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CFD Investigation of a Hospital'sIsolated Clean Room's Air Flow Pattern and Particle Transport

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ABSTRACT
Globally,Coronavirusspreadcausesconcernandworryamongsocietyatlarge,inparticularamonghealthcareworkers as they are at an increased risk for infection. It is aninfectious virus that transmits through inhalation or contactwith droplets that are produced by people who are infectedwhen they sneeze, cough, or speak. COVID-19 can also betransmittedbyairbornemeansinaconfinedenvironmentwithin the immediate environment of the infected person. Thisstudy has been conducted to determine whether conditioned airreleasedfromairconditionerscanbemixedwithaerosolsanitizer toreach every corner of the isolationroom and killtheCOVID-19virus.Thisstudyconsidersseveralfactorsaffectingaerosolsanitizerdeliverysystemssuchastemperature, turbulent kinetic energy, and flow dynamics thatweretakenintoaccountduringtheComputationalFluidDynamics (CFD) analysis. In this CFD study, the problem ishandled with the SST k–ε model which involves four transportequations.Fromtheanalysis,itwasconcludedthathighturbulentfieldsgeneratedinsidetheisolationroomcould efficientlydistributesanitizerintheisolationcleanroomspacetoreduceorkilltheCOVID-19virus.

Keywords:COVID-19,Airborne,Conditionedair,Isolationroom, Turbulent kinetic energy, Clean room, ComputationalFluid Dynamics(CFD

I. INTRODUCTION

Covid-19isavirusthatcausesillnessesrangingfromthecommon cold to more serious illnesses including Middle Eastrespiratorysyndrome(MERS)-CoVandsevereacuterespiratorysyndrome(SARS)-CoV(Andrewsetal.,2020).Coronavirus is a positive single-strand enveloped, RNA virusranging from 60 nm to 140 nm in diameter, it is a large familyofvirusesanditcomesunderthesubfamilyofOrthocoronavirinae, it is because of the “crown-like” spikes ontheirsurface(Wu,ChenandChan,2019).2019-nCoVinfection,namedCOVID-19isafifth-categorynotifiablecommunicable disease that originated in Wuhan at China onDecember 31, 2019. 98.6 % fever, 69.6 % fatigue, and 59.4 %dry cough are the common symptoms of early clinical causesfrom Wuhan, China. The spread of COVID-19 disease is veryfast because within 2 months (December 31, 2019, to February17,2020)1,772deathsand70,635confirmedcasesarereportedin China. In this short period, the diseasewasspreadto 25 other countries along with 794 cases and three deaths [3].The virus was identified and named coronavirus on 7th January2020.Thecoronavirushad>95%homologywiththebatcoronavirusand > 70%similaritywiththeSARS-CoV,(Singhalet al., 2020). Due to the massive spread of thevirus, India and other countries put screening machines in theairport to detect symptomatic people returning from China andother countries and placed them in isolation, and testing themfor COVID-19. It was quickly discovered that the virus may betransmittedfrom asymptomatic to symptomatic personsandevenbeforesymptomsappeared.Asaresult,nationssuchas India,whoevacuatedtheircitizensfromWuhanthroughspecialaircraft,isolatedeveryonewhowassymptomaticand otherwiseforkeptthemunderobservationfor 14daysafter testing. In India, the first case of COVID-19 infection wasreported on January 27, 2020, in Kerala. In Kerala, the firstinfected person is a 20-year-old female who returned to Keralafrom Wuhan city (China) on 23rd January 2020 owing to theCOVID-19outbreaksituationinChina.Dueofhertravelhistory from Wuhan, the district quick response team chose toadmithertoanisolationroomdesignatedforthecoronapandemic.‘Isolationistheseparationofillpeoplewith transmissible diseases from infected persons to protect non-infected persons, and commonly ensues in hospital settings.Generally,anisolationroomcouldalsobeequippedwithnegativepressuretoreducethespreadingofthevirusviaaerosols, but for large droplets like for SARS CoV, there is noneed for a negative pressure room, (Freedman, 2020). If earlydiagnosisispossiblebeforeovertviraldrop,isolationofpatients is very efficient in stopping transmission. Isolation isnotaneffectivestrategytostopthetransmissionofaninfluenzapandemic,itisonlyacontrollingstrategy,itisbecausetheisolationstartsonlyaftertoshowtheclinicalsymptomsorreportthepositiveforthevirus.Similartocommunity transmission, Severe Acute Respiratory SyndromeCoronavirus2(SARS-CoV-2)hasalsocausedhealthcare-associated issues in hospitals, leading to concerns regarding thespreading of the disease. SARS-CoV-2 is transmitted not onlythroughdirectcontactwithdropletsbutalsothroughenvironmentalcontaminationorairbornetransmissionin specificsituations,suchasduringaerosol-generatingprocedures (AGPs). An isolation room is important to reducetheairbornetransmissionofSARS-CoV-2frominfectedpersons to susceptible patients and other persons in hospitals,this room is designed in such a way that it provides appropriateair handling and good ventilation,(Jacob, Yadav and Sikarwar,2019). An isolation room is built and equipped with all of thenecessaryamenitiestoguardagainstvirtuallyallcommonroutesofinfectiousmicrobetransmission,suchascontact,droplet, and vector-borne.The designing and implementation ofan HVAC system for an isolation room is a serious matter, itrequires more care and attention because the most predominantmodeofinfectioncommunicationisairbornetransmission.Generally, there are two types of isolation rooms, one is thenegativepressureroom(Class-N),thisisolationroomisapplicable for those patients who are suffering from infectiousdiseases like TB and SARS. The aim of admitting infectedpersons in Class-N isolation rooms is to reduce transmission ofdiseaseviaairbornetransmission.Positivepressurerooms(Class-P) are another form of isolation room. Positive pressureroomsareconstructedinspecifichospitalstosegregateseriously immune-compromised patients, such as those withAIDS.,(CommitteeandControl, 2007).

