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Design And Simulation Of Covid Diagnostic Room For A Hospital

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ABSTRACT

As a result of the respiratory illness 2019-nCoV, a deadly coronavirus family (2019-nCoV) has spread around the world and become a pandemic threat. Sneezing, coughing, and speaking generate virus-containing droplets, which are then inhaled or touched. 2019-nCoV can also be spread through the air if an infected person is in a closed environment. Using conditioned air discharged from air-conditioning equipment in combination with aerosol sanitizer to treat the covid diagnostic room and eliminate the 2019-nCoV virus, this study examines the effectiveness of this approach. Alternative bed arrangements for the covid diagnostic room were considered. A transition SST k-model, consisting of four transport equations, is used in the current work to numerically simulate laminar-transitional flows. Using strong turbulence fields created in the covid diagnostic room to distribute sanitizer across the entire volume of the covid diagnostic room is effective at killing 2019-nCoV.

Keywords: Covid diagnostic, Ventilation, Air conditioning, CFD, Simulation

1. INTRODUCTION

Global pandemic of 2019-nCoV, a severe respiratory disease caused by a coronavirus (2019-nCoV) [1]. A contagious virus, it is spread by inhalation or contact with nuclei of droplet nuclei smaller than 5 micrometres in size that are produced by infected individuals while sneezing, coughing, or even speaking. The mucosae of the nose, mouth, and conjunctiva of the eyes of people who are in close contact with a confirmed 2019-nCoV patient or an active carrier of the virus can accumulate exhaled droplets. By direct or indirect contact with fomites, such as clothing, utensils or furniture touched by or in the immediate environment of the 2019-nCoV patient, the virus can be transmitted. Initial symptoms of the disease are typically characterised by a fever, breathlessness, cough, throat pain, and a general feeling of weakness [2]. Age, lung condition, immunity and socio-demographic profile all contribute to the rapid death of those who are infected with the disease. Several studies have shown that COVID 19 is extremely harmful and that it spreads throughout the world [3].

According to the World Health Organization (WHO), the disease has spread to 212 countries and territories around the globe [4], [5]. Aerosol therapy during treatment of pulmonary critical illness such as asthma, bronchoscopy, Chronic Obstructive Pulmonary Disease (COPD), tracheostomy and other related diseases [6] has also been reported to increase the risk of airborne transmission of 2019-nCoV[7]. Virus-containing droplets present in the air, as well as coughing and sneezing aerosols, serve as a vehicle for the transmission of disease [7, 8]. The respiratory system's infectivity is also affected by relative humidity, temperature, rainfall, etc. [9].

Medical authorities have not yet approved any specific treatment, medication, therapy, or vaccine for 2019-nCoV because its characteristics are not fully understood. Infected individuals have a 2-3% mortality rate; older individuals and children as well as those with a prolonged illness and low immunity are at greater risk. Travel bans, complete lockdowns, containment zone identification, home quarantines for all citizens and strict monitoring of citizens' movements have been implemented by the medical boards and health administration to combat the spread of 2019-nCoV. Health care and sanitary personnel can also reduce transmission by controlling indoor dust levels and temperature and humidity, improving hygiene, sanitising, wearing masks, and using personal protective equipment (PPE). 2019-nCoV confirmed patients and patients with symptoms must be treated in isolated rooms or separate ICUs in hospitals in order to prevent the spread of this disease. AII stands for "Airborne Infection Covid diagnostic Rooms".

The exhaust air from AIIs is also likely to contain virus particles, so an effective strategy is needed to stop the spread of infection. - Two ICU wards at Huoshenshan Hospital in Wuhan, China, were found to have 2019-nCoV virus genetic material in the air about 4 metres from the affected patients [10]. Defensive measures should be taken to disinfect exhaust air, including HEPA filtration, sanitization and heating [11]. A very small number of studies, however, have focused on the design of an effective ventilation system and the factors that influence room ventilation in order to reduce viral transmission[12].

