et al. conducted a study on airflow in classrooms using computational fluid dynamics (CFD) and compared various turbulence model types. They found that the RNG k-turbulence model outperformed the Reynolds stress turbulence model in predicting airflow, making it suitable for comparison [9]. Emmerich et al.'s study examined indoor CO_2's impact on ventilation and indoor air quality (IAQ) standards. The study expanded to include CO_2 concentrations' impact on building occupants, perception of bioeffluents, and use of indoor CO_2 concentrations to predict ventilation rates [10]. Bamodu, Oluleke, et al. studied the use of a 4-way cassette air conditioner in Eastern China for cooling-mode office ventilation, comparing it to a wall-mounted mixing ventilation system and comparing interior climates using CFD [11]. Houri et al. conducted research at Tottori University in Japan on indoor air contamination in classrooms. They monitored CO_2 content and used an infrared ray absorption-type CO_2 monitor to assess air quality. They found that non-ventilated rooms had CO_2 levels exceeding the Japanese government's maximum of 1,500 ppm. Unventilated rooms with closed doors had excess air. Fan ventilation reduced CO_2 levels during lectures, but in subsequent lectures, they exceeded the norm due to a lack of ventilation. The study suggests the need for ventilation during lectures [12]. Simone and Olesen conducted an experiment in a simulated home room with radiant floor heating and cooling and mixing ventilation systems to determine the impact of modest ventilation rates on thermal comfort and ventilation efficacy. They monitored air temperature, operational temperature, and air velocity profiles to determine thermal comfort. The study found that low floor temperatures were necessary to maintain the ideal reference temperature in the stratified thermal environment [13]. Mahyuddin and Alshitawi's experiment examined the distribution of CO2 in classrooms and its impact on various circumstances. They found that higher CO2 concentrations could indicate insufficient ventilation and that CO2 levels influence the dynamic relationship between population, activity levels, and occupancy times. The study also examined the effects of ventilation strategy and airflow rate on CO_2 accumulation and distribution [14]. Guangyu et al. conducted tests on ventilation efficiency and airflow distribution systems to assess effective methods for air distribution. They identified eight ventilation strategies but did little research on other aspects. They created five indices to assess air exchange rate, removal of pollutants and heat, air spread, and air exchange effectiveness [15]. Although there are many models in the literature study, the previous literature review demonstrates that there have been numerous studies focusing on various methods for cooling and ventilating space and improving indoor air efficiency. As a result, this study aims to evaluate the performance of a new model mathematically and by taking into account various conditions, student numbers, and heat loads, as well as the impact of cooling and ventilation. This study aimed to improve indoor air quality and thermal comfort in offices, factories, and workshops in the hot and dry Iraqi climate. It used two types of ventilation systems (mixing and displacement) combined with a personal ventilation system. Numerical tests were conducted to predict temperature distribution, air movement, and speed in a thermally isolated room. Results showed a positive effect of the personal ventilation system in both cases, with a more pronounced effect in the first case [16]. The study investigates the impact of adding a ventilation system with impinging and personal ventilation on thermal loads in a thermally isolated office room using sandwich panels. The results show an improvement in heat levels near the thermal manikin and a small difference between the main source of ventilation and heat at 1.8 meters. The research aims to prove the efficiency of this system in Iraqi summer weather, achieving energy savings and providing respiratory and thermal comfort, thereby promoting sustainable development [17]. The apparatus and boundary conditions in this investigation are new. To ensure efficient removal of pollutants and modification of air quality, the ventilation performance will be assessed based on the indoor CO_2 concentration.

2. Numerical Simulation

In order to forecast parameter distributions, this study combines a numerical simulation effort to track the airflow in a model room. The following assumptions form the basis of the numerical work in this study.

1. Steady flow
2. Three dimensional
3. Newtonian fluid
4. Incompressible fluid
5. Air is the working fluid and behaves as an ideal gas.

