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Computational Fluid Dynamics (CFD)-Based Assessment of Thermal Comfort of Public-School Classroom in Canduman National High School: Building 1 Room 1

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Abstract **- Thermal comfort in Philippine public schools is a critical challenge due to tropical climates and high occupant density. This study assesses the thermal environment of Building 1 Room 1 at a DepEd public school (Canduman National High School) using a hybrid approach: in-situ field measurements for parameter assessment and Computational Fluid Dynamics (CFD) for spatial visualization. The research integrated field data with SolidWorks 2025 simulations, employing a methodological innovation that averages three distinct fan orientations to approximate the behavior of oscillating and orbiting fans.**

Compliance was evaluated against ASHRAE 55-2023 (Predicted Mean Vote/Predicted Percentage Dissatisfied and Adaptive Comfort) and Philippine Green Building Code (PGBC) standards. Field measurements recorded averages of 29.74°C air temperature, 59.11% relative humidity, 32.30°C mean radiant temperature, and 0.54 m/s air velocity. Analysis yielded a PMV of 1.00 and a PPD of 26%, though the environment remained within the 80% adaptive comfort acceptability limits. Structurally, the classroom exceeded the PGBC's 10% window-to-floor ratio threshold and provided a fresh air delivery rate of 88.34 cubic meters per hour (cmh) per person.

CFD validation across the fan-orientation scenarios demonstrated high model accuracy, with error metrics remaining within acceptable thresholds. By successfully quantifying these thermal dynamics, this study establishes a technical baseline for future structural and ventilation improvements in high-density DepEd public-school classrooms.

Keywords - Thermal Comfort, Computation Fluid Dynamics (CFD), ASHRAE 55-2023, Adaptive Comfort Model, Department of Education (DepEd), Public-School Classroom, Predicted Mean Vote (PMV), Predicted Percentage Dissatisfied (PPD), Philippine Green Building Code (PGBC), Window-to-Floor Ratio, Ventilation Rate, SolidWorks 2025, SolidWorks Simulation.

I. INTRODUCTION

Naturally ventilated classrooms in Philippine public schools commonly rely on electric fans as the primary means of mitigating thermal discomfort caused by the tropical climate. However, there is limited quantitative evidence to determine whether these fan-assisted ventilation systems provide acceptable thermal comfort and effective airflow distribution in accordance with established standards such as ASHRAE 55-2023, and the Philippine Green Building Code (PGBC). The absence of validated engineering-based assessments creates uncertainty regarding the actual thermal and ventilation performance of these learning environments. A study by Gunnarsen and Santos found that individual control over air velocities remains an alternative for improving the warm environment [1]. A more recent study by Aqilah, Rijal, and Zaki showed that the comfort temperature of the residents increased by 1°C when using the fan [2].

Internatial studies highlgiht the importance of engineering-based evaluations using CFD. CFD modelling has been effectively used to visualize airflow patterns and evaluate ventilation efficiency in tropical school building [3]. In Indonesia and Thailand, similar warm-humid contexts, researchers found that optimized fan placement and hybrid ventilation systems significantly improved thermal comfort without requiring mechanical air conditioning [4].

The main objective of this study is to evaluate baseline thermal comfort conditions and airflow characteristics of a fan-assisted, naturally ventilated DepEd public-school classroom via the established thermal comfort standards of ASHRAE 55-2023 using in-situ field measurements, and validated CFD simulation.

II. METHODS

A. Process Flow

Figure 1 shows the first flow process of the study. The study started with a collection of data. In-situ data collection was conducted for five days in the month of January 2026 from 11:35AM to 4:00PM capturing key microclimatic parameters: air temperature, relative humidity, mean radiant temperature, and air velocity.