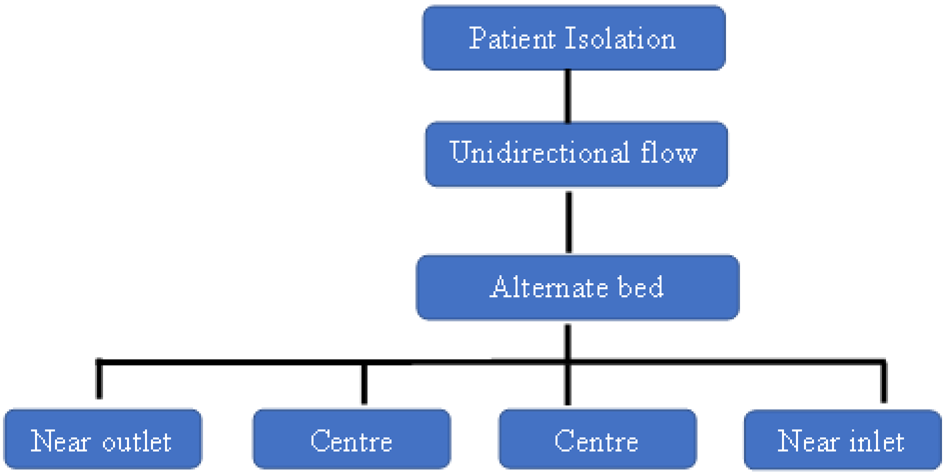

Fig.1. Covid diagnostic room of hospital

Due to airborne or droplet contact diseases, the risk of infection for hospital staff is higher. Numerous researchers studied air quality, comfort, and HVAC system performance [13] in different types of buildings using computational fluid dynamics (CFD) models. To investigate airflow and contaminant dispersion in rooms where many parameters are involved, this is a very robust and efficient tool to use. An airborne particle tracking CFD analysis may be used to simulate and determine a control strategy for the trajectory of infectious particles moving in the air[14]. As medical treatments are often ineffective, it is reasonable to investigate the possibility of sanitising the confined volume of air in airborne infection covid diagnostic rooms and intensive care units (ICUs) in hospitals. Aerosolized sanitization systems can be designed to effectively sanitise the air inside the room used to treat 2019-nCoV patients. Doctors, nurses, and other health care workers must be protected at all costs. To date, however, no work has been published on this topic. Aerosol sanitizer delivery systems are described in this paper, which maximise the effectiveness of conditioned air released from an air-conditioning machine by mixing with aerosol sanitizer and isolating every corner of the room.

2. METHODOLOGY

Fig.1 displays the flow chart of the hospital's covid diagnostic room using four parameters for CFD analysis. Fig. 2 clearly depicts a CAD model of ancovid diagnostic hospital room completely equipped with four patient beds and other physical features (vent, door, sanitizer machine, exhaust vent, etc.). The proportions of the CAD model were obtained from a hospital, which included patient beds, a door, a sanitising machine, and other items. The covid diagnostic room's length, width, and height are 9000 mm, 6022 mm, and 3689 mm, respectively. For grid generation, the fluid volume (air as the working fluid) is taken from the CAD model. These fluid quantities are then subdivided into different control volumes. Specific dimensions of the covid diagnostic room, hospital beds (2120 mm x 970 mm x 2122 mm), door (1285 mm x 1022 mm), exhaust vent (1700 mm x 300 mm), sanitising machine (375 mm 322 mm), and air conditioning vent (1000 mm x 1000 mm) were taken into account for the CFD simulation work in the current study. The proposed approach, on the other hand, can be effectively used for any alternative shape of physical facilities in the hospital covid diagnostic room.