To develop a better control strategy for avoiding the furtherspread of SARS-CoV-2 in a hospital room and for the betterutilization of the resources available, it is required to study thetrajectory of infectious particles, quality of air, comfort level,and performance of the HVAC system. Numerical techniquessuchascomputationalfluiddynamics(CFD)toolscanbeutilized for this purpose. Along with advanced particle trackingtechniques and Computational fluid dynamics (CFD), it will beable to study the air quality inside a room effectively. By fixingall parameters such as temperature and mass flow rate of inletair, the bed arrangements can be varied for knowing the bestarrangement of beds. The effect of sanitized air in the room canbefound outbyusingthe particletracking method.

II. SIMULATION METHODOLOGY

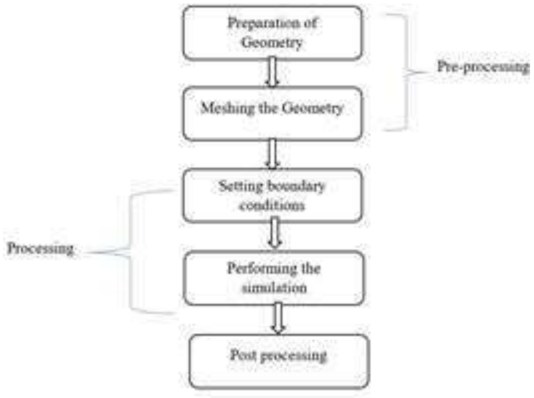
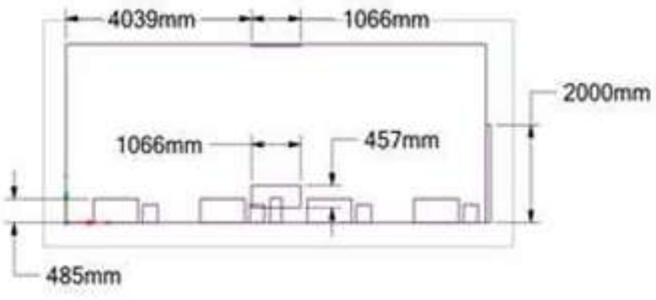
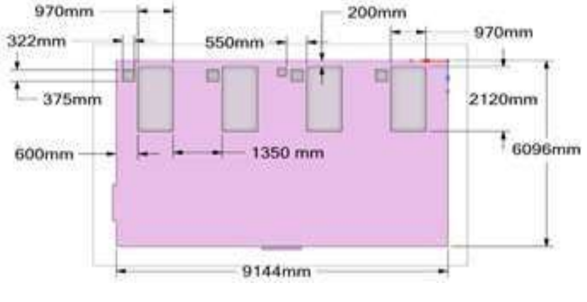