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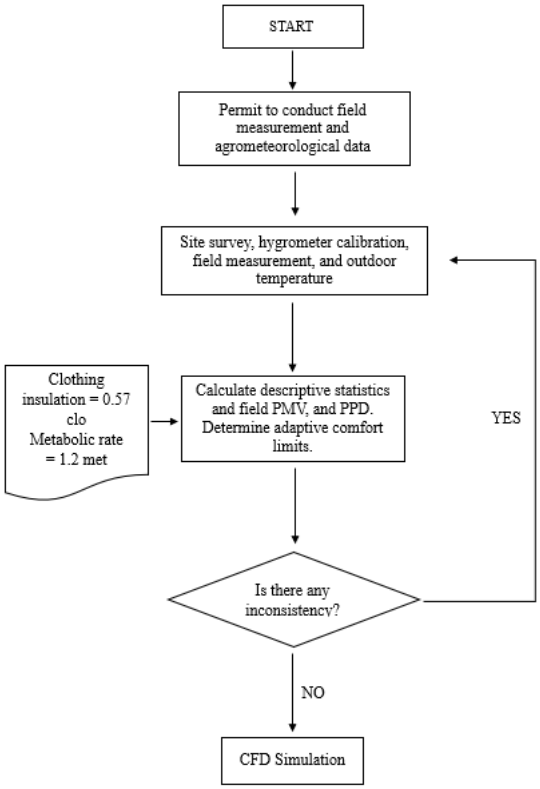


Fig. 1. In-situ Field Measurement Flow Process

The field measurement was conducted at Canduman National High School building 1, room 1 in three different locations inside the classroom, as shown in figure 2, using calibrated hygrometers, globe thermometer, and hot-wire anemometer. Hygrometers were verified by using a Normalized Root Mean Squared Error (NRMSE).

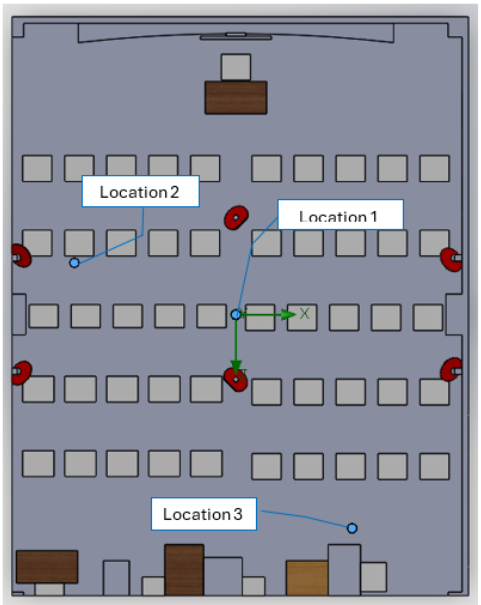


Fig. 2. Sensor Location

Agrometeorological data or outdoor temperature was retrieved from Climate and Agrometeorological Data Section (CADS), Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). These empirical data points are then processed using standardized occupant parameters by ASHRAE 55-2023, specifically a clothing insulation value of 0.57 clo and a metabolic rate of 1.2 met, to calculate descriptive statistics and field-based PMV and PPD indices [5]. Once the data is confirmed to be consistent and accurate, it serves as the foundational input for the CFD simulation phase.

After getting field data, figure 3 demonstrates the flow process for the next steps.

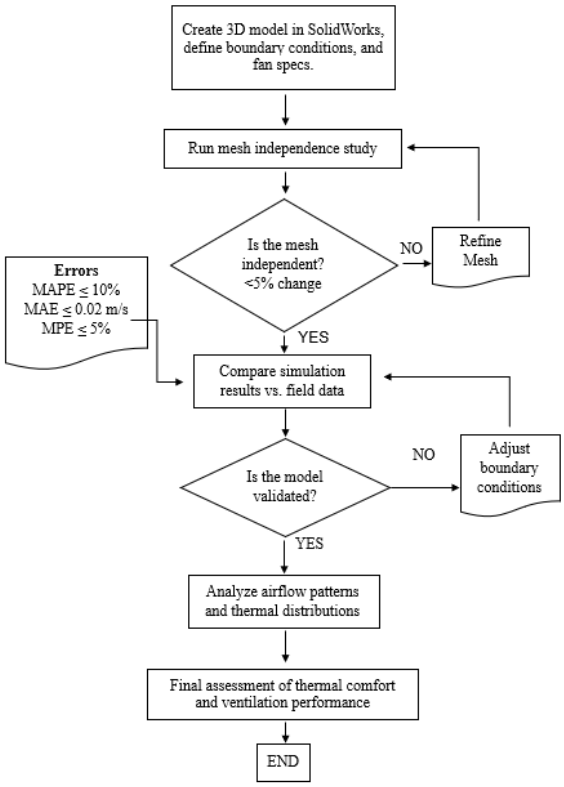


Fig. 3. CFD Simulation Flow Process

Model construction followed using SolidWorks 2025, accurately reflecting room dimensions, window openings, furniture layout, and simplified human profiles as shown in figure 4.

