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CFD Analysis on the Effect of Acrylic Barriers in Preventing Contagion Spread in a Philippine Classroom Setting Following Quarantine Guidelines

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Abstract *- The resumption of face-to-face classes by the Philippine Department of Education (DepEd) requires a study of the planned measures to mitigate the risk of airborne diseases such as COVID-19. This study used computational fluid dynamics (CFD) streamline analysis to compare air flow in an open-air ventilation classroom that follows the DepEd standards when physical barriers divide individuals inside the room, and a similar setup without barriers. Visual inspection of streamlines generated at inlet speeds of 1 m/s, 2 m/s, and 3.5 m/s, showed that barriers in the setup only prevent airborne contamination if all individuals remain at their assigned positions at all times, without movement to enter, transit, or exit. The barriers facilitate air swirls that pose a risk to individuals who enter these regions of trapped air. Regardless of inlet velocity, the case with physical barriers installed was universally found to be effective in preventing transmission if all movement inside the room is completely restricted but was found have a greater risk of infection if any movement of individuals inside the classroom, whether it be to enter, transit, or exit within the room, is allowed. Thus, the setup without barriers was found to be generally more effective in preventing the spread of COVID-19.*

Keywords: CFD; airflow; COVID-19; barriers; streamline

I. INTRODUCTION

COVID-19 is the term given to the disease caused by the SARS-CoV 2 virus. First reports of the virus emerged during the closing months of 2019 and it spread globally during the early months of 2020 [1]. As a response to the virus, governments worldwide placed drastic measures in order to minimize its spread. However, some of these measures have also brought about negative economic and social effects, as documented in a report by the World Health Organization (WHO) [2]. According to the Centers for Disease Control and Prevention (CDC), the SARS-CoV-2 virus is primarily transmitted through direct contact, droplet or airborne transmission [3]. The virus is spread by infected individuals, and it is very difficult to identify infected individuals as they are often asymptomatic [4].

The COVID-19 pandemic demanded numerous changes in the educational sector particularly in the Philippines, such as the implementation of online learning media as well as pandemic health protocols like physical distancing commonplace in the learning environment

[5,6]. Community lockdowns popularized online learning platforms, which have been found to bring learning challenges due to the struggle in adjusting to the new learning environment [7] and adverse effects on the well-being of students caused by isolation and perceived future uncertainty [8].

In October 2021, the Philippine government announced that it would be reopening schools once again for face-to-face classes [9], which was realized in August 2022 [10]. Regarding this, the Philippine Department of Education (DepEd) released a set of tentative guidelines regarding the conduction of face-to-face classes in 2021 [11], which recommended the use of barriers for each student's table and a distance of at least 1 meter between chairs. Further documentation from DepEd shows visual proposals for the spacing of tables and chairs within a standard classroom [12]. This visual proposal is shown in Figure 1.

Figure 1. Proposed classroom setup from DepEd [12].

The importance of determining the effectiveness of barriers in a Philippine classroom setup provides the primary rationale for this study that was conducted. This study focused on flow analysis using computational fluid dynamics (CFD) to analyze the streamlines generated in a limited face-to-face public school classroom setup.

The use of CFD to observe aerosol and pathogen spread in indoor and outdoor spaces has been documented in papers such as the reports by Peng, Chen, and Liu [13] and Scott [14]. Their reports emphasized the merits of CFD as a cost-effective, powerful, and safe method of performing analyses that focus on the spread of pathogens. Other relevant studies have also been conducted that use CFD. The study conducted by Mariam et al. [15], which used a CFD setup of 2 individuals inside an enclosed space with a single inlet and two outlets, found that social distancing was not inherently necessary as good ventilation was much more important in preventing the spread of contaminated particles. In line with this, Motamedi et al. [16] studied various ventilation strategies for an office setup and found setups with multiple openings and forced ventilation to have the lowest global infection risk throughout the room among the cases studied. Hassan and Megahed [17] conducted a CFD analysis of an open public space setting with conditions simulating regions in Egypt, determining that certain seating configurations affected pathogen spread, such as the use of backrests which encourage individuals to face upwards, causing droplets to disperse efficiently. The study conducted by

Alrebi et al. [18], which was a CFD analysis of the emergency department of a hospital in Saudi Arabia, discovered that the turbulence level of the setup is at higher levels when 1 m above the floor, affecting pathogen spread.

There have also been studies that have focused on the effectiveness of barriers in the spread of pathogens in an indoor setting. In particular, the study by Liu et al. [19] determined that the effect of dividers in blocking the path of particle transmission was limited due to the gathering of particles inside partitioned spaces, increasing the risk of infection for the next individuals that may be placed within the spaces. In contrast, another study, conducted by Ren et al. [20], claims that the use of barriers can reduce the risk of infection by 72%. However, despite the extensive and recent CFD research regarding aerosol and pathogen spread, there is still a gap of knowledge specifically regarding the effectiveness of barriers in preventing pathogen spread in the proposed Philippine face-to-face classroom setting. Thus, there is sufficient need for such a study that focuses particularly on the effectiveness of barriers in typical Philippine public classrooms.

The following are the objectives that this study aimed to fulfill:

- Design aerodynamic models for a classroom based on guidelines and specifications sourced from relevant local government branches such as the Department of Education (DepEd) and the Department of Public Works and Highways (DPWH);
- Conduct CFD simulations were using the classroom models, as well as a visual evaluation of the generated streamlines;
- Compare the streamlines for the classroom setups without barriers and with barriers, and determine which among the cases increase the risk of airflow contamination; and
- Conclude whether the addition of barriers or the removal of barriers in the generated classroom setup provides reasonable protection from airborne diseases such as COVID-19.

II. METHODOLOGY

In order to determine if the addition of table barriers is beneficial in preventing the airborne transmission of diseases such as COVID-19, a CFD analysis methodology was implemented. The dimensions of a typical Philippine classroom, using data from documents from DepEd [21] and the DPWH [22], were used to create a classroom model including the positions of students and teachers inside the classroom. Two different models of the classroom were generated, one without barriers dividing the individuals inside and another with barriers.