Figure 1: Flow chart of CFD Analysis procedure

Computational fluid dynamics, or CFD, is the computer-basedmodellingofsystemsinvolvingfluidmovement, heattransport, and related phenomena such as chemical reactions.The equations that control fluid motion can be approximatednumericallyusingCFD.Thefollowing steps arerequiredtouse CFD to analyse a flow problem. The fluid flow is firstdescribedusingmathematicalequations.Asetofpartialdifferentialequationsisgenerallyused.Afterthat,theequations are discretized to give a numerical equivalent. Afterthat,thedomainissplitintolittlegridsorelements. Finally, theseequationsaresolvedusingtheinitialandboundary conditions of the specific problem. The technique of solutionmight be either direct or iterative. In addition, the method'sconvergence, stability, and accuracy are all controlled by a setof control parameters.Therearethreemain elements inallCFDcodes:(1)Apre-processorthatinputstheproblemgeometry, generates the grid, and defines the flow parameterand boundary conditions for the code. (2) A flow solver, whichis used to solve the flow's governing equations under the givenconditions. A flow solver can utilise one of four methods: I thefinite difference technique; (ii) the finite element method; (iii)the finite volume method; and (iv) the spectralapproach. (3) Apost-processor, which is used to massage the data and show theresults in a graphical and easy-to-read format. Figure 1 showsthebasicstepsofa CFDstudy.

In this work, the isolation room of a hospital was taken as thephysicaldomain.Theisolationroominthathospitaliscategorized as two, namely unidirectional flow room (SplitHVACroom)andmultidirectionalflow room (CentralisedHVACroom).Theunidirectionalflowroomisspeciallycreated as an isolation room to handle the pandemic situation.In this room, only one patient is occupied. The multidirectionalflow room was the actual isolation room in that hospital. Theroom is designed for placing 8 beds but due to the pandemicsituation and the nature of the disease, only 4 beads are placedin this isolation room. Figure 2 shows the dimensions of theCADmodel,whichistakenoriginallyfromthehospitalisolation room. Patient bed, Sanitisingmachine,airinletandair outlet (Ventilation), etc are the main component consideredin the model. The selected isolation room has 9144 mm length,6096 mm width, and 3658 mm height. In this CAD model, thepatient bed has 2120 mm length, 970 mm width, and 485 mmheight. The beds are placed at a distance of 1354 mm. Thesanitizermachine used in the room has 250 mm length, 250mmwidth,and550mmheight.IntheselectedroomtheHVAC inlet vent has 1066 mm length and 457 mm width. Thewent is located at the center of the room at a distance of 3658mmfrom thefloorlevel.Theisolationroom isanegativepressure-maintainedroom,thereisonlyoneoutletventisplaced near the bottom of the sidewall. The length and width ofthe exhaust vent were 1066 mm and 457 mm respectively. Theventisplacedatadistanceof450mmfromfloorlevel.Accordingto(Bhattacharyyaetal.,2020)thebedsarearranged linearly along the length of the room and the oppositeside of the exhaust ventilation. However, the proposed modelcanbemeritoriouslyusedforanyothercombinationofphysicalgeometryandbed allocationinthe isolationroom.