A finite volume method for continuity, momentum, and energy equations was used in computational fluid dynamics (CFD) to solve a three-dimensional (k-ε) turbulence model that controls the turbulent flow in a room and it is the most suitable model for the cases. Using the values of k and ε, the amount of turbulence viscosity can be calculated at any point of the solution field. Figure 1 show the test room that have been simulated.

Figure 1: Test room.

2.1 Room geometry

A model lecture hall with lights, a lecturer, a table, and students as a thermal load was employed as the room model in this case study. The lecture room's components—students, lighting, lecturer, and table—are first built in Solidworks to create a three-dimensional solid model, which is then used to generate the geometry for the computational model. Three factors that lead to the lecture hall were examined and modeled. All models were meshed using ANSYS 17.0 software and FLUENT code to get them ready for a solution stage.

2.2 The model

Every human body was represented as a cylinder with a cap, measuring (0.3D × 1.2H) m^2. People were represented by a cylinder with a surface area of 1.5 square meters, a height of 1.2 to 1.6 meters, and a constant state thermal load of 100 watts based on the average height of a seated adult. The table is assumed to be adiabatic because, under steady-state conditions, its surfaces will be almost identical in temperature to the fluid surrounding it. Under conditions of comfort and gradient, no further heat from the space's interior temperature is allowed to move vertically. Every occupant's metabolic rate is calculated to be 60 W/m^2. The rate at which CO_2 was released from human mouths was calibrated to be 0.01 grams per second (g/s), or 0.31 liters per minute, or 0.005 liters per second. An idle person's exhaled breath contains roughly 4-5 percent CO_2. The ASHRAE standard 62-1-2013 recommends a temperature of approximately 34 ^oC and a relative humidity of approximately 95% when someone exhales while performing light work.

2.3 Mesh independency

This update has resulted in the addition of new mesh pieces and ways to connect them (how cells are connected to one another). Numerous solver strategies emerged because of CFD analysts' access to increasingly sophisticated algorithms and potent computers as the field developed [18]. The most basic mesh classifications are based on a mesh's degree of connectivity or the kind of components it comprises. The most prevalent forms of 3D mesh elements are hexagons (sometimes called hexes or hex components), tetrahedra, square pyramids (often called pyramids), and extruded triangles (also known as wedges or triangular prisms). A 3D mesh's nodes do not always need to be on the same plane. It is important to notice that the faces from the earlier 2D elements surround each of these items. Several recent solvers also handle polyhedral components with arbitrary numbers and types of faces.

The final point in a well-constructed mesh is the total number of cells. A substantial number of cells is needed for high resolution, but the memory required rises with the number of cells. Current computational resources allow the solution of over 5 million cells on a Windows platform with two CPUs. For the current cause, many meshes containing 5.3 million cells were obtained.

Table 1: The different number of elements with average of air parameters and CO_2.

Type of mesh	Number of elements	Skewness	Air temperature °C	CO_2 concentration ppm	Air velocity m/s	Humidity ø
Corse mesh	2352551	0.208	26.1	751	0.33	42.4
Fine mesh	5358357	0.205	26.6	760	0.34	43
Percentage difference			1.8%	1.1%	2.9%	1.3%

2.4 Navier-Stokes Equations

Newton's second law of motion serves as the foundation for the fluid flow equations determining momentum (the conservation of momentum). The Navier-Stokes equations are what are referred to as the "instantaneous equations for an incompressible fluid," and they are more logically represented in Cartesian tensor notation.

$$\frac{\partial(\rho uu)}{\partial x}+\frac{\partial(\rho vu)}{\partial y}+\frac{\partial(\rho wu)}{\partial z}=-\frac{\partial p}{\partial x}+\mu\left[\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right] \quad \dots (1)$$

$$\frac{\partial(\rho uv)}{\partial x}+\frac{\partial(\rho vv)}{\partial y}+\frac{\partial(\rho wv)}{\partial z}=-\frac{\partial p}{\partial y}+\mu\left[\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right]+S_{bj}$$

$$\frac{\partial(\rho uw)}{\partial x}+\frac{\partial(\rho vw)}{\partial y}+\frac{\partial(\rho ww)}{\partial z}=-\frac{\partial p}{\partial z}+\mu\left[\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right] \quad \dots (2)$$

Where *u*, *v* and *w* are stream-wise, lateral and vertical velocity component respectively. *X*, *y* and *z* are the corresponding directions. S_{bj} is the buoyancy source or sink term.