The CFD simulations for the two models were run using inlet velocities of 1, 2, and 3.5 m/s. The 1 m/s inlet velocity was selected as a reference to the methodology of a similar study by Rencken et al. [23], which used a 1 m/s inlet velocity through windows for a similar classroom setup with a natural ventilation case. The 3.5 m/s velocity was taken from the average wind speed in Manila in 2022, which was recorded to be 7.95 miles per hour or approximately 3.5 meters per second, as reported by Weatherspark [24]. The 2 m/s velocity was added as a value in between 1 m/s and 3.5 m/s to address the gap in between the two velocities. Upon running the CFD simulations, the streamlines generated from the two models were visually inspected, and the circulating flows and air swirls within the two setups were compared. Furthermore, streamlines from the approximate locations of the human models inside of the classroom were generated, and the paths taken by these mouth streamlines were compared between the case without barriers and the case with barriers. If a setup was found to have fewer air swirls or less mouth streamline cross-contamination than the other, that setup was determined to be more effective in preventing the transmission of airborne diseases.

2.1 Classroom CAD Model

A three-dimensional model of a classroom patterned after the standard Philippine public high school classroom was developed by the researchers using the software Fusion 360. The classroom dimensions were developed according to the architectural designs made by the DPWH [22]. The positions of the seats were modeled after the guidelines mandated by DepEd [21]. The classroom is 7 m by 9 m by 2.85 m in size, as illustrated in Figure 2. On one side of the classroom are two windows that are 2.7 m by 1.2 m in size, both of which are elevated 0.9 m above the floor and are separated by a column that is 430 mm wide. On the opposite side of the windows are the two doors to each classroom which measure 0.9 m by 2.1 m in size. On the same wall with the doors are two smaller windows that are 1.5 m by 1.3 m in size. The setup contains 15 seats in a class, with each person placed at least 1 meter apart from each other. Each table in the proposed setup has a rigid barrier covering the front and side of the seat. Each seat is also occupied by a student. The seated students are modeled as cuboid bodies with a height of 1.0 m, a length of 0.5 m, and a width of 0.25 m. On top of these bodies are cuboid heads, with dimensions 0.16 m x 0.15 m x 0.2 m, and rectangular mouth surfaces of dimensions 0.06 m x 0.03 x 0.005 m. These approximate dimensions for individuals sitting down were taken from the study conducted by Abuhegazy et al. [25]. A seated teacher with a desk is also placed in front of the students. The teacher is modeled similarly to the students in terms of estimated dimensions. The teacher is seated in order to place the teacher directly in front of a barrier, similar to the students, for an ideal case where the streamlines of all individuals inside the room are affected by barriers directly in front of them. For all the setups, the air inlet was set through the side with the door and small windows, and the outlet was set through the other side with the large windows.

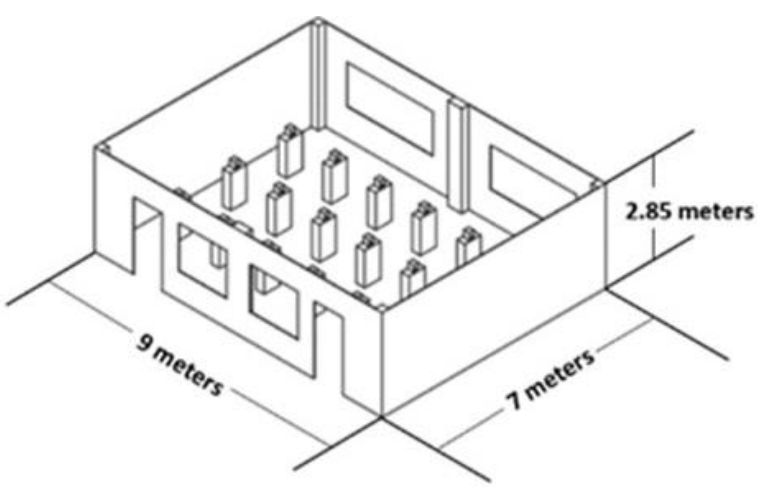

Figure 2. Model of empty classroom space, including basic dimensions.

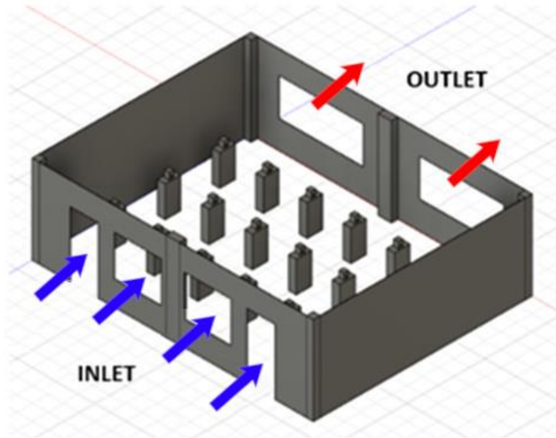

Figure 3. Classroom setup without barriers, including inlets and outlets.

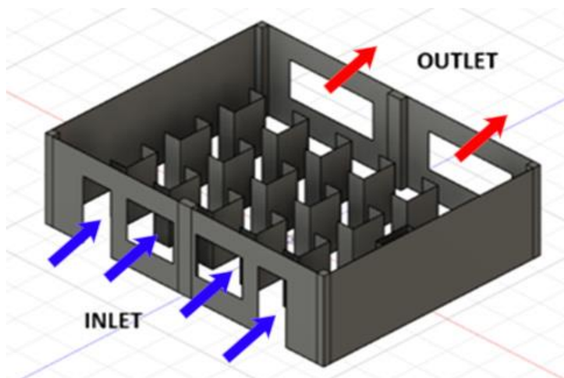

Figure 4. Classroom setup with barriers, including inlets and outlets.

