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VARIATION OF NATURAL VENTILATION WITH FLOOR LEVEL AND ORIENTATION OF CLASSROOMS

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ABSTRACT

In recent times, the multi-storey school building has emerged as a new trend in Nigeria due to land cost in the urban area and population increase due to urban migration resulting from insecurity in rural areas. Among other factors, the floor level and orientation of space are believed to affect its natural ventilation. More so, electricity per capita consumption in Nigeria is very low, suggesting passive ventilation in the building. The ventilation in the classroom is usually through wind-driven systems (windows). The study sought to establish the variation of natural ventilation among classrooms on different floor levels and orientations. In the ex-post facto design, instruments were employed to observe wind speeds and directions in and around selected classrooms, in a school building block with two wings on three-floor levels, with a perimeter fence, and located in a built-up residential area. The classrooms on the ground floor were half-opened casement windows, while those on the upper floors had sliding windows. Data generated were subjected to descriptive statistical analysis. In the longer wing classrooms, the mean wind speed and standard deviation obtained were 0.17m/s and 0.123 on the ground floor; 0.15m/s and 0.104 on the first floor; and 0.18m/s 0.126 on the second floor. Corresponding results in the shorter wing classrooms were 0.12m/s and 0,077 on the ground floor; 0.11m/s and 0.095 on the first floor; and 0.17m/s and 0.126 on the second floor. Ventilation coefficients were 0.13, 0.11 and 0.13 respectively on the ground, first, and second floors in the longer wing classrooms, while those in the shorter wing classrooms were 0.13, 0.12 and 0.19 respectively. The findings revealed some direct variation in natural ventilation with the floor level in the studied classrooms, which was more manifested as the level of the floor increased upwards. In conclusion, the floor level and orientation affect wind-driven ventilation. As such, there is also a need for further field studies on more suitable cases (higher floor levels) to ascertain the level of significance of this variation and the optimisation window area base on floor levels for orientation for wind-driven natural ventilation.

Keywords: **Classroom, hot-wire anemometer, natural ventilation, Orientation, Wind-driven ventilation.**

1.0 INTRODUCTION

Natural ventilation (NV) is a long-term strategy for increasing building energy efficiency and lowering carbon emissions (Song et al., 2021). In recent times, the multi-storey school building has emerged as a new trend in Nigeria due to land cost in urban areas and urban migration due to insecurity in rural areas. More so, electricity per capita consumption is very low, suggesting passive ventilation in the building (Aaron and Felix, 2020; Ayoosu, Lim, Leng, and Idowu, 2021). The energy-saving and thermal comfort potential of natural ventilation in multi-storey buildings through architectural strategies have been enunciated in the literature (Zomorodian and Nasrollahi, 2013). Such systems could be based on incorporating features that enhance wind-driven or buoyancy-driven (stack effect) ventilation or both (Zhang et al., 2021).

The wind-driven ventilation is dependent on wind pressure differentials across building zones, the magnitude of which changes with airspeed following the Venturi effect or Bernoulli's principle of fluid dynamics (Blocken, Moonen, Stathopoulos, and Carmeliet, 2008; Kamela, 2007; Khan, Su, and Riffat, 2008). The airspeed on the windward side of the building reduces as it collides with the building resulting in an increased pressure (Boutet, 1987; Yi et al., 2019). Conversely, the airspeed on the top and the leeward sides of the building rises, resulting in reduced pressure (Song et al., 2018). The pressure effect of the wind on a building is primarily dominated by the building's shape, wind velocity and direction (Liu et al., 2021; Wood and Salib, 2013). The American Society of Heating, Refrigerating and Air-conditioning Engineers, ASHRAE (1995) enunciated that the magnitude of the speed of unobstructed wind outdoor increases exponentially with a limited height above ground level. The changes in airflow pattern created by building obstruction increase the wind velocity at the base and side of the building much above the speed of the unobstructed air stream (Boutet, 1987; Wood and Salib, 2013).