Table-1. Thermo-physical properties of the computational domain

Domain	Material	Density Kg m^{-3}	CP J Kg^{-1} K^{-1}	Thermal conductivity W m−1 K−1	Viscosity Kg m^{-1} s^{-1}
Fluid	Air	1.225	1006.43	0.0242	1.789E−5
Walls	Calcium carbonate	2788	853	2.23	-
Bed	Steel	700	2310	0.173	-
Body	Approximate to human bones	1800	3470	0.45	-

Patient Body Approximations: The patient's body provides a constant source of sensible heat at approximately 70 watts of strength. This equates to approximately 588 W m^3. It was modelled as a 1.76-meter-long, 0.3048-meter-diameter cylinder. To replicate a material similar to human flesh, the density is set at 1780 kg m^3, the specific heat at 3455 J /Kg.K, and the thermal conductivity at 0.32 W /m.K. In order to keep things simple, no other heat sources were considered in this work. The purpose of this research is to imitate the human body in the presence of externally supplied conditioned air at 300 K and 50% relative humidity. The problem is rendered transitory, and as such, it is solved until a stable state in terms of net heatexchange over the entire area is achieved (Table 1).

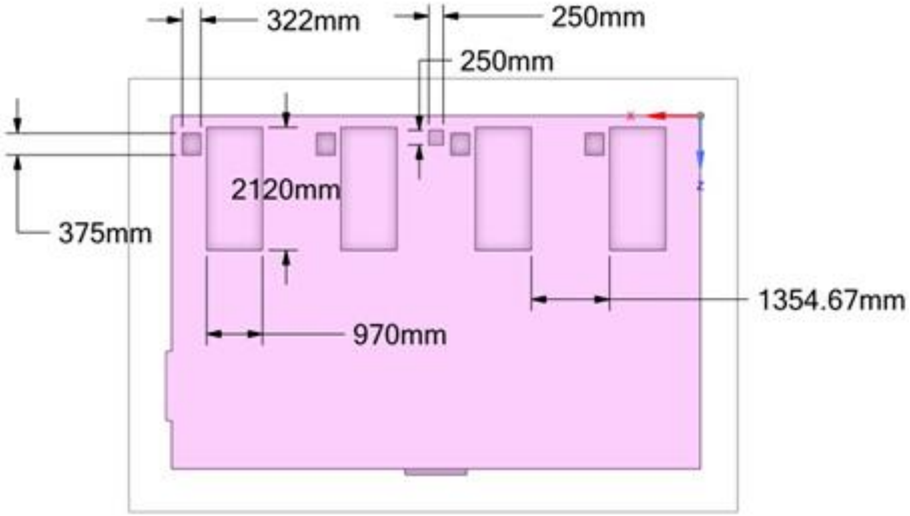

Fig.2. Covid diagnostic room of hospital

Fig.2 depicts the grid generation of several control volumes, which include four patient beds, a door, an exhaust vent, a sanitising machine, and an air-conditioning vent. These models are created using tetrahedral and hexahedral pieces. The complicated parts are filled with hexahedral meshing, while the remaining parts of the control volumes are filled with tetrahedral meshing. Governing equations such as mass, momentum, and energy equations are solved on each computational element using a finite volume based CFD approach. Boundary conditions are a key requirement for any CFD simulation, and the current investigation is no exception. Fig.3 depicts the mesh model used in the CFD analysis.