2.2 Fluid Domain Spatial Mesh

The fluid bodies (air) that were used to analyze air flow in the setup were created through Boolean subtraction of the classroom CAD models (with barriers and without barriers) from a rectangular prism with the same dimensions as the classroom, using Fusion 360. The fluid domains were then exported to the ANSYS R22 Mechanical software, where the meshes were made. The mesh sizes vary throughout the spaces with a growth rate of 1.2. The resulting meshes were then exported to ANSYS Fluent R22, where the tetrahedral elements were converted into polyhedral elements. The size of the mesh elements was selected through a grid independence test, which is discussed in greater detail in Section 2.4.

2.3 Study Parameters

The study made use of the ANSYS R22 Fluent software to simulate the airflow throughout the model. The simulation was run in "Transient mode" using the Realizable k-epsilon turbulence model. This turbulence model was selected as it produces a good simulation of indoor airflow according to a study conducted by Hussain et al. [26], which compared the accuracy of various turbulence models in approximating indoor temperature conditions within atria of two existing buildings. Although the large building atrium environments investigated by Hussain et al. differ from the classroom environment investigated in this study, further rationale for the selection of the Realizable k-epsilon turbulence model was due to its use in the studies conducted by Motamedi et al. [16] and Liu et al. [19], which investigated the effects of barriers and dividers on airborne pathogen transmission in indoor office and dining environments, respectively. The 'Coupled' algorithm was used which solves the momentum and pressure-based continuity equations together. This algorithm is especially necessary for transient simulations with poor mesh quality, and if large time steps are used. Flux type was selected to be 'Rhie-Chow: distance-based'. For spatial discretization, the Pressure, Momentum, Turbulent Kinetic Energy, Turbulent Dissipation Rate, and Transient Formulation variables were all set to second-order. The walls and surfaces were defined as "non-slip" with "standard" roughness models.

2.4 Independence Tests

A grid independence test was performed by selecting mesh sizes, then performing a comparison of outlet mass flow rates with the mesh sizes used along with visual inspection of differences in the generated streamlines for identical setups with different mesh sizes. If a smaller mesh size yielded streamlines that visually differed from larger mesh sizes, or if the outlet mass flow rate for a smaller mesh size yielded a difference greater than 0.05% from the mesh size immediately larger than it, the smaller mesh size was selected. If these criteria were not observed, the larger mesh size was selected.

Three initial meshes were constructed for both the setup with barriers and without barriers, with the refined elements sized at 70 mm ("coarse"), 52.5 mm ("medium"), and 35 mm ("fine"). The comparisons of outlet mass flow rates for each mesh size, for the setups with barriers and without barriers, are summarized in Tables 1 and 2, respectively. The grid independence test for the setup with barriers did not yield percent differences among the different mesh sizes that were greater than 0.5%. However, upon visual inspection, it was determined by the researchers that the fine mesh size was the most optimal for the setup with barriers. The setup without barriers also did not yield percent differences among the different mesh sizes that were greater than 0.5%. Furthermore, the researchers did not observe visual differences in the streamlines for the setup. However, for a more analogous comparison for both the setup with barriers and the setup without barriers, the fine mesh size was also determined to be most appropriate for the setup without barriers. Ultimately, the mesh size for both setups was set to 35 mm ("fine"). The resulting meshes are illustrated in Figures 5 and 6.

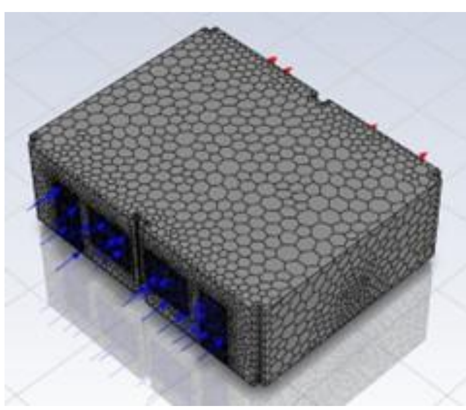

Figure 5a.

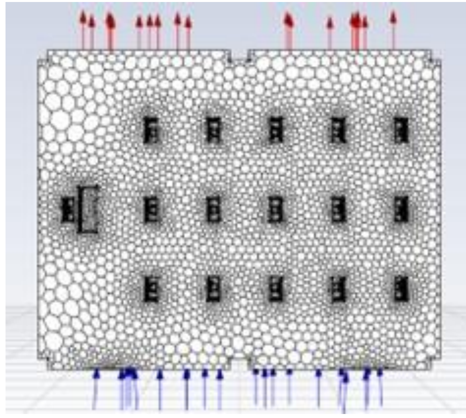
Figure 5b.

Figure 5. Isometric and underside views of the fluid domain mesh without barriers.

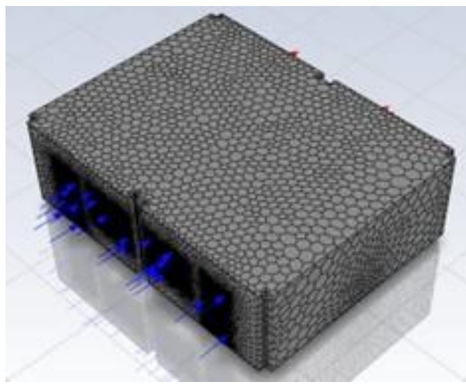
Figure 6a.

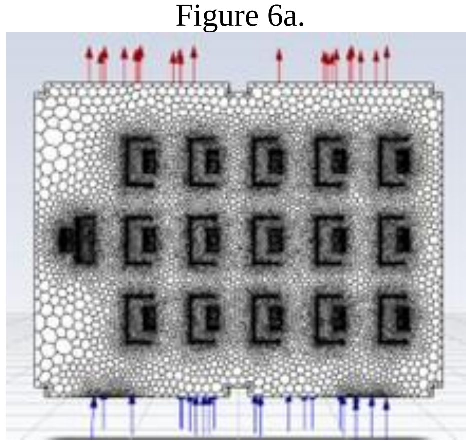
Figure 6b.

Figure 6. Isometric and underside views of the fluid domain mesh with barriers.

Table 1. Outlet mass flow rates for the candidate meshes for the setup with barriers.

Mesh Element Size (mm)	Outlet Mass Flow Rate (kg/s)	% Difference from Greater-sized Mesh
70 ("Coarse")	32.930901	N/A
52.5 ("Medium")	32.93666	0.01749
35 ("Fine")	32.933914	0.008337

Table 2. Outlet mass flow rates for the candidate meshes for the setup without barriers.