2.5 Boundary Conditions

The flow and heat variables at the model's boundaries are established by the boundary conditions. It must be precisely defined because it is an essential component of the FLUENT simulation. The boundary conditions applied in the present work are those shown in Table (2) which shows the thermal conditions in detail.

Table (2) Boundary conditions.

Room dimensions	(3 m×2.5 m× 2.3 m)
Dimension of computer table	(1 m ×0.6 m ×0.8 m)
Occupants dimension model	(0.3 dimeter×1.2 high) m
Dimension of lecture lights	2 lamp light = (0.1 m ×1 m)
Dimension of grill inlet top	(0.3 m ×0.3 m)
Dimension of supply ceiling cassette 4way	(0.05 m ×0.5 m)
Dimension of suction ceiling cassette	(0.5 m ×0.5 m)
Dimension of duct outlet bottom	(0.3 m ×0.3 m)
Dimension of computer	(0.4 m ×0.3 m ×0.1 m)
Door dimensions	(0.8 m ×1.8 m)
Nose diameter	(0.012 m)

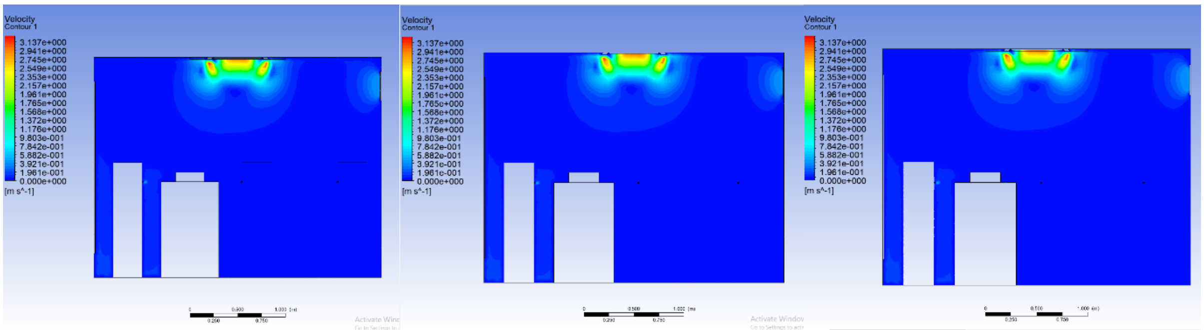
3. Results and Discussion

The results obtained from typical interior spaces with various air-cooling modes by ceiling-type 4-way cassette air-conditioners, ventilation strategies, and contamination sources were numerically studied. The findings indicate that utilizing a numerical code that necessitates verification and validation of the output can benefit from being able to modify these parameters.

For the first case study, the statistics in the space are computed using the ceiling air conditioning system, which is running at a flow rate of 1512 m^3/h and a supply temperature of TS (21 ^oC). The fresh air ventilation system has been turned off, and there is no air infiltration and no air change rate. For the first case study, the data in the room are calculated for the second case study by running the ceiling air conditioning system at a flow rate of 1512 m^3/h and a supply temperature of TS (20 ^oC). The fresh air ventilation system is now functioning. The flow rate is 135 m3/h, and the air change rate is 7.8 h/h. The third case study runs the ceiling air conditioning system at a flow rate of 1512 m3/h and a supply temperature of TS to calculate the data for the area (19 ^oC). The ventilation system for fresh air is currently operational. The flow rate is 171 m3/h, and the air change rate is 9.9 per hour. When compared to the findings from the laboratory, the results' accuracy is respectable.