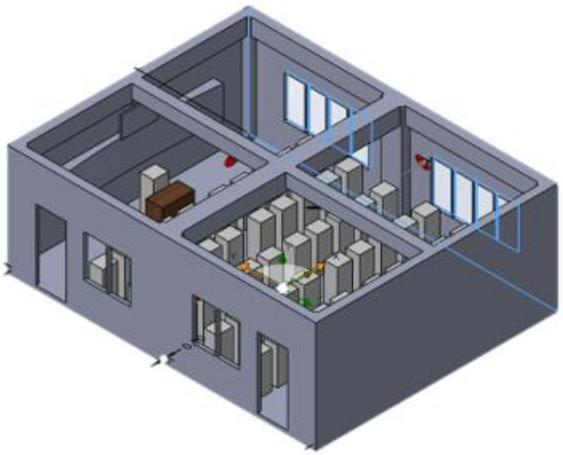


Fig. 4. 3D Model Isometric View

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Specific boundary conditions where and mechanical fan specifications were applied based on the gathered field data. Reynolds-Averaged Navier-Stokes (RANS) equations closed with the standard k-epsilon turbulence model to balance computational efficiency with accurate jet flow predictions. To eliminate the influence of grid density on the results, a mesh independence study was conducted [6-7]. The mesh is systematically refined until the variance in key parameters reaches a threshold of less than 5% change. Once mesh independence was established, the simulation results were rigorously compared against the in-situ field data using Maximum Percentage Error (MPE) of ≤5% for air temperature and mean radiant temperature [8], Mean Absolute Error (MAE) of ≤0.02m/s for air velocity [9], and Mean Absolute Percentage Error (MAPE) of ≤10% for relative humidity [10]. The simulation assumed a steady-state condition, hence the model represent the time-averaged as shown in figure 5, three different fan setup, thermal environment including the oscillating and orbiting of the fans rather than capturing transient effect like sudden wind gusts.

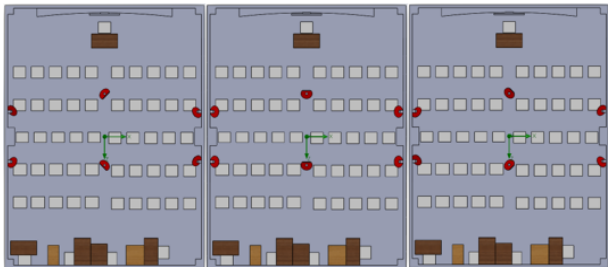


Fig. 5. Classroom Fan Setups

Following the succesful validation, the study proceeds to a detailed analysis of airflow patterns and thermal distributions within the classroom. The calculation of thermal comfort indices was conducted using the Center for the Build Environment (CBE) Thermal Comfort Tool developed by UC Berkeley [11].

B. Instruments

Three Tapo T310 with one Tapo H100 was used to measure the air temperature and RH. This sensor has a temperature range of -20°C to 60°C with an accuracy of ±0.3°C. The relative humidity has a range of 0 to 99% RH with an accuracy of ±0.3% RH. For the measurement of MRT, three custom globe thermometers were utilized, consisting of a 70mm matte black sphere and an INKBIRD IBS-TH2 Plus. The INKBIRD IBS-TH2 Plus has a temperature range of -40°C to 125°C with an accuracy of ±0.5°C. Using the external probe of the INKBIRD IBS-TH2 Plus, the sensor was centrally suspended within a 70mm matte-black spherical shell. This custom globe thermometer was specifically designed to minimize thermal lag in transient indoor environments. The use of this in-house developed apparatus follows the methodological precedents of Humphreys [12] and Benton et al. [13]. Hygrometers were calibrated using a calibrated device from the Department of Science and Technology. To measure the air velocity, a UNI-T UT362H hot-wire anemometer with a range of 0-30m/s and an accuracy of ± (4% of reading +0.1m/s) was used. All sensors were placed at a height of 1.1m to correspond to a seated occupant's head, in accordance with ASHRAE 55-2023 recommendation [5]. A laptop with a specification of 16GB RAM, 12th Gen Intel Core i5, and 477GB SSD (NVme) was used for 3D modeling in SolidWorks 2025, simulation of SolidWorks Simulation, and Microsoft Excel for the extracted data.