Mesh Element Size (mm)	Outlet Mass Flow Rate (kg/s)	% Difference from Greater-sized Mesh
70 (“Coarse”)	32.932274	N/A
52.5 (“Medium”)	32.936607	0.01316
35 (“Fine”)	32.927994	0.02615

The time independence test was performed to determine the optimal incremental change in time for solving the governing equations. Time step sizes of 0.4 s, 0.2 s, and 0.1 s were investigated. Similar to the grid independence test, a smaller time step size was selected if it yielded streamlines that visually differed from larger mesh sizes, or if the outlet mass flow rate differed from the previous greater-sized time step by greater than 0.5%. If these criteria were not observed, the larger time step size was selected. The comparisons of outlet mass flow rates for each time step, for the setups with barriers and without barriers, are summarized in Tables 3 and 4, respectively. For the time independence test performed by the researchers, there were no observable visual differences in streamlines among the time step sizes for both the setup with barriers and without barriers, and the outlet mass flow rate differences were found to be less than 0.5% even for the largest time step sizes of 0.4 s and 0.2 s. Thus, it was concluded that a time-step size of 0.4 s for the setups, both with barriers and without barriers, was adequate.

Table 3. Outlet mass flow rates for the candidate meshes for the setup with barriers.

Time Step Size (s)	Outlet Mass Flow Rate (kg/s)	% Difference from Greater-sized Time Step
0.4	32.937141	N/A
0.2	32.927999	0.02776
0.1	32.930902	0.008816

Table 4. Outlet mass flow rates for the candidate meshes for the setup without barriers.

Time Step Size (s)	Outlet Mass Flow Rate (kg/s)	% Difference from Greater-sized Time Step
0.4	32.940187	N/A
0.2	32.927999	0.03700
0.1	32.940186	0.03701

2.5 Study Design

To investigate the effect of using barriers in a classroom setup, CFD simulations were run for the base setup of a classroom with no barriers on the tables (“Without Barriers”) and another setup utilizing barriers (“With Barriers”). The simulation used the parameters established previously, with a mesh size of 35 mm, a time step size of 0.4 seconds, and a total of 75 time steps. Different inlet velocities of 1, 2, and 3.5 m/s were also simulated to check the effect of wind speed on the formation of vortices in the setup. The variation in the inlet velocities selected was expected to provide a more comprehensive illustration of the behavior of airflow across the classroom.

The vector and airflow paths in each classroom setup were visually inspected through streamline analysis, and compared to determine whether there is a difference in the airflow. Particularly, the presence of air swirls were noted as representing poor ventilation. The streamlines emanating from the individuals' mouths were also traced, by identifying points that are located as close to the mouths of the human models as possible. The y-coordinates of these points were all set to 1.08 m, but the x- and z- coordinates of these points vary per individual.

The rationale for the primarily visual manner of comparison between the setup without barriers and the setup with barriers is that the airborne pathogens that may exist within the classroom space will travel via the streamlines. If the streamlines persist inside the classroom without flowing out, then the pathogens will remain inside of the classroom and will increase the risk of infection among individuals inside. Therefore, a setup with fewer areas containing circulating flows was considered more desirable in mitigating the risk of airborne pathogen infection.

Assumptions for this setup are that 1) temperature variations are negligible, and environmental conditions are steady, i.e., steady stream of wind entering the classroom, no human movement which can affect the air stream; 2) Air droplets are ignored for simplification, virus transmission is assumed to be through aerosols; 3) Air will serve as a tracer gas that will replace aerosols; and 4) Air will only enter through the inlets.

III. RESULTS AND DISCUSSION

3.1 Results from 1 m/s Inlet Velocity Setups

Visual inspection of the results for the 1 m/s inlet air velocity case without barriers reveals the consistent presence of air swirls behind the teacher as well as at the fifth row of students towards the back of the classroom, as illustrated in the top view of the model in Figure 7 and more clearly in the isometric view of the model in Figure 8. The presence of such air swirls indicates poor ventilation in these areas of the classroom, and an increased risk of spreading droplets with SARS-CoV-2 if infected droplets were to be released around these areas. Furthermore, as visualized in Figure 8 the air coming from the mouth of the teacher easily moves close to the position of the students in the front row, and the air coming from the mouths of the students close to the inlet side of the classroom easily moves towards the students in the same row that are situated closer to the outlet side of the classroom. The air swirls in Figure 7 also cause cross-contamination of the mouth streamlines in Figure 8, as observed for the mouth streamlines of the students in the fifth row towards the back of the classroom.

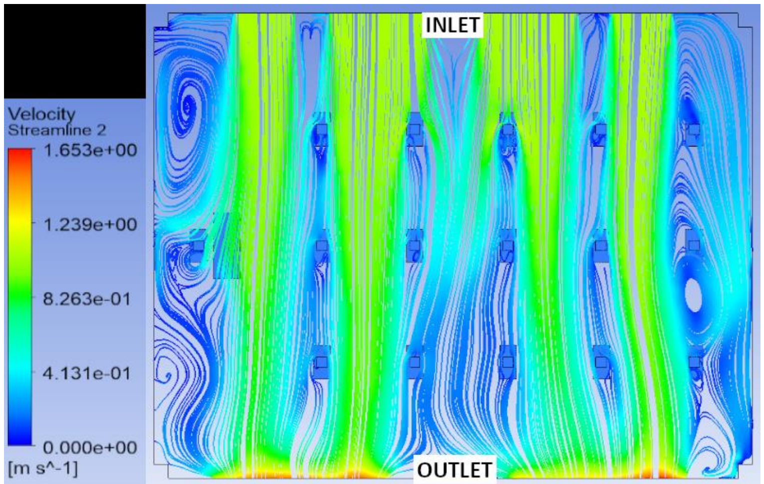

Figure 7. Streamline of Setup Without Barriers and 1 m/s inlet speed at 1.08 m height (mouth level).