3.1 Air velocity distribution

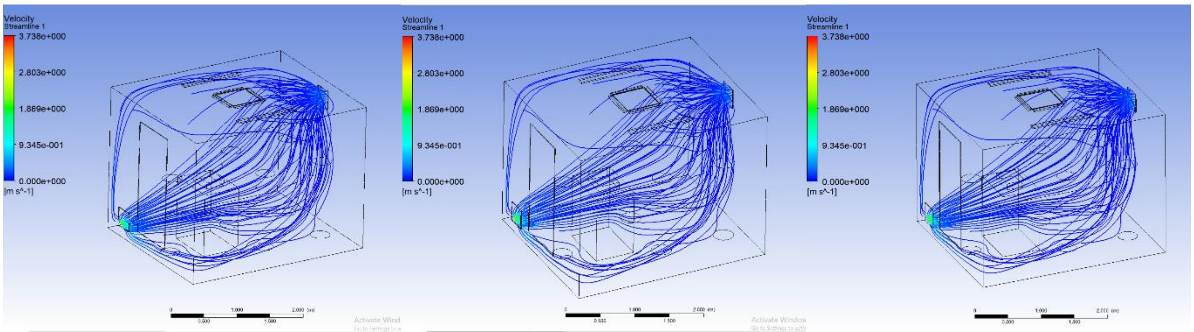
The simulation's air velocity profile was derived using the experimental data's input velocity. Furthermore, the air velocity within the chamber was examined at various heights and places. By moving the sensors' point of reference, four positions and five heights were recorded line by line in this simulation. The vertical air velocity simulation results at the three temperatures are shown in figure 2. With the exception of the level closest to the ceiling, line 1's air velocity was lower than that of the other line. The air from the ceiling airflow inlet is to blame for it. In general, lower levels have lower velocities than higher ones. Low-altitude air distribution was impacted by ceiling ventilation; the anticipated outcomes of the air velocity profile were previously covered in the section on the air temperature profile, which resulted in a drop in temperature at these altitudes.



19 °C 20 °C 21 °C

Figure 2: Velocity contours at 0.4 ventilation velocity.

Since air velocity aids in sweat evaporation and produces a cooling sensation, it is a crucial thermal comfort metric. On the other hand, if too much of it is provided, it may feel drafty. Generally, one wants an average air velocity of less than 0.15 m/s. The air velocity in every instance toward the top of the room at above two meters is noticeably higher than 0.15 m/s, according to the velocity streamlines of the simulated scenarios displayed in figure 3. However, given that the air supply inlet is situated there, this is to be expected. The patterns demonstrate how the air conditioner's thrown air is directed toward the walls as it approaches the occupied area and then returns to the center of the space. The air velocity falls off significantly as it approaches the occupied zone and reaches the target range. Building on the above observation, the supply inlet air velocity has little effect on thermal comfort in this environment and, therefore, could be taken into consideration for energy reduction, e.g., by reducing fan speed; however, the impact of this choice on air quality may need to be taken into account.