III. RESULTS AND DISCUSSIONS

The results and discussions present the calibration results of the hygrometers, data gathered from field measurements, and the results obtained from the CFD simulations.

A. Calibration Results

Prior to conducting the in-situ field measurements, an empirical sensor calibration experiment was performed to ensure accuracy of the hygrometers against a calibrated reference instrument. All deployed Tapo T310 Temperature and relative humidity sensors, as well as INKBIRD IBS-TH2 Plus units, demonstrated high precision and strictly complied with the acceptability threshold below 10% tolerance boundary using the NRMSE. The data acquisition setup was verified as reliable for baseline in-situ field measurement.

B. Environmental Conditions

- The center of the room (location 1) had an average air temperature of 29.74°C. The students' area (location 2) had an average air temperature of 29.90°C. The teachers' area (location 3) had an average air temperature of 29.58°C.
- The classroom air was moderately humid. At locations 1, 2, and 3, the average relative humidity was 59.08%, 58.58%, and 59.67% respectively. Such humidity can inhibit evaporative cooling and intense thermal discomfort.
- The mean radiant temperature in locations 1, 2, and 3 are 32.05°C, 33.16°C, and 31.68°C respectively. The mean radiant temperature is above the air temperature at each location, indicating the influence of warm surrounding surfaces and solar gains. Location 2 showed the highest mean radiant temperature due to direct sunlight.
- Airflow patterns differed markedly by location. Location 2, near the fan, has the highest mean velocity of 0.92m/s up to 1.58m/s. In contrast, location 3, farther from the fan, had much lower air movement with a mean of 0.28m/s peaking only at 0.50m/s. Location 1 was intermediate with a mean of 0.39m/s. These variations reflect uneven airflow distribution across the classroom. Areas near the fan benefited from breezes, whereas the areas farther from the fans and openings experienced near-stagnant air at time.

C. PGBC Standard

The PGBC provides certain minimum requirements aimed at ensuring adequate ventilation and daylight in naturally ventilated spaces. Two relevant metrics are the window-to-floor ratio and the ventilation rate per occupant. The classroom's design and measured performance are compared to these benchmarks.

- The PGBC stipulates that regularly occupied rooms should have openable window areas equal to at least 10% of the floor area. The classroom in question is approximately 7m by 9m in size giving a floor area of

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63m2 [14]. The total area for all twelve windows of 8.85m2. Therefore, it meets the 10% window-to-floor of the PGBC. The results show that even with adequate window area, the distribution of air and heat within the room was uneven – suggesting that geometry and placement of openings, not just total area, are critical.

- The PGBC recommends a minimum outdoor air supply of 17cmh per person for classrooms [14]. With a maximum of 50 students and 5 teachers typically, a 17cmh per person rate would require about 697cmh of outdoor air entering the room. The velocity measurement taken from all the windows has an average of 0.1525 m/s. The amount of fresh air per person is 88.34 cmh. This shows that it complies with the PGBC minimum outdoor air supply of 17 cmh per person.

D. ASHRAE 55-2023 Thermal Comfort Indices

The result showed a consistent thermal discomfort across the classroom.