Recent empirical studies have indicated that natural ventilation could be enhanced in tall buildings by incorporating architectural features like window openings optimally. A survey of passive architectural design elements has identified window type as another strategy for improving natural ventilation. It opined that a projected window is desirable for optimal ventilation, followed by a casement window (Ayoosu, Lim, Leng, Aule, and Gabriel, 2020). However, window design in multi-storey classroom buildings considered the aesthetics concept of symmetry and balance where the same window sizes are employed irrespective of floor level and orientation. More so, most of the studies, including Acred and Hunt (2014) and Raji, Tenpierik, Bokel, and van den Dobbelsteen (2020), focus only on natural ventilation buoyancy-driven design strategies and features such as atria, solar chimneys and double-skin facades. But the buoyancy-driven ventilation strategies may not be suitable for some uses, such as schools, and little is known or reported on empirical studies on wind-driven ventilation in tall buildings for such uses. The study seeks to ascertain the effect of floor level and space orientation differentials on wind-driven natural ventilation in classrooms in a school's multi-storey building.

2.0 MATERIALS AND METHOD

The research design employed in this study is the causal-comparative or Ex-post facto as espoused in Firdaus, Zulfadilla, and Caniago (2021) and Koleoso (1999), in which the dependent variables (floor level and orientation) were observed after the facts of the independent variables (classroom). The study object was a block of a school building with two wings and three-floor levels. The school building (Bilsag Unique International Academy, Jimeta-Yola, Nigeria), enclosed in a perimeter wall fence, was found most suitable among similar ones due to its location within the neighbourhood low-rise buildings, vegetation and other obstruction to airflow, as well as due to ease of accessibility as shown in figure 1 (a). The classrooms on the ground floor were half-opened casement windows, while those on the upper floors had sliding windows. At each wing of the building, a cluster of

Classrooms on the three floors with direct adjacency were selected for the study. Hot-wire anemometer was employed to observe wind speed five times, at intervals of five seconds, at six points in the classroom on a reference height of 1200mm above the finished floor level in each of the selected classrooms, as shown in figure 1 (b-d). The observations were simultaneously conducted in all the classrooms in each wing and on the ground outside the perimeter wall fence. While taking the readings, all window was kept open throughout. An improvised wind vane placed beside the outdoor wind speed equipment was deployed to observe wind direction. The data generated were analysed with descriptive statistics, including mean, standard deviation and frequency. The ventilation coefficient was computed by dividing the mean indoor wind speed by mean outdoor wind speed.