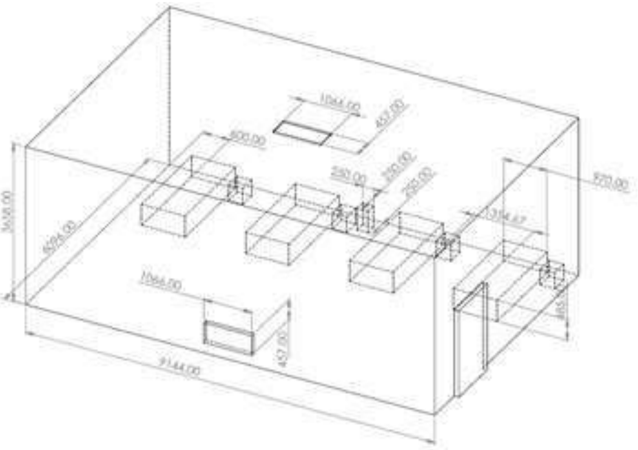


Figure2: SchematicdiagramofPhysicaldomain

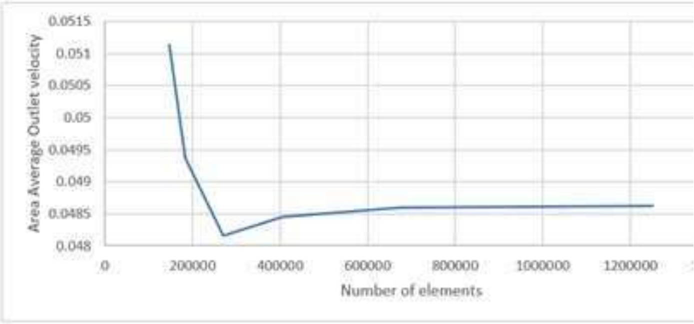


Figure 3: Graphical representation of the mesh dependency study of Element size

Afterpreparingthegeometrythenextstepisgeometrymeshing. The mesh is created for all selected elements thatdirectlyaffecttheresultofthestudy.Herethemeshwascreatedforvariouscontrolvolumesincluding4beds, sanitizing machine, inletvent,and exhaustvent.

There are generally 3 different types of meshes are used likefine mesh, medium mesh, and coarse mesh. The selection ofmesh type is considered based on the problem and requiredaccuracy. In this work, accuracy is the main factor so here tochosefinemesh.Themeshtypedependsuponthemeshelement size. For obtaining a good result there is a minimummesh element is required concerning the element size. Whenthe mesh size increases the required mesh element decrease,which reduces the computation time. But it affects the result.When the mesh size decreases the required mesh element forthe domain gets increased, which increases the computationtime. But to get a good result. The mesh dependency study isoneoftheeffectivemethodstofindtheminimummesh element required without affecting the result. In this problem tochose a fine mesh having a mesh size of 100 mm. Figure 3showsthegraphicalrepresentationofthemeshdependency study having an element size of 100 mm. From the graph, it isclear that after 6 lack the result becomes stable, below that theresult is not accurate and that is not taken for the study. Henceinthisstudytoselect675488elementshavingthe sizeof100mm. Here the meshes are generated with Tetrahedral andHexahedralelements,whichisshownin figure4.

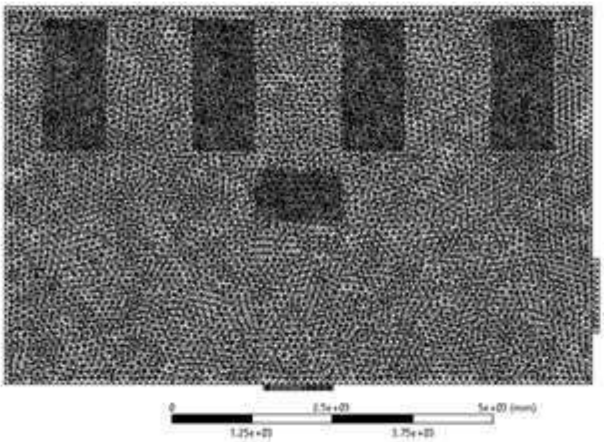


Figure 4: Mesh view of Hospital Isolation room

BoundaryConditionplaysanimportantroleinanyCFD simulation study and the present study like that. The air inlet isplaced at the center of the ceiling of the room with a mass flowrate of 0.029 Kg/s, uniformly distributed in the room with aninlettemperatureof21^0C.Apressureoutletwithgaugepressurezeroisconsideredattheexitductofthesystem. Similarly, the sanitized air coming from the sanitizer machinewas 0.000184 Kg/swith an inlettemperature of 30^0C.Theapplied boundaryconditionsareshowninTable 1.