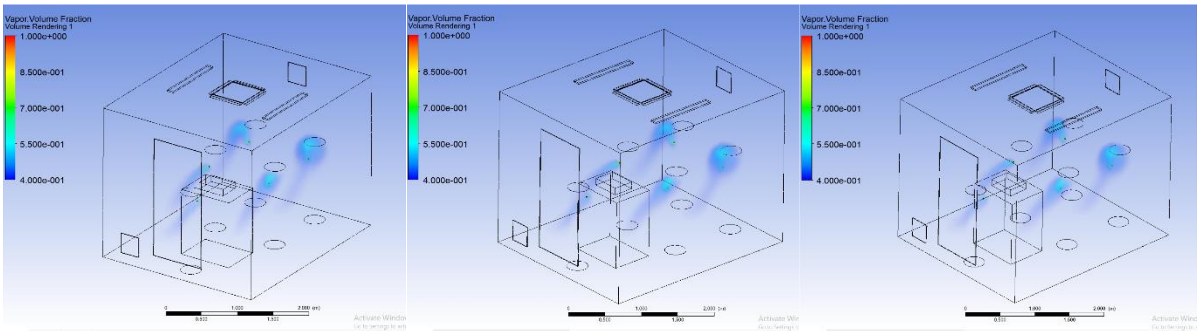


19 °C 20 °C 21 °C

Figure 3: Velocity streamlines at 0.4 ventilation velocity.

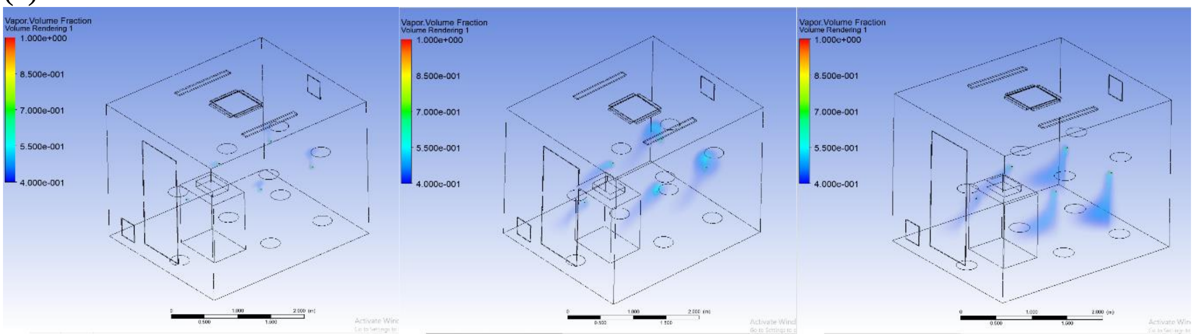
3.2 Vapour concentration

Figure 4 shows the volume fraction for the vapour through the room. Using different temperatures and ventilation velocities throughout the simulations, the results were extracted.



19 °C 20 °C 21 °C

(a)



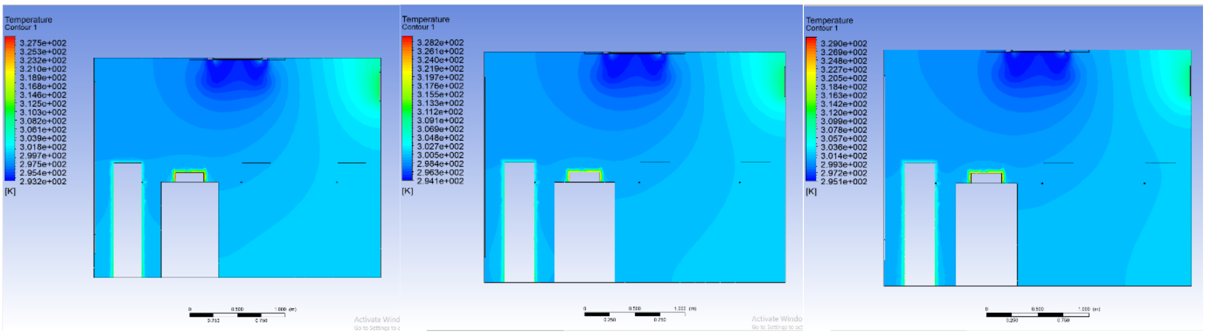
19 °C 20 °C 21 °C

(b)

Figure 4: Vapor volume fraction at a: 0.4 ventilation velocity and b: 0.5 m/s ventilation velocity.

3.3 Temperature pattern

Figure 5 displays the patterns of temperature distribution for the simulated instances. The patterns indicate that the lower-temperature air is placed below and the higher-temperature air is located at the top of the room, above the inhabited zone. In circumstances where the supply temperature is higher, this is more noticeable. Lowering the 4-way cassette air conditioner's supply temperature will improve thermal comfort because thermal stratifications cause poor thermal comfort. Furthermore, lowering the supply temperature will improve energy efficiency and perhaps save energy.