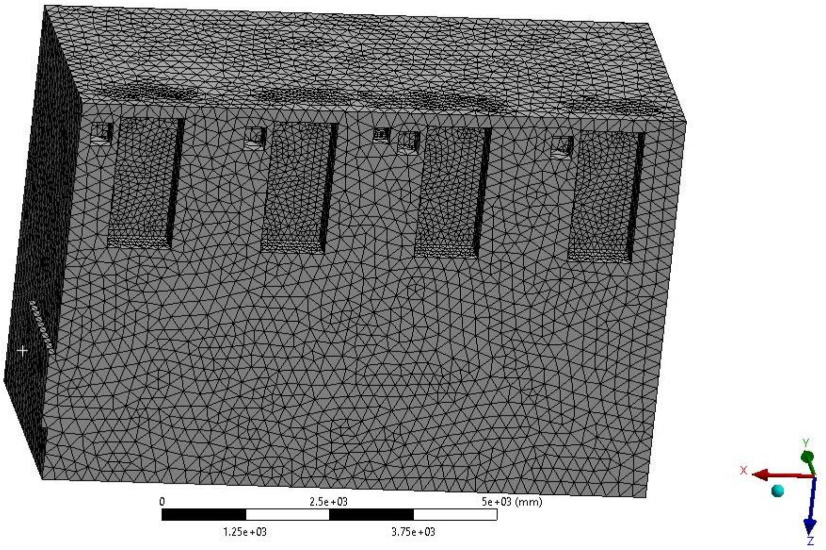

Fig.3. Meshing of a hospital covid diagnostic room

The intake conditions are stated at the covid diagnostic room's ceiling, with a velocity of 3.90 m/s applied uniformly and an inlet temperature of 25 °C. The mass flow rate is 29.77 kg/s. At the ducting system's exit, no-slip, no-temperature jump conditions are used. Similarly, inlet parameters are set at the covid diagnostic room's sanitising machine, with a velocity of 1.45 m/s applied uniformly, an inlet temperature of 30 °C, and a mass flow rate of 1.856 kg/s. Discreteness is required for the numerical solution of any governing equation expressed in a partial differential equation. For this reason, second-order upwind methods with Boussinesq approximation [4] are used. To purify the air in the covid diagnostic chamber using chemical diffusion, it is necessary to simulate both the diffusion and the natural ventilation process, which incorporates pressure forces, buoyant forces, and aspects of forced-convection, as well as conductive and convective heat transfer. An unstable CFD study is performed to have a better understanding of the system's flow physics.

In the current study, the transition SST $k - \varepsilon$ model, which contains four transport equations, is used to numerically describe the laminar-transitional flows[15]. This particular transition SST $k - \varepsilon$ model is composed of the SST $k - \omega$ model and two additional transport equations, one developed for the transition onset criteria and the other for flow separation induced transition, in terms of momentum thickness. For the first time, Reynolds number created the SST $k - \omega$ turbulence model to successfully combine the precise formulation in the near-wall region where positive pressure gradient exists[16]. The four transport equations that were utilised are listed below.

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho k u_i) = \frac{\partial}{\partial x_j}\left(\Gamma_k \frac{\partial k}{\partial x_j}\right) + \widetilde{G}_k - Y_k + S_k \qquad (2.1)$$

$$\frac{\partial}{\partial t}(\rho \omega) + \frac{\partial}{\partial x_j}(\rho \omega u_i) = \frac{\partial}{\partial x_j}\left(\Gamma \omega \frac{\partial \omega}{\partial x_j}\right) + G_\omega - Y_\omega + D_\omega + S_\omega \qquad (2.2)$$

$$\frac{\partial(\rho\gamma)}{\partial t} + \frac{\partial(\rho U_j \gamma)}{\partial x_j} = P_{y1} - E_{\gamma 1} + P_{\gamma 2} - E_{\gamma 2} + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\gamma}\right)\frac{\partial \gamma}{\partial x_j}\right] \qquad (2.3)$$

$$\frac{\partial(\rho \tilde{Re}_{\theta t})}{\partial t} + \frac{\partial(\rho U_j \tilde{Re}_{\theta t})}{\partial x_j} = P_{\theta t} + \frac{\partial}{\partial x_j}\left[\sigma_{\theta t}(\mu + \mu_t)\frac{\partial \tilde{Re}_{\theta t}}{\partial x_j}\right] \qquad (2.4)$$

3. RESULTS & DISCUSSION

CFD models are widely accepted and utilised in many buildings to explore thermal comfort, indoor air quality, room load, HVAC performance, and so on. CFD is one of the most versatile and powerful technologies for studying fluid flow (air as the working fluid) and pollutant dispersion in the comfort zone.