Table 1: Boundary Conditions

Boundary	**Type**	**Value**	
		Temperature °C	**Mass flow rate** Kg/s
Air inlet	Mass flow inlet	22	20
Sanitizer inlet	Mass flow inlet	30	1.85
Outlet	Constant Pressure outlet	Gauge pressure= 0	
Beds	Stationary no slip wall with constant heat flux	90W/m2	
Walls	Adiabatic		

Governing equations play an important role in CFD study. TheCFD commonly studies the physics of fluidmechanics andthermalscience,forwhichtherearedifferenttypesofequations are considered like Continuity equations,Navier-Stokes equations, and energy equations, these equations areconsidered as the main fundamental governing equation usedfor CFD study(Wah-yen et al., 2017). The above-mentionedequationsarecommonlyusedforstudiesonthefieldofmultiphase flow (Laleh, Svrcek and Monnery, 2011), simplecreeping flow(Joseph, 2006), and Couette flow(Taylor, Transand Lond, 1923), nanofluids motion(Bahiraei, 2016), movingboundariessimulation(DasandCleary,2016), andaerodynamic design having complex geometry (Bai and Wang,2016).ThegoverningequationsaredevelopedfromthefundamentalprinciplesofNewton’sLawsandReynold’stransporttheorem,whichcanbegenerallyexpressedasinintegralform.ThesegoverningequationscanbealsorepresentedintheEulerianapproachforgettingpreciseanalysis (Wah-yen et al., 2017). In this study, the problem ishandled as air circulation in a close environment containingseveralobstacles.Insuchconditionsgenerally,turbulence models were used. The selection of an appropriate turbulencemodel for a particular problem was a difficult task because theselection of turbulence model affect the analysis result. DirectNumerical Simulation (DNS), Large Eddy Simulation (LES),and Reynolds- Averaged Naiver –Stokes (RANS) turbulencemodels are the most commonly used turbulent models (Seriesand Science, 2018) . The Direct Numerical Simulation (DNS)Naiver-Stokesmodelisusedwherethepreciseresultisimportant, here the model is used without any approximation tocompute turbulent flow. When the DNS model is used then tocollect 100% accurate data andalongwith torequire largecomputer capacity. The isolation room is a large enclosed roomhavingmanyobstacles,insuchkindsofproblemstheuseoftheDNSmodelisnotpracticallysuitable,thereisahighReynoldsnumberintheflowfieldwhichneeded highcomputational capacity and time. Generally, the LES modelwas used in the macroscopic structure of the turbulent flow.

BysimulatingtheturbulentflowusingReynolds-AveragedNaiver –Stokes (RANS) model to usen airflow parametersinsteadofinstantaneousflowparameters.Insuchkindofproblem, both LES and RANS models provide good results,even though the RANS K-Ɛ model is widely used in such kindofresearchproblembecauseofitssimplicityandeaseofunderstanding(Series andScience,2018).Oneof themostoften used models for capturing the influence of turbulent flowconditions is the k-omega (k−ω) turbulence model. It is part oftheReynolds-averagedNavier-Stokes(RANS)familyofturbulence models, which simulates all turbulence effects. It's amodelwithtwoequations.Thatmeansinadditiontothe conservationequations,itsolvestwotransportequations(PDEs), which account for the historical effects like convectionand diffusion of turbulent energy. Turbulent kinetic energy (k),which defines the energy in turbulence, and particular turbulentdissipationrate(ω),whichdeterminestherate ofdissipationperunitofturbulentkineticenergy,arethe twoconveyedvariables.Theturbulencescaleisanother nameforit.

III. RESULT AND DISCUSSION

Thisworkistostudythethermalcomfortandindoorairquality in an isolation room of a hospital. The physical study ofsuch kind of problem is very difficult because of its cost, time,andqualityoftheresult.InsuchasituationCFDstudyisoneof the effective methods to study the characteristics of fluidflowandtheparticlesspreadinginaclosedarea.Thisparticular study is to investigate the optimized position of asanitizing machine without affecting the thermal comfort in anisolationroomprovidingHVACventilation.Fourconfigurations are studied in which the sanitizer machine isplacedinlocationssuchas250mm,1500mm,3000mm,4500mm from the longest side wall near the bedside, which isshown infigure 5.