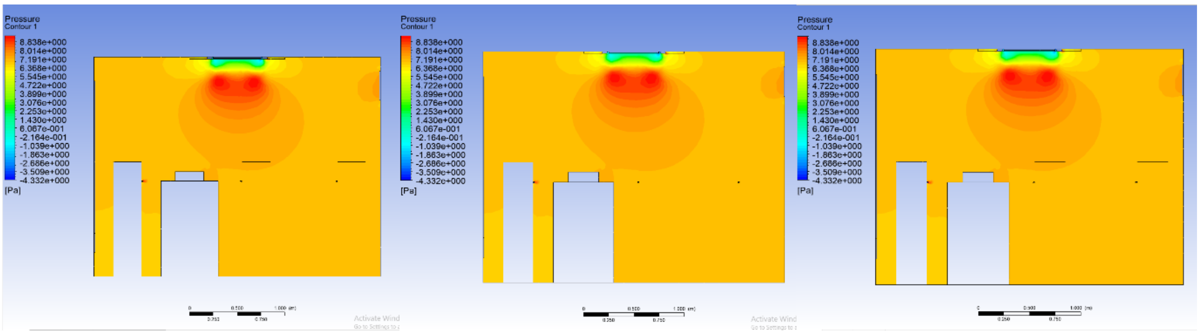


19 °C 20 °C 21 °C

Figure 5: Temperature contours at 0.4 ventilation velocity.

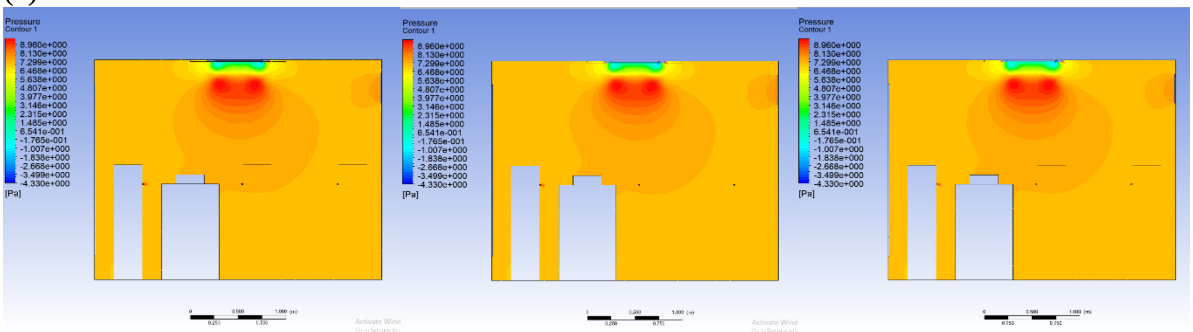
3.4 Pressure pattern

Figure 6 shows the pressure contours through the room. Using different temperatures and ventilation velocities throughout the simulations, the results were extracted.



19 °C 20 °C 21 °C

(a)



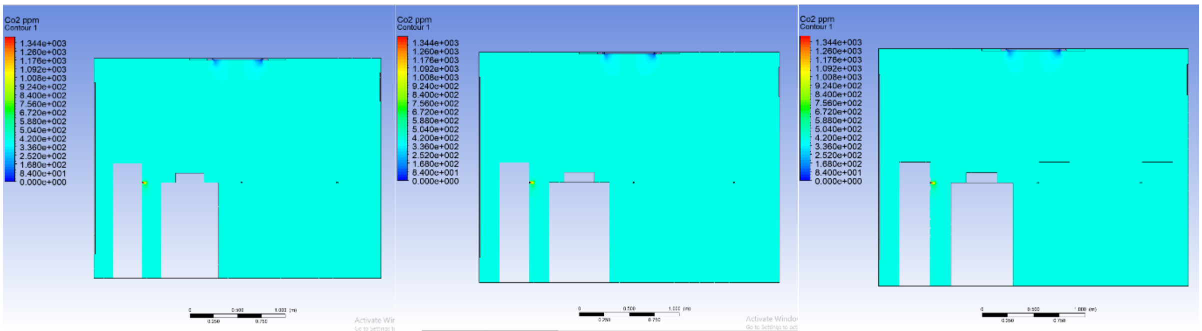
19 °C 20 °C 21 °C

(b)