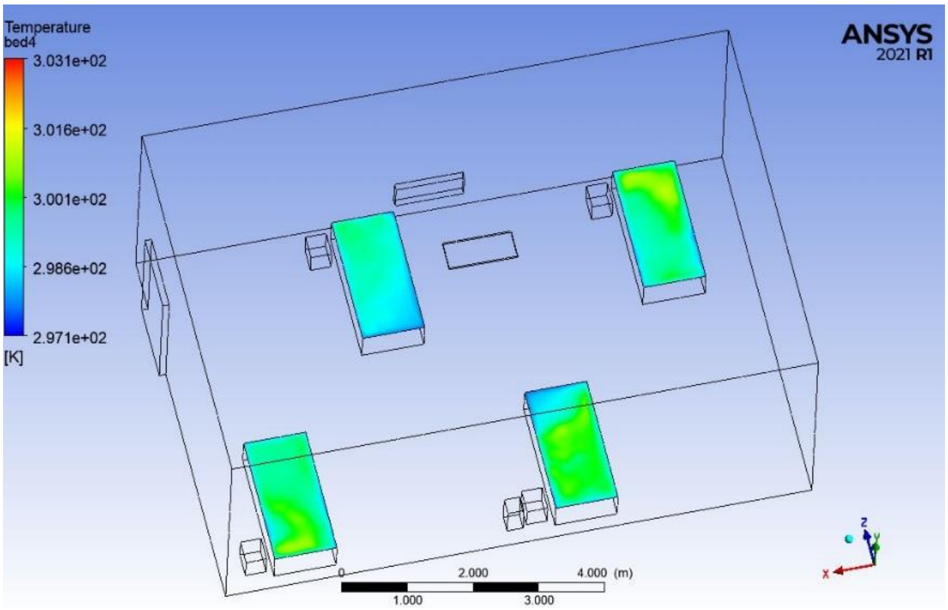

Fig.4. Temperature on bed inside covid diagnostic room

The temperature on bed inside the covid diagnostic room in shown in Fig.4. Maximum temperature on the bed lies in between 300.1 K to 301.6 K. And velocity stream line inside the covid diagnostic room is shown in Fig. 5. Maximum velocity inside the covid diagnostic room is witnessed as 6.892 m/s.

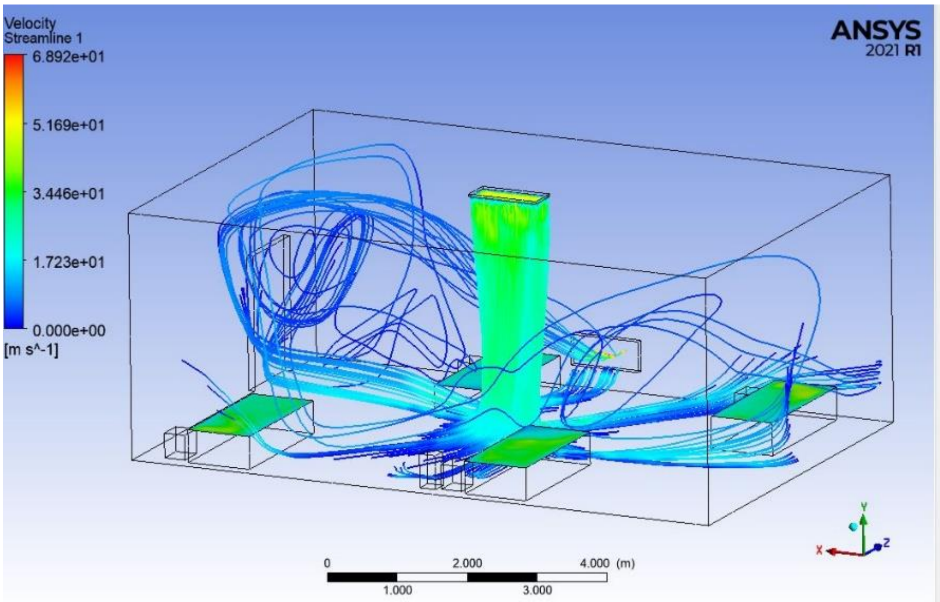

Fig.5. Velocity streamline in covid diagnostic room

In this study, a computational technique is applied. This study is too computational to analyse the flow characteristics of the sanitizer-laden conditioned air inside the room, which is necessary for disinfecting the room air and thereby protecting the lives of doctors, nurses, and healthcare professionals.