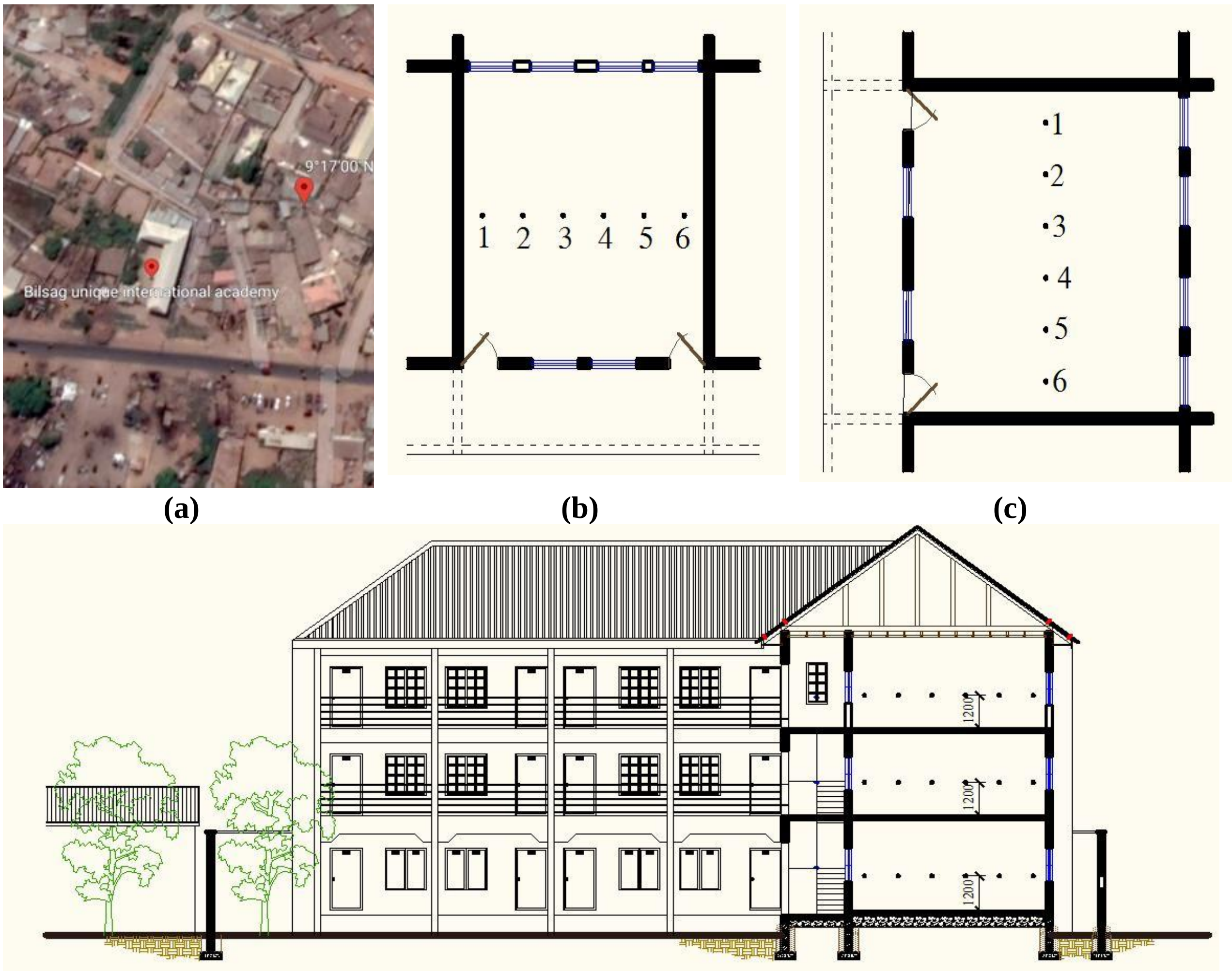

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Figure 1 The study Site/Building: (a) site; (b) Short wing classroom floor plan; (c) Long wing classroom floor plan; (d) site/building typical section

3.0 MAIN RESULTS

The wind speeds observed in the classrooms along the longer wing of the studied building are presented in table 1, while those of the shorter wing is presented in table 2. On the other hand, figures 2 and 3 are graphical indications of the variation in outdoor wind speeds concerning the longer and shorter wings observations. An illustration of the variation of the derived mean ventilation coefficients in the six studied classrooms is in figure 4. The relative incidence or dominance of outdoor wind directions observed in the study is illustrated in figure 5.

In the longer wing of the building, the mean wind speed in the classroom on the ground floor is 0.17m/s (standard deviation, 0.123); those of the classrooms on the first floor and second floor, respectively, are 0.15m/s (standard deviation, 0.104) and 0.18m/s (standard deviation, 0.126). The derived ventilation coefficients in the classrooms are 0.13 on the ground floor, 0.11 on the first floor and 0.13 on the second floor. Wind directions normal (NML) or at acute angles (ACA) to the external walls of the classroom were majorly recorded, with a minor parallel (PRL) incidence.

On the other hand, in the shorter wing, 0.12m/s is the mean indoor wind speed (with a standard deviation of 0.077) observed in the classroom on the ground floor. In the classrooms on the first floor and second floor, the mean indoor wind speeds are 0.11m/s (with a standard deviation of 0.077) and 0.17m/s (with a standard deviation of 0.077). The ventilation coefficients derived from the mean indoor wind speeds in the classrooms are 0.13 on the ground floor, 0.11 on the first floor and 0.17 on the second floor.

It was found that there is no difference in the ventilation coefficients of the classrooms between the two wings on the ground floor. However, there are differences in the ventilation coefficients in the study classrooms between the wings and even between the floors on a wing on the upper floors. It seems to suggest that natural ventilation varies with differences in floor level in multi-storey buildings as envisaged from extant literature (ASHRAE,1995; Wood and Salib, 2013).

Also, there is no consistency in both the magnitude and direction of the observed differences among the ventilation coefficients in the study classrooms. Whereas there is a decrease in ventilation coefficients of the classrooms from the ground floor to the first floor, there was an increase from the first to the second floor. The inconsistency may be due to the effects of the variation in classroom window types between the ground floor and the upper floors on the one hand and the perimeter wall obstruction to wind airflow on the ground floor on the other. The casement window type of the ground floor classrooms might create higher wind pressure differentials than the sliding windows on the upper floor classroom walls, even though the window opening areas are approximately the same across the three floors. In the same vein, a higher-pressure differential might also be created by the perimeter wall adjacent to the ground floor classrooms and thus induce higher ventilation in the ground floor classrooms than in the second-floor classrooms.