- At the center location, the average PMV was approximately 1.15 and PPD of 33%. This corresponds to a thermal sensation slightly warm.
- The students' area at location 2 had a slightly lower PMV and PPD due to the elevated air velocity providing some cooling. The average PMV was approximately 0.82 and PPD of 19%. This corresponds to a thermal sensation of slight warmth.
- The teachers' area at location 3 exhibited the most severe thermal stress, with a PMV of 1.26 and PPD of 38% due to its stagnant air.
- With the aggregated mean environmental parameters, the PMV was 1.00 and PPD of 26%. In sum, the indoor climate, as measured, fails to meet the conventional thermal comfort standards.
- Given that the classroom is naturally ventilated and occupants may adapt to the local climate, it is also pertinent to evaluate the conditions against adaptive comfort standards. Agrometeorological data from CADS, PAGASA for January 2026 established a prevailing mean outdoor air temperature of 27.65°C, representing a 21-day weighted average prior to the in-situ data collection. Utilizing the CBE Thermal Comfort Tool, the 80% acceptability threshold for this climate was determined to range from 22.90°C to 31.10°C.
- Analysis of the field-gathered data revealed a mean air temperature of 29.74°C and a mean radiant temperature of 32.30°C, resulting in a calculated operative temperature of 31.02°C. Although this value approaches the upper boundary of the 31.10°C limit, the classroom remains within the 80% thermal acceptability envelope.

E. CFD Simulation Results

To ensure numerical stability and accuracy, a mesh independence study was conducted across three levels of refinement (levels 2, 3, and 4). The air temperature and relative humidity at locations 1, 2, and 3 were used as the primary variable for comparison. The transition from level 3 to level 4 yielded negligible variations, demonstrating that the results are no longer sensitive to further mesh refinement. The results indicate that even at the most sensitive monitoring point, the numerical solution remained stable as the cell count increased, effectively eliminating the risk of errors.

The CFD model was then validated by comparing simulated data against the in-situ field measurements across three locations in the classroom. The validation focused on air temperature, relative humidity, mean radiant temperature, and air velocity.

In the first simulation (setup 1), the MPE for air temperature at locations 1, 2, and 3 was recorded at 0.6389%, 0.0669%, and 0.6761%, respectively. These results indicate that the highest deviation occurred at location 3, yet all points remained well within the established MPE<5% accuracy threshold. The MAPE for relative humidity across all three locations was 0.7863%, falling significantly below the 10% limit. The radiative heat analysis showed MPE values for MRT of 2.40%, 0.3317%, and 4.51% for locations 1, 2, and 3 respectively. While the maximum error was observed at location 3, it remained within the acceptable 5% variance. Conversely, the air velocity yielded a MAE of 0.357m/s, which exceeds the target threshold of 0.02m/s. This discrepancy suggests that a single-angle steady-state simulation is insufficient to capture the dynamic flow patterns of the classroom's fans.

In the second simulation (setup 2), the MPE for air temperature at locations 1, 2, and 3 was recorded at 0.4035%, 0%, and 0.6423%, respectively. These results indicate that the highest deviation occurred at location 3, yet all points remained well within the established MPE<5% accuracy threshold. Regarding hygrometric data, the MAPE for relative humidity across all three locations was 0.60%, falling significantly below the 10% limit. The radiative heat analysis showed MPE values for MRT of 2.81%, 0.2413%, and 4.45% for locations 1, 2, and 3 respectively. While the maximum error was observed at location 3, it remained within the acceptable 5% variance. Conversely, the air velocity yielded a MAE of 0.6687m/s, which exceeds the target threshold of 0.02m/s. This discrepancy in the setup 2 became more pronounced. The increased error in this configuration suggests that this specific fan angle created localized high-velocity zones.

In the third simulation (setup 3), the MPE for air temperature at locations 1, 2, and 3 was recorded at 0.7061%, 0.1338%, and 1.01%, respectively. These results indicate that the highest deviation occurred at location 3, yet all points remained well within the established MPE<5% accuracy threshold. Regarding hygrometric data, the MAPE for relative humidity across all three locations was 1.03%, falling significantly below the 10% limit. The radiative heat analysis showed MPE values for MRT of 2.18%, 0.8142%, and 4.67% for locations 1, 2, and 3 respectively. While the maximum error was observed at location 3, it remained within the acceptable 5% variance. Conversely, the air velocity yielded a MAE of 0.3693m/s, which exceeds the target threshold of 0.02m/s, similar to setup 1. While this result remains outside the strict validation limit, it completes the three-part sampling of the fans' range of motion. By capturing this angle of the airflow distribution, the study provided the necessary data points to calculate a comprehensive average, moving the research toward a more representative steady-state model.