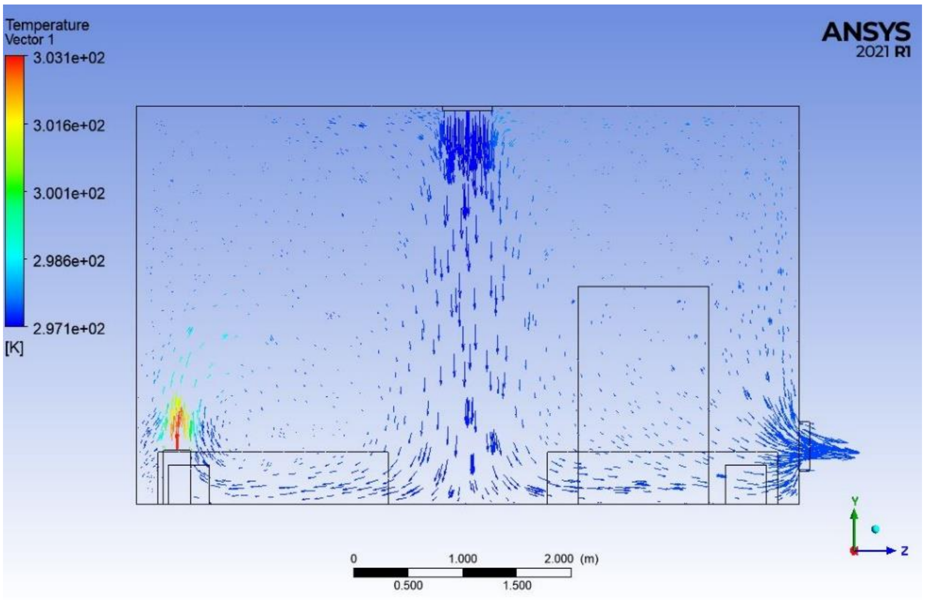

Fig.6. Scaled temperature vector

Fig.4 depicts the sections' intake and output. The current numerical model and methodology are tested against published experimental and numerical works [17] before investigating the fluid dynamics/pattern of hospital covid diagnostic room shape. Fig.4 shows the computational domain and velocity at various locations in the proposed room, and it is clear from the figure that it has extremely high agreement with the experimental and numerical published data.

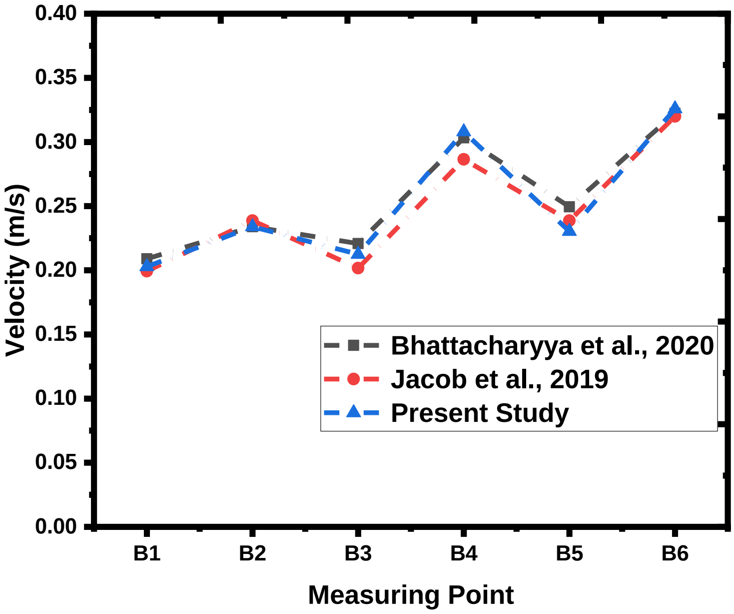

Fig.7. Velocity distribution at various locations inside chamber (4 m X 3 m X 2.5 m) for inlet supply velocity 1.36 m s^{-1}