The difference in the ventilation coefficients between the classrooms on the second floor is higher in magnitude than between those on the first floor. The cause of this variation is not very clear, but it might not be unconnected with the variation in the incidence of wind directions, as illustrated in figure 4. There seem to be a higher prevalence of wind incident on the corridor and blowing normal or at an acute angle to the classrooms on the building shorter wing,

Table 1 Longer wing classrooms observed wind speeds (m/s)

Ground Floor					First Floor						Second Floor				
0.28	0.27	0.07	0.08	0.19	0.13	0.14	0.11	0.04	0.27	0.37	0.38	0.11	0.06	0.24	0.56
0.38	0.14	0.05	0.03	0.19	0.16	0.14	0.16	0.21	0.25	0.26	0.29	0.03	0.15	0.05	0.37
0.43	0.17	0.01	0.12	0.5	0.32	0.12	0.25	0.03	0.14	0.14	0.32	0.10	0.04	0.26	0.22
0.47	0.25	0.03	0.24	0.04	0.65	0.06	0.20	0.16	0.30	0.03	0.42	0.11	0.18	0.11	0.13
0.31	0.39	0.1	0.12	0.05	0.25	0.02	0.13	0.06	0.15	0.01	0.22	0.11	0.08	0.09	0.31
0.15	0.17	0.31	0.06	0.02	0.19	0.10	0.07	0.11	0.27	0.06	0.13	0.35	0.03	0.16	0.21
0.10	0.11	0.07	0.29	0.07	0.10	0.13	0.21	0.21	0.14	0.01	0.18	0.16	0.08	0.31	0.07
0.15	0.22	0.24	0.08	0.22	0.28	0.23	0.04	0.23	0.02	0.01	0.15	0.21	0.08	0.16	0.10
0.11	0.04	0.15	0.01	0.14	0.08	0.18	0.16	0.23	0.15	0.04	0.16	0.28	0.17	0.35	0.01
0.30	0.14	0.03	0.09	0.17	0.06	0.09	0.07	0.18	0.19	0.16	0.47	0.23	0.20	0.12	0.06
0.28	0.11	0.05	0.38	0.32	0.19	0.25	0.09	0.10	0.16	-----	0.37	0.05	0.02	0.01	0.15
0.13	0.06	0.28	0.23	0.15	0.25	0.06	0.06	0.12	0.09	-----	0.41	0.09	0.06	0.09	0.20
N=60	*Mean=0.17 VC = 0.13*		*SD=0.123*		*N=70*		*Mean=0.15 VC = 0.11*		*SD=0.104*		*N=60*	*Mean=0.18 VC = 0.13*		*SD=0.126*	

Mean outdoor wind speeds 1.36m/s; SD = 0.872

Table 2 Longer wing classrooms observed wind speeds (m/s)