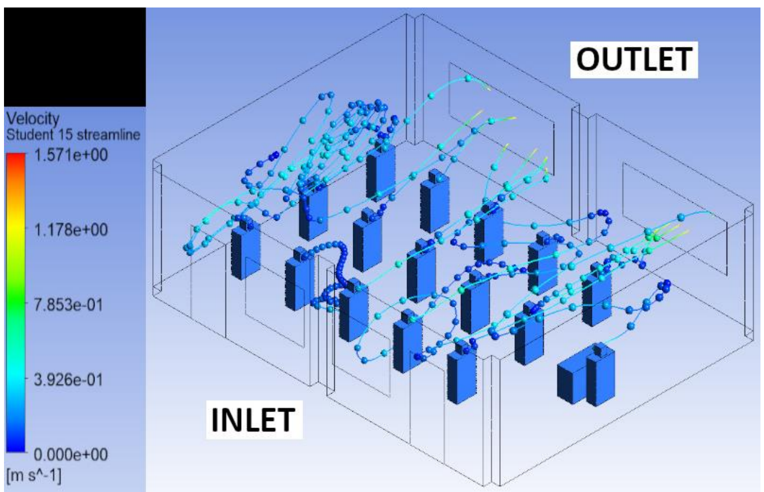

Figure 8. Isometric view of streamline from human mouths of Setup Without Barriers and 1 m/s inlet speed, including the restriction of circulation towards the back of the classroom.

The visual streamline analysis for the 1 m/s case with barriers, documented in Figures 9 and 10, reveals that the number of air swirls within the classroom increases compared to the case without barriers. The air swirls behind the teacher remain, and new air swirls develop within the position of each individual inside the room, as well as in between each of these positions. The increased presence of air swirls implies an even poorer overall circulation of air around the classroom. However, it is noted by the researchers that these air swirls, despite increasing in number, are isolated and do not spread air between or among the individuals in the classroom. This shows that if each individual stays within their assigned position inside the room, the spread of SARS-CoV-2 droplets among individuals inside the room is less likely compared to the 1 m/s case without barriers.

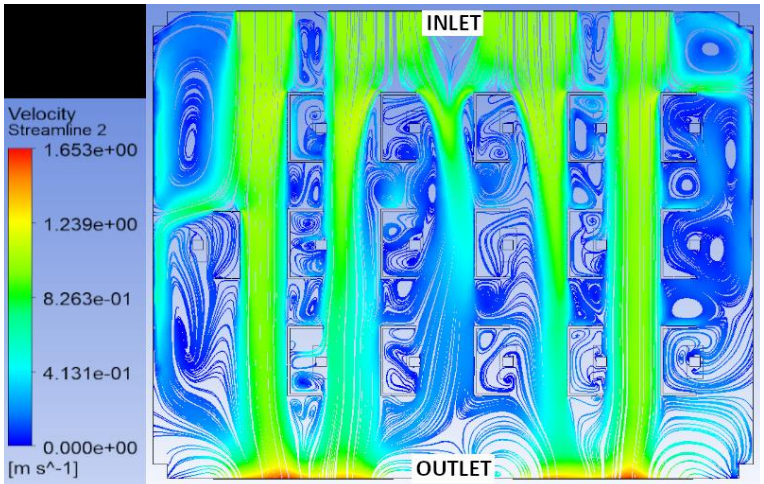

Figure 9. Streamline of Setup With Barriers and 1 m/s inlet speed at 1.08 m height (mouth level).

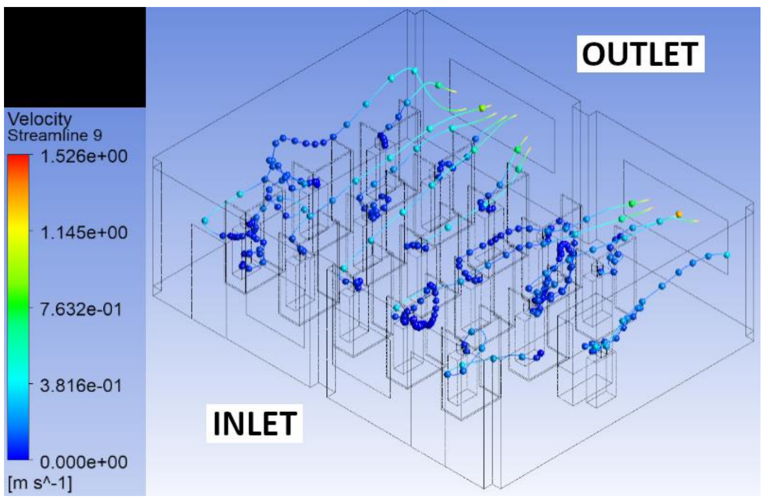

Figure 10. Isometric view of streamline and particle track from human mouths of Setup With Barriers and 1 m/s inlet speed.

3.2 Results from 2 m/s Inlet Velocity Setups

Visual inspection for the 2 m/s case without barriers in Figure 11 yields an analysis similar to the 1 m/s case without barriers in Figure 7. Figure 11 presents the streamlines that were generated for the simulation that was run for the case without barriers and a 2 m/s inlet air speed. Of note in Figure 11 is the presence of circulating air swirls at the back of the teacher position (on the left side of the figure) as well as at the fifth row of students towards the back of the classroom (on the right side of the figure), identical to what is observed in Figure 7.

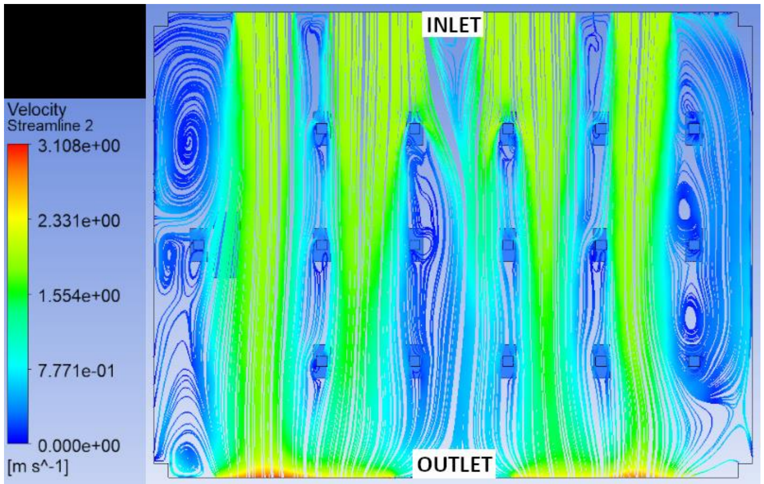

Figure 11. Streamline of Setup Without Barriers and 2 m/s Inlet Speed at 1.08 m Height (mouth level).