Figure 6: Pressure contours at a: 0.4 ventilation velocity and b: 0.5 m/s ventilation velocity.

3.5 CO_2 concentration distribution

Based on the distribution of CO_2 content in the space, it was able to evaluate the indoor air quality using the results it had gathered. Figure 7 displays the contours of carbon dioxide concentration for a chosen vertical and horizontal plane for each of the three breathing models. It is evident that the local CO_2 distribution in the room is the only factor influenced by the breathing model selection. The area above and close to the person had the largest differences in CO_2 concentration across the models taken into consideration. There are minor variations in carbon dioxide's spatial distribution in the upper portion of the space. Furthermore, a stratification of the room's CO_2 concentration was noted. Although it was anticipated that the larger CO_2 concentration would be found at the bottom of the chamber, it is concentrated in the upper portion of the space. Since the air that humans breathe out mixes relatively little with the surrounding air due to natural convection, there is a minor amount of temperature and CO_2 distribution stratification. This stratification is generated by the greater temperature of the air that humans breathe out. The temperature and air velocity are two other factors that affect indoor air quality.



19 °C 20 °C 21 °C

Figure 7: CO_2 concentration at 0.4 ventilation velocity.

4. Conclusions

The research focuses on air change rate, pollution removal efficiency, and temperature removal efficiency for designers. The study applied a numerical model to a classroom with a vertical split, revealing a lack of thermal comfort and a negative impact on students' and lecturers' health due to stale air, unpredictable temperature, and velocity distribution. The method was used to examine ventilation and cooling system behaviour within a room zone and the key results are:

1. The air's velocity and temperature are two other factors that affect indoor air quality. Indoor air quality is primarily determined by CO_2 concentrations and can be improved by effective ceiling device mixing. Based on the distribution of CO_2 content in the space, the results enabled us to evaluate the indoor air quality. The contours of carbon dioxide concentration for a chosen vertical and horizontal plane for each of the three breathing models It is evident that the choice of breathing model only affects the room's local CO_2 distribution. The area closest to the person and above the person showed the largest differences in CO_2 concentration between the models under consideration. In the top portion of the space, there are slight variations in the spatial distribution of carbon dioxide.
2. In addition, there was a stratification of the room's CO_2 concentration. The upper portion of the room has a concentration of more CO_2 than anticipated, even though the lower portion of the room should have the highest concentration. The reason for this stratification is that human breath has higher temperatures than the surrounding air. This leads to a modest distribution of CO_2 and temperature stratification because the air mixes very little with the surrounding air under natural convection conditions.
3. The laboratory results demonstrated that even though the room temperature could be adjusted to a desired level by using the ceiling-mounted cooling system, the air quality in the room would not be at a desirable level, and the concentration of carbon dioxide in the majority of the rooms would be higher than 100 parts per million. It has a bad vibe about it.
4. The concentration and humidity of the air have been greatly decreased with the usage of air ventilation; this value was lowered to 16 percent.
5. Additionally, there was a rise in the average room temperature in the first example of 0.8 degrees and the second case of nearly 2 degrees.

Remaining gas may be utilized for ventilation system testing, sample collection, virus ratio awareness, and comparison with the particular degree of infection to safeguard speakers from dangerous infectious illnesses that might be shared with passengers. The Ministry of Health can prepare a weakened influenza virus that can be used to inject this system into space.

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