Figure 6 shows thenon-dimensional temperature contourplotin the isolation room when both the sanitizing machine andHVAC system workingtogether. Here themassflow rateoftheHVACsystemandthesanitizingmachinearec onstantthroughoutitsworking,itis20Kg/sand1.85Kg/srespectively. Similarly, the air outlet temperature of the HVACsystem and the sanitizing machine are constant throughout itsworking,itis22^0Cand30^0Crespectively.

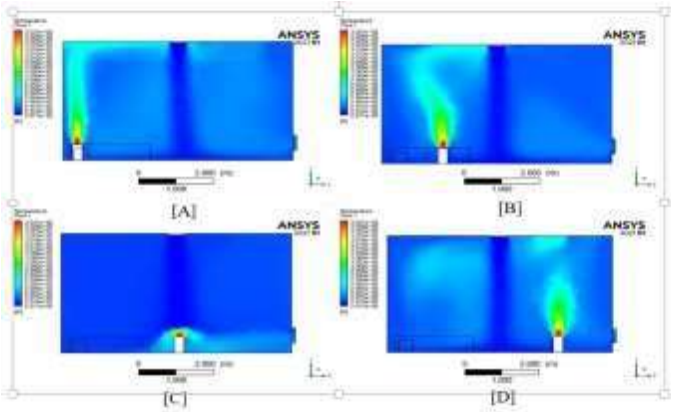


Figure 6: Temperature contour when both the sanitizing machine and HVAC working together (A): Sanitizing machine at 250 mm away from bedside longwall, (B): Sanitizing machine at 1500 mm away from bedside longwall, (C): Sanitizing machine at 3000 mm away from bedside longwall, (D): Sanitizing machine at 4500 mm away from bedside longwall

From figure 6 it is clear that the isolation room maintained astandard air temperature by mixing the sanitizer released fromthesanitizingmachineatwasrelativelyhighertemperaturewith the cool air coming from the air-conditioning vent. Due tothe temperature gradient and velocity, the air coming from thesanitizing machine and HVAC vent become mixed well. Anasymmetric pattern appears in the air coming from theair-conditioning vent from the top of the isolation room because oftheinfluenceofthevelocityandtemperaturegradient maintainedbythesanitizingmachine.Figure7showsthevelocity vector diagram when both the sanitizing machine andHVACworkingtogetheratfourdifferentpositions ofsanitizing machine intheisolationroom.

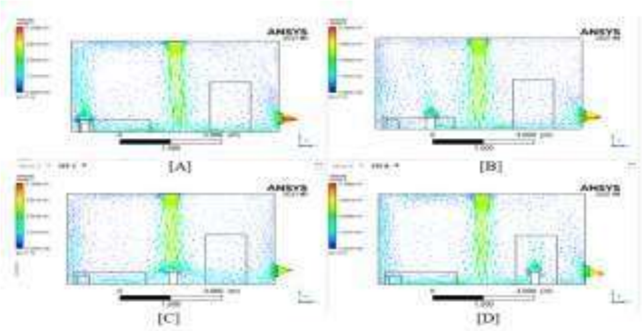


Figure 7: Velocity vector diagram when both the sanitizing machine and HVAC working together (A): Sanitizing machine at 250 mm away from bedside longwall, (B): Sanitizing machine at 1500 mm away from bedside longwall, (C): Sanitizing machine at 3000 mm away from bedside longwall, (D): Sanitizing machine at 4500 mm away from bedside longwall

the velocity vectors are represented in velocity magnitude, thatis the fastest fluid flow represents the larger velocity vector.From the velocity vector, it is clear that the flow from the topHVACventslowsdownwhenitcomesincontactwithsanitizer flow. When both the flows slow down when it strickson the walls. Due to the mixing of sanitizer and cool air andbounding walls, there have to form large-scale eddies and flowcirculation.