The streamlines for the 2 m/s case with barriers, as illustrated in Figure 12, reveal similar findings upon visual inspection and comparison to the streamlines in the 1 m/s case with barriers in Figure 9. The multiple air swirls within the barriers and in between each student that was observed in the 1 m/s case all remain in the 2 m/s case. The barriers initially contain the air flow of individuals, which consequently means that the 2 m/s case still shows the benefit of a reduced risk of spreading SARS-CoV-2 among individuals if the seating position is always maintained under all circumstances. However, the issue of poor overall air ventilation still poses the risk of contamination with potentially contaminated air swirls remaining inside the classroom. Figure 12 presents the streamlines that were generated for the simulation that was run for the case with barriers and a 2 m/s inlet air speed.

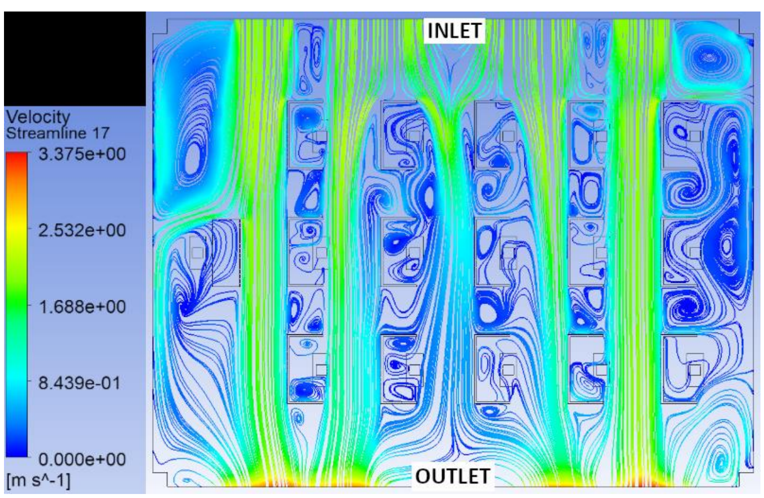

Figure 12. Streamline Setup With Barriers and 2 m/s Inlet Speed at 1.08 m height (mouth level).

3.3 Results from 3.5 m/s Inlet Velocity Setups

The 3.5 m/s case without barriers follows a trend identical to that which was observed for the 1 m/s and 2 m/s cases without barriers. Figure 13 presents the streamlines that were generated for the simulation that was run for the case without barriers and a 3.5 m/s inlet air speed. In Figure 13, the same presence of air swirls particularly behind the teacher (on the left side of the figure) and at the fifth row of students towards the back of the classroom (on the right side of the figure) is observed in this case, just as it was observed in the cases of lower speed.

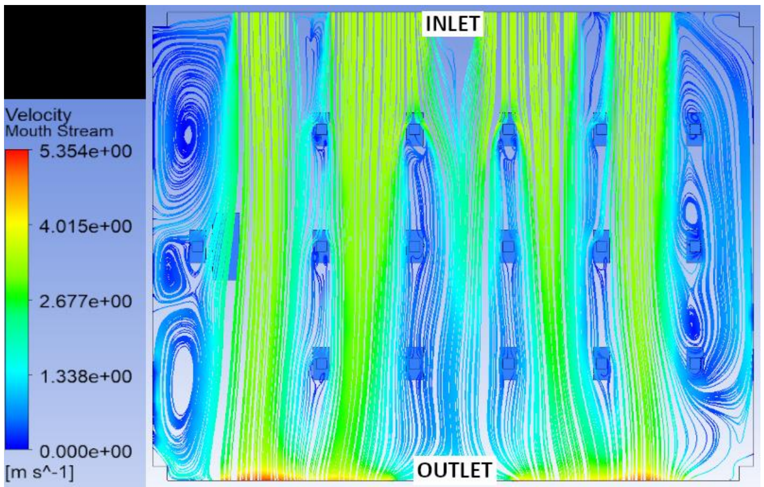

Figure 13. Streamline of Setup Without Barriers and 3.5 m/s inlet speed at 1.08 m height (mouth level).

For the setup with barriers, illustrated in Figure 14, it is noted by the researchers that the increase in air swirls that was observed in the 1 m/s and 2 m/s cases is also present in the 3.5 m/s case. Regardless of the changes in inlet air speed that were considered in this study, the observations regarding the circulation of air do not change substantially so as to affect the perceived risk of spreading SARS-CoV-2 droplets within the classroom. Figure 14 presents the streamlines that were generated for the simulation that was run for the case with barriers and a 3.5 m/s inlet air speed.

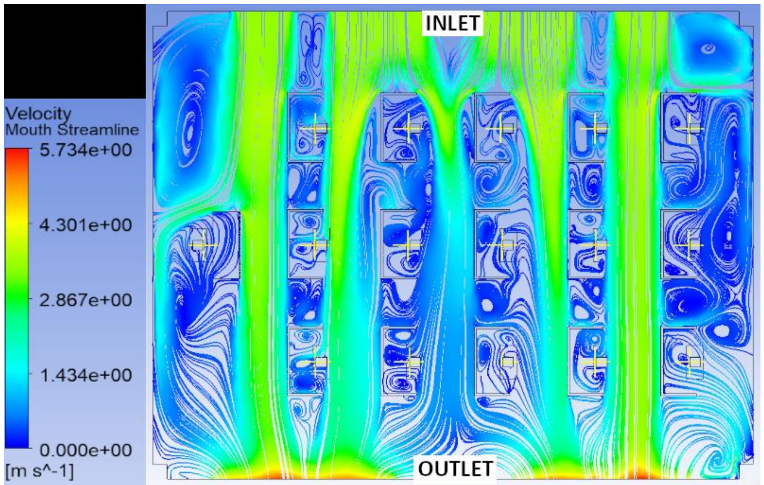

Figure 14. Streamline of Setup With Barriers and 3.5 m/s Inlet Speed at 1.08 m Height (mouth level).