In a transient flow, the time step is the incremental change in time for which the governing equations are being solved. The time step in the current computation is varied from 250 to 1200-time steps, with a time step size of 0.01 s, and the flow visualisation results are shown in Figs. 5 and 6. When the sanitizer machine is not running, streamlines develop from the top of the covid diagnostic room (isometric view) ventilation at different time instants. These figures show that the streamlines are sliding downhill, producing an impact on the patient beds as well as the covid diagnostic chamber floor. Following that, the flow striking the floor rebounds and extends towards the walls. Another view (from the top) of the ever-changing streamlines is shown in Fig. 6. These statistics indicate that the fluid flow that influences the covid diagnostic hospital room started from the clean air openings (vents) located at the top of the covid diagnostic room (ceiling), regardless of the direction of observation.

Fig. 5 depicted the flow visualisation findings obtained after simulating over 1200-time steps for various time instants. When compared to Figs. 5 and 6, it is clear that the changes in the streamlines are minimal, despite numerous CFD simulations. This result adds to the previously given results and suggests that time step independence has been achieved. It is clear from the above figures and discussion that concerns about flow unsteadiness have been established, and full consideration now turns to a deeper investigation of the temperature, turbulent kinetic energy, and flow dynamics for the simulated covid diagnostic hospital room when both air-conditioning vent and sanitising machine work together. The time-averaged non-dimensional temperature contour figure in Fig. 6 depicts the temperature distribution in the covid diagnostic room when both the air-conditioning vent (24 °C) and the sanitising machine (30 °C) are operational. According to Fig. 6 (refer to the right side of the image), the sanitising machine emits sanitizer at a significantly higher temperature, which mixes with the cool air from the air-conditioning vent. Because of the velocity and temperature differential available between the flows of the sanitising machine and the air-conditioning vent, better mixing is achieved. The cool air coming from the air-conditioning machine at the top of the covid diagnostic chamber has an asymmetric pattern due to the influence of the sanitising machine's velocity and temperature gradient.

Fig.5 depicts the velocity vectors showing instantaneous velocity field while both the AC vent and the sanitising machine are operational, and this is a planar section image of the 3D field. The velocity vectors are shown in magnitude order; consequently, larger velocity vectors indicate quicker fluid flow. The flow from the top (downward flow) likewise slows down as it comes into contact with the other flow, as seen in the image (sanitizer, horizontal flow). It has also been observed that when the flows collide with the walls, they both slow down slightly. Flow circulation and large-scale eddies were discovered as a result of the mixing of fluxes between cool air and sanitizer, as well as due to bounding walls. It is predicted that the entire covid diagnostic room air will be cleaned owing to thorough mixing of cool air and sanitizer, and that this sanitising by volume will also ensure that the covid diagnostic room is totally virus free and the occupants (patients) can stay comfortably. Fig.7 displays the velocity distribution with 5 measuring points and compares it to prior investigations. The new study is related to prior investigations. These findings and unique notion could be used to help flatten the 2019-nCoV curve.

4.CONCLUSION

When dealing with 2019-nCoV, the primary goal is to manage and prevent the virus's transmission rather than to treat and cure people who are affected. To protect the lives of healthcare workers, it is critical to reduce the danger of airborne virus transmission in hospital covid diagnostic rooms to the bare minimum. Simultaneously, it is necessary to maintain a low enough infection level in order to control the rising prevalence of 2019-nCoV. This study was carried out to determine how the airflow patterns in the covid diagnostic chamber. The purpose of this investigation was to see if conditioned air emitted by air-conditioning equipment paired with aerosol sanitizer could mix with the 2019-nCoV virus and eradicate it from the covid diagnostic room. A CFD analysis was undertaken to acquire a better understanding of the effects of variables like as temperature, turbulent kinetic energy, and flow dynamics on aerosol sanitizer delivery systems. In order to numerically describe the laminar-transitional flows, transition SST k −ε model, which requires four transport equations, the current work applies four equations. The results reveal that large turbulence fields formed in confinement covid diagnostic rooms help to disperse sanitizer and kill or decrease the 2019-nCoV virus. Ans also alternate bed arrangements shows better results when compared to any other bed arrangements in ancovid diagnostic room

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