Inthesefourdifferentconfigurations,configurationD(Sanitizingmachineat4500mmawayfrombedsidelongwall)is formed through mixing so that the entire air in the isolationroom becomes sanitized without affecting the thermal comfortofthe patients.

Figure 8 shows the turbulent kinetic energy contour plot of themixed air in the isolation room. From these figures, it is clearthat there have two vortices are found and high turbulent zonesareformedinsidetheisolationroom.Theextreme turbulence generatedwithin theisolation chamber represents fullmixingof both airs, ensuring that airborne virus/germs are disinfectedusingthesanitizer-ladenair

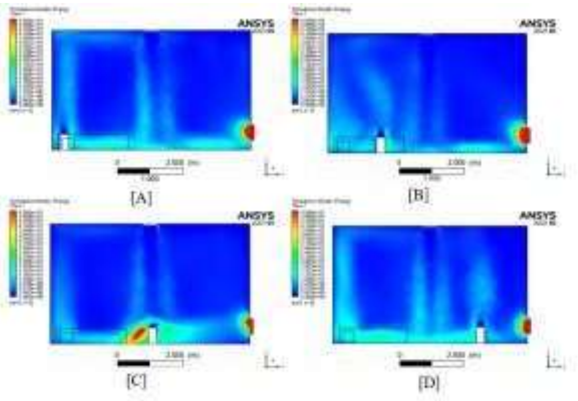


Figure 7: Turbulant kinetic energy when both the sanitizing machine and HVAC working together (A): Sanitizing machine at 250 mm away from bedside longwall, (B): Sanitizing machine at 1500 mm away from bedside longwall, (C): Sanitizing machine at 3000 mm away from bedside longwall, (D): Sanitizing machine at 4500 mm away from bedside longwall

IV. CONCLUSION

Type of patients is one of the major factors that considered thearrangement of an isolation room in a hospital. The isolationrooms for infectious patients and immune-suppressed patientsare different from each other. The infectious patient is thosewhoproduceinfectiousmicro-organismsthroughbreathing,coughing, and sneezing. A TB or a SARS patient would be asuitable example of such kind of patient. Coronavirus disease(COVID-19)isaninfectiousdiseasecausedbytheSARS-CoV-2virus.Whenaninfectedpersoncoughs,sneezes,speaks, sings, or breathes, the virus spreads in minute liquidparticlesfromtheirmouthornose.Largerrespiratorydroplets tosmalleraerosolsareamongtheparticles.Asaresult,a minimum of 1-meter distance between the patient bed and theisolation room ismaintained.In theisolation room toprovidean HVAC system tomaintain goodthermal comfort tothepatients. The disinfection of the circulated air in the isolationroombecomesamajorchallenge.Airsanitizationusingasanitizing machineis one of the suitable disinfection methodsin an isolation room. But the usage of a sanitizing machineaffectsthe thermal comfortofthe room.

This study was performed to understanding the airflow patternsintheisolationroom.Thisstudyhasbeenconductedtodeterminewhetherconditionedairreleasedfrom airconditioners can be mixed with aerosol sanitizer to reach everycorner of the isolation room and kill the COVID-19 virus. Thisstudyconsidersseveralfactorsaffectingaerosolsanitizerdelivery systems such as temperature, turbulent kinetic energy,and flow dynamics thatwere taken into account during theCFD analysis. In this CFD study, the problem is handled withthe SST k–ε model which involves four transport equations.Accordingtothefindings,strongturbulence fieldscreatedinsidetheisolationroommaybeaneffectivemeansofdispersing sanitizer in a confined isolation room volume to killorreducetheCOVID-19virus.Fortheparticularselectedisolation room, configuration D (Sanitizing machine at 4500mmawayfrombedsidelongwall)issuitabletogetbetterdisinfection without compromising the thermal comfort of thepatients.

In the future, the same model will be used to study the isolationroom arrangement having any other physical dimensions. Thisstudyfocusesontheisolationroomarrangementforaninfectious patient, but in the future, it also is used to study theisolationroomarrangement forimmune-suppressedpatients

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