3.4 Analysis

It was found from the results that consistently in all cases, more air swirls occur when barriers are placed in the setup. This means that aerosols are more likely to remain suspended within the classroom if barriers are placed. However, there is one scenario where barriers may be considered effective in reducing the risk of infection. When tracing the streamlines from the individuals' mouths in the cases without barriers, it can be noted that these streamlines are more likely to pass very close to other individuals. The presence of barriers causes the mouth streamlines to instead move around the areas enclosed by the barriers, avoiding the spaces of other individuals. However, upon exiting the barriers, the streamlines tend to then circulate and linger between the open spaces that are not enclosed within the barriers, instead of immediately exiting the room. This creates an environment where the barriers only reduce the risk of aerosol infection if the individuals are permanently seated at their designated positions at all times. Should any one individual leave their position to move around or exit the classroom, or even enter the classroom in the first place, they will be exposed to these air swirls within the open spaces in between the barriers, where there is a great risk of aerosol infection. The expectation of all individuals being unable to enter, exit, or move around the classroom is deemed by the researchers to be unreasonable in most realistic cases. Thus, in truly realistic cases, the risk of aerosol infection in the setup used for the study is increased by the presence of barriers.

Furthermore, regardless of the differences in inlet air speed, the changes to the behavior of air within the classroom with regards to the risk of spreading droplets are minimal. Visual inspection of Figures 7, 11, and 13 shows that there were no observable changes in the locations of air swirls regardless of the inlet air speed for the setup without barriers. This lack of observable differences can also be noted in Figures 9, 12, and 14, which illustrate the air flow within the classroom for the setup with barriers. From these findings, it can be determined that for the particular setups used in this study, changes in air inlet speed between 1 m/s and 3.5 m/s do not substantially affect the air flow so as to change the tendency to produce air swirls in particular areas of the room setup used.

IV.CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

From the results, it is concluded that, for the classroom setup and layout that is proposed by DepEd [11], the effectiveness of the barriers in preventing the spread of pathogens such as SARS-CoV-2 is situational. Placing barriers may be deemed effective at preventing the spread of airborne pathogens, provided that the individuals inside the classroom do not ever move from their positions under any circumstances. However, if any one individual moves away at any point in time from their assigned position, including any form whatsoever of entrance, exit, or transit around the classroom, the increase in air swirls facilitated by the presence of barriers then poses a risk of facilitating the spread of airborne pathogens. Changes in inlet air speed between 1 m/s and 3.5 m/s do not substantially change the behavior of air inside the classroom so as to affect the presence of air swirls observed, and thus has no effect on the risk of airborne pathogen infection.

In summary, this study was able to fulfill the following objectives and obtain the following conclusions:

- Aerodynamic models were designed for a classroom based on guidelines and documentations sourced from DepEd [12, 21] and the DPWH [22].

- CFD simulations were conducted using the classroom models, and a visual evaluation of the generated streamlines was also conducted.

- Upon comparison of the streamlines for the classroom setup without barriers and with barriers, it was found that although the setup with barriers prevented airflow cross-contamination among individuals in their proper positions within the classroom, the barriers in the setup also increased the number of air swirls within the classroom which increases the risk of contamination through suspended particles in the barrier space.

- Finally, it was determined that for this study, the conditions that must be met for the setup with barriers to provide protection from SARS-CoV-2 are conditions concerning movement within the classroom that cannot reasonably be fulfilled. In realistic general scenarios, the setup with barriers poses a greater risk of facilitating airborne transmission of pathogens than the setup without barriers due to the poor ventilation. Therefore, for the setup used in this study, the setup without barriers provides more effective protection from airflow cross-contamination, and consequently, the spread of SARS-CoV-2 and COVID-19, compared to the setup with barriers.

4.2 Recommendations

The researchers' recommendations for future studies are as follows:

1. Include more boundary conditions and other additional variables in the model. Although this research was conducted under the premise that the mechanical aspect would still yield usable data, an even more detailed analysis of the behavior of air flow and droplet movement could be generated if factors such as humidity, temperature, heat

sources such as body heat, and breathing of the individuals, were included in the simulation.

2. Perform validation of the findings for the cases analyzed in this study using physical experiments. This study elected to use a purely CFD-based approach to collecting data, similar to the methodology described in the study conducted by Liu et al. [19] which investigated aerosol distribution in an indoor dining environment. However, other similar studies involving indoor environments, such as those conducted by Ren et al. [20] and Motamedi et al. [16], performed physical validation using on-site monitoring and wind tunnel comparison, respectively. Such validation may allow for a further in-depth analysis of the CFD results.

3. Use a different model for the classroom that may include changes in variables such as basic dimensions, positions of individuals, and inlet and outlet locations. There are still further variations in the layouts of Philippine classrooms, particularly schools that are not directly managed by the local government, or tertiary education centers.

4. Study the buildup of particle concentration in the room. It was discussed in this study that the poor ventilation, particularly in the setup with barriers, was a risk factor for pathogen spread within the classroom due to the presence of air swirls where viral particles may build up. More studies regarding the local or global transient buildup of concentration in the room could therefore be a future topic of interest.

5. Simulate with moving physical models or varied positioning of individuals. The physical models used in this study, particularly the models for the individuals within the room, are all assumed to be in a stationary state. A simulation with moving physical models or varying positions of individuals would provide more cohesive information regarding the effects of the air swirls generated within the room by the addition of barriers on contagion spread.