Ground Floor						First Floor						Second Floor				
0.13	0.12	0.03	0.24	0.05	0.06	0.25	0.1	0.1	0.17	0.02	0.15	0.18	0.1	0.09	0.11	0.18
0.25	0.08	0.11	0.42	0.06	0.1	0.07	0.07	0.07	0.18	0.01	0.07	0.19	0.03	0.16	0.07	0.14
0.24	0.07	0.15	0.18	0.05	0.1	0.15	0.09	0.09	0.25	0.03	0.14	0.39	0.31	0.25	0.21	0.13
0.17	0.2	0.13	0.02	0.04	0.15	0.07	0.01	0.01	0.05	0.11	0.21	0.31	0.2	0.14	0.23	0.16
0.1	0.18	0.08	0.03	0.02	0.11	0.02	0.05	0.05	0.01	0.16	0.01	0.44	0.08	0.18	0.08	0.11
0.31	0.13	0.05	0.07	0.15	0.03	0.21	0.16	0.16	0.04	0.05	0.01	0.29	0.13	0.15	0.05	0.06
0.15	0.43	0.08	0.12	0.16	0.17	0.19	0.06	0.06	0.01	0.02	0.17	0.3	0.08	0.06	0.08	0.22
0.12	0.13	0.28	0.07	0.1	0.12	0.18	0.26	0.26	0.07	0.09	0.01	0.06	0.03	0.11	0.08	0.14
0.11	0.24	0.06	0.06	0.03	0.18	0.07	0.04	0.04	0.05	0.12	0.01	0.16	0.05	0.1	0.04	0.4
0.05	0.17	0.03	0.17	0.05	0.18	0.09	0.13	0.13	0.05	0.05	0.11	0.21	0.1	0.25	0.05	0.08
0.13	0.13	0.15	0.07	0.16	0.13	0.1	0.01	0.01	0.15	0.03	0.15	0.24	0.07	0.25	0.13	0.1
0.17	0.13	0.02	0.13	0.13	0.11	0.53	0.03	0.03	0.1	0.04	0.18	0.42	0.03	0.37	0.05	0.01
0.09	0.08	0.07	0.07	0.2	----	0.06	0.11	0.11	0.03	0.1	0.08	0.75	0.09	0.08	0.18	0.07
0.08	0.13	0.1	0.05	0.25	----	0.29	0.23	0.23	0.1	0.06	0.09	0.4	0.16	0.38	0.13	0.02
0.15	0.16	0.14	0.01	0.1	----	0.14	0.03	0.03	0.03	0.09	0.25	0.14	0.07	0.12	0.14	0.04
0.05	0.06	0.08	0.09	0.01	----	0.26	0.01	0.01	0.07	0.01	0.05	0.28	0.1	0.16	0.06	0.05
0.08	0.03	0.13	0.12	0.07	----	0.07	0.11	0.11	0.04	0	0.05	0.51	0.13	0.07	0.14	0.28
0.19	0.12	0.05	0.06	0.21	----	0.19	0.05	0.05	0.1	0.02	0.18	0.25	0.28	0.08	0.21	0.21
N=102		*Mean=0.12 VC = 0.13*		*SD=0.077*			*N=108*	*Mean=0.11 VC = 0.12*		*SD=0.095*		*N=90*	*Mean=0.17 VC = 0.19*		*SD=0.126*	

Mean outdoor wind speed = 0.90m/s; SD = 0.753

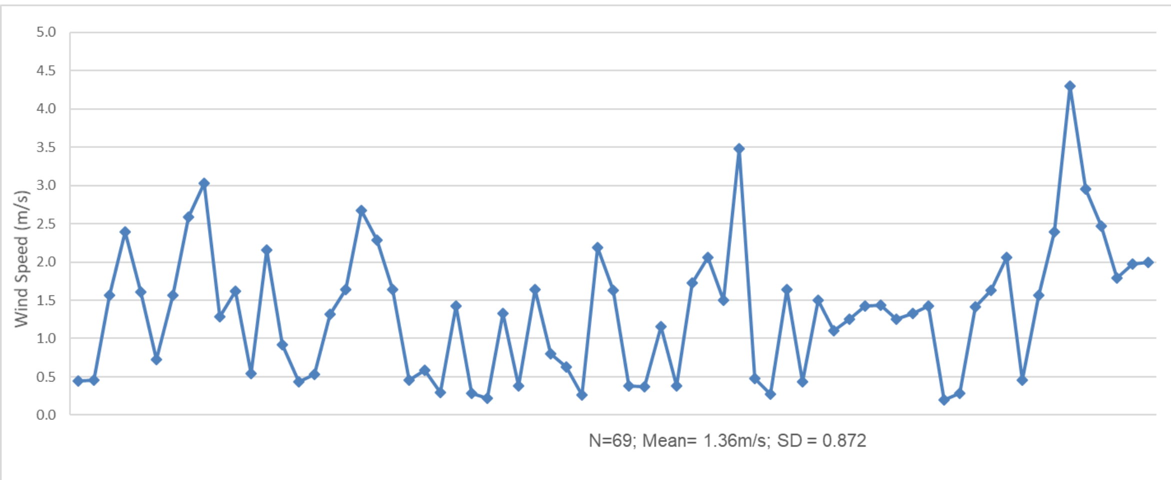


Figure 2 Longer wing (L/wing) outdoor wind speeds