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The comprehensive validation of the classroom model was achieved by averaging the results of three distinct fan-angle configurations shown in table 1, a methodology that effectively captured the time-averaged airflow of the orbital and oscillating fans within a steady-state framework. The approach successfully neutralized the localized discrepancies found in individual trials, which recorded a MAE as high as 0.6687m/s, resulting in a final air velocity MAE of 0.0266m/s. While the calculated MAE for air velocity marginally exceeds the strict ≤0.02m/s threshold, it remains well within the uncertainty range of physical instrumentation. The anemometer utilized for in-situ measurements (accuracy of ±4% + 0.1m/s) possesses a calculated uncertainty of ±0.1216 at the average recorded velocity. Thermal parameters also demonstrated high fidelity in the average model, with MPE for air temperature of 0.5828%, 0.0669%, and 0.7776% at location 1, 2, and 3 respectively. The average MPE for MRT are 2.46%, 0.3016%, and 4.55% at location 1, 2, and 3 respectively. The MAPE for relative humidity has an average 0.8065%. These results confirm that while a single-angle simulation is insufficient for dynamic fan movement, the average steady-state results provide a scientifically valid representation of the thermal environment.

TABLE 1. COMPARATIVE AVERAGE SIMULATION RESULTS

Parameters	Source / Location	Average Value	Source / Location	Average Value	Source / Location	Average Value
Air Temperature (°C)	Field 1	29.74	Field 2	29.9	Field 3	29.58
	CFD 1	29.913	CFD 2	29.92	CFD 3	29.81
Relative Humidity (%)	Field 1	59.08	Field 2	58.58	Field 3	59.67
	CFD 1	58.517	CFD 2	58.507	CFD 3	58.87
MRT (°C)	Field 1	32.05	Field 2	33.16	Field 3	31.68
	CFD 1	31.26	CFD 2	33.26	CFD 3	30.24
Air Velocity (m/s)	Field 1	0.39	Field 2	0.96	Field 3	0.28
	CFD 1	0.3913	CFD 2	0.968	CFD 3	0.2097

F. Spatial Distribution Contour Plots

Following the numerical validation of the CFD model, this section presents the spatial distribution of the classroom's thermal parameters through contour plots and flow trajectories.

The spatial distribution of air temperature across the three simulated setups is visualized through the contour plots in figure 6. These plots illustrate the thermal gradients within the classroom at a cross-sectional plane corresponding to 1.1m. Across all three configurations, majority of the classroom area remains within a stable temperature, indicated by the dominant green shading. The scale ranges from a minimum of 28.00°C to a maximum of 31.00°C, which increments of approximately 0.33°C per color band.

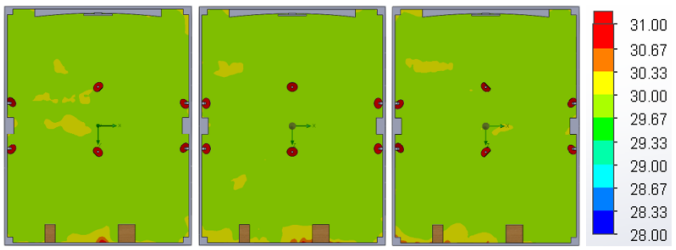


Fig. 6. Air Temperature Contour Plots

The spatial variance of relative humidity across the three simulated configurations is presented in figure 7. It presents the RH contour legend and has computational range from a minimum of 55.00% to a maximum of 60.00%. With increments of approximately 0.56% per color band, this high-resolution scale is designed to detect subtle shifts in moisture distribution caused by internal occupant latent loads and external air exchange.

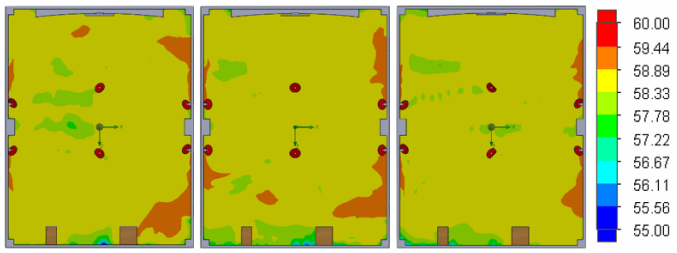


Fig. 7. Relative Humidity Contour Plots

In figure 8, the legend for the MRT contour plots establishes a quantitative range from a minimum of 30.00°C to a maximum of 35.00°C, with increments of 0.56°C per color band. Unlike the relatively uniform air temperatures profiles, the MRT plots reveal significant localized thermal plumes, and sharp gradients influenced by the classroom's geometry and external solar. The background radiant environment for most of the classroom seating area falls within the 1.0°C to 1.5°C range. These hot streaks primarily originate from the sun rays entering in the window and doors on the left side, illustrating the localized radiant heat gain from the windows. The presence of a consistent deep blue to cyan range in the classroom indicates that the internal radiant environment is primarily governed by the building's shaded surfaces rather than localized metabolic heat. This suggests that the high occupant density of 55 occupants does not significantly raise the MRT of the classroom.

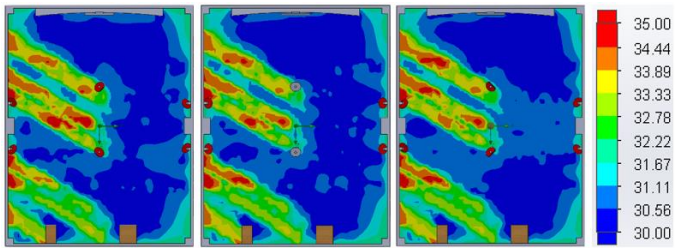


Fig. 8. Mean Radiant Temperature Contour Plots

The spatial distribution of air velocity across the three simulated setups is presented in figure 9. Areas shaded in red and orange represent air velocities exceeding 0.889 m/s, illustrating the core flow of the fans. The plots reveal significant spatial variance between the three setups, confirming that the fan's orientation drastically alters the localized cooling effect across the 55 occupants.

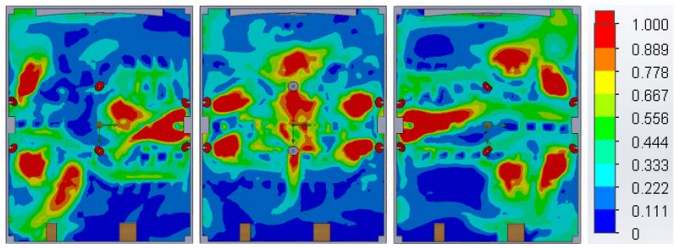


Fig. 9. Air Velocity Contour Plots

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IV. CONCLUSION

The study has established that standard architectural compliance with the PGBC does not guarantee thermal comfort in high-density tropical learning environments. While it was previously unquantified in the Philippine context, the study proves that even when classrooms exceed the 10% window-to-floor ratio and meet the 17 cmh/person ventilation rate, they still fail internationally recognized PMV/PPD comfort thresholds. This establishes a critical "compliance-comfort gap" that justifies a policy shift from measuring total opening area to evaluating actual spatial airflow distribution.

Furthermore, this study has established that air velocity, rather than air temperature, is the primary determinant of environmental viability in DepEd public-school classrooms, which was previously unsupported by local empirical data. As evidenced by the difference between the PMV model and the adaptive comfort model, this research establishes that elevated air speeds effectively extend the physiological tolerance of occupants. This makes fan-assisted natural ventilation a technically sufficient solution for the Philippine climate when properly distributed.

A significant methodological contribution of this work is the implementation of simulating three distinct fan-angle orientations, which enables the accurate representation of dynamic mechanical systems within a steady-state CFD framework. Previously, the oscillating and orbiting movement of fans presented a modelling limitation that often led to high localized errors. By simulating three distinct snapshots of fan angles and averaging the results, this study reduced individual setup air velocity errors to a validated.

Finally, the results of this assessment justify the adoption of the Adaptive Comfort Model as the official evaluative standard for DepEd infrastructure policy. By establishing that fan-assisted classrooms can remain within the 80% satisfaction threshold despite high ambient heat, this study justifies a sustainable, low-carbon cooling strategy that prioritizes convective pathing and strategic fan placement over the expensive installation of mechanical air conditioning.

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