References

[1] Mohan B, Vinod N. 2020. COVID-19: An insight into SARS-CoV2 Pandemic Originated at Wuhan City in Hubei Province of China. Journal of Infectious Diseases and Epidemiology. 6(4). https://doi.org/10.23937/2474-3658/1510146

[2] World Health Organization. 2022. Retrieved from https://www.who.int/news/item/13-10-2020-impact-of-covid-19-on-people's-livelihoods-their-health-and-our-food-systems on 13 Nov 2021.

[3] Centers for Disease Control. 2020. Retrieved from https://www.cdc.gov/coronavirus/2019-ncov/science/science-briefs/sars-cov-2-transmission.html on 13 Nov 2021.

[4] World Health Organization2020. Retrieved from: https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions on 14 Nov 2021.

[5] Tria JZ. 2020. The COVID-19 pandemic through the lens of education in the Philippines: The new normal. International Journal of Pedagogical Development and Lifelong Learning. 1(1). https://doi.org/10.30935/ijpdll/8311.

[6] Crawford J, Butler-Henderson K, Jurgen R, Malkawi BH, Glowatz M, Burton R, Magni P, Lam S. 2020. COVID-19: 20 countries' higher education intra-period digital pedagogy responses. Journal of Applied Learning & Teaching. 3(1):9-28. https://doi.org/10.37074/jalt.2020.3.1.7

[7] Barrot JS, Llenares II, del Rosario LS. 2021. Students' online learning challenges during the pandemic and how they cope with them: The case of the Philippines. Educ Inf Technol 26:7321–7338. https://doi.org/10.1007/s10639-021-10589-x

[8] Copeland WE, McGinnis E, Bai Y, Adams Z, Nardone H, Devadanam V, Hudziak JJ. 2021. Impact of COVID-19 pandemic on college student mental health and wellness. Journal of the American Academy of Child & Adolescent Psychiatry. 60(1):134–141. https://doi.org/10.1016/j.jaac.2020.08.466

[9] Philippine Star. 2021. Retrieved from: https://www.philstar.com/headlines/2021/10/19/2135227/face-face-classes-start-30-schools-november-15-deped on 9 Oct 2021.

[10] CNN Philippines. 2022. Retrieved from https://www.cnnphilippines.com/news/2022/8/22/Face-to-face-classes-school-year-2022-2023-COVID-19-pandemic.html on 4 September 2022.

[11] Department of Education. 2021. Retrieved from deped.gov.ph/wp-content/uploads/2021/09/DEPED-DOH-JMC-No.-01-s.-2021_.pdf on 5 Nov 2021.

[12] DepEd Tayo. 2020. Retrieved from: https://web.facebook.com/depedtayo/photos/a.197329230688458/936313323456708 on 7 June 2023.

[13] Peng S, Chen Q, Liu E. 2020. The role of computational fluid dynamics tools on investigation of pathogen transmission: Prevention and control. Science of the Total Environment. 746. https://doi.org/10.1016/j.scitotenv.2020.142090

[14] The SIMULIA Blog. 2021. Retrieved from https://blogs.3ds.com/simulia/how-simulation-can-help-reduce-risk-covid-19-in-classrooms/ on 8 Nov 2021.

[15] Mariam AM, Joshi M, Rajagopal PS, Khan A, Rao MM, Sapra BK. 2021. CFD simulation of the airborne transmission of COVID-19 vectors emitted during respiratory mechanisms: Revisiting the concept of safe distance. ACS Omega. 6(26):16876–16889. https://doi.org/10.1021/acsomega.1c01489

[16] Motamedi H, Shirzadi M, Tominaga Y, Mirzaei PA. 2021. CFD modeling of airborne pathogen transmission of COVID-19 in confined spaces under different ventilation strategies. Sustainable Cities and Society. 76. https://doi.org/10.1016/j.scs.2021.103397

[17] Hassan AM, Megahed NA. 2021. COVID-19 and urban spaces: A new integrated CFD approach for public health opportunities. Building and Environment. 204. https://doi.org/10.1016/j.buildenv.2021.108131

[18] Alrebi O, Obeidat B, Atef Abdallah I, Darwish EF, Amhamed A. 2021. Airflow dynamics in an emergency department: A CFD simulation study to analyse COVID-19 dispersion. Alexandria Engineering Journal. 61:3435-3445. https://doi.org/10.1016/j.aej.2021.08.062.

[19] Liu Z, Li R, Wu Y, Ju R, Gao N. 2021. Numerical study on the effect of diner divider on the airborne transmission of diseases in canteens. Energy & Buildings. 248. https://doi.org/10.1016/j.enbuild.2021.111171

[20] Ren C, Xi C, Wang J, Feng Z, Nasiri F, Cao S, Haghighat F. 2021. Mitigating COVID-19

infection disease transmission in indoor environment using physical barriers. Sustainable Cities and Society. 74. https://doi.org/10.1016/j.scs.2021.103175.

[21] Department of Education. 2017. Retrieved from https://www.deped.gov.ph/wp-content/uploads/2017/12/DO_s2017_064.pdf on 13 October 2021.

[22] Department of Public Works and Highways. 2017. Retrieved from: https://www.dpwh.gov.ph/dpwh/node/12515 on 14 October 2021.

[23] Rencken GK, Rutherford EK, Ghanta N, Kongoletos J, Glicksman L. 2021. Patterns of SARS-CoV-2 aerosol spread in typical classrooms. Building and Environment. 204. https://doi.org/10.1016/j.buildenv.2021.108167

[24] Weatherspark. 2022, [accessed]. Retrieved from https://weatherspark.com/m/134588/3/Average-Weather-in-March-in-Manila-Philippines#Figures-WindSpeed on 14 May 2022.

[25] Abuhegazy M, Talaat K, Anderoglu O, Poroseva SV. 2020. Numerical investigation of aerosol transport in a classroom with relevance to COVID-19. Physics of Fluids. 32(10). https://doi.org/10.1063/5.0029118.

[26] Hussain S, Oosthuizen PH, Kalendar A. 2012. Evaluation of various turbulence models for the prediction of the airflow and temperature distributions in atria. Energy and Buildings. 48:18-28. https://doi.org/10.1016/j.enbuild.2012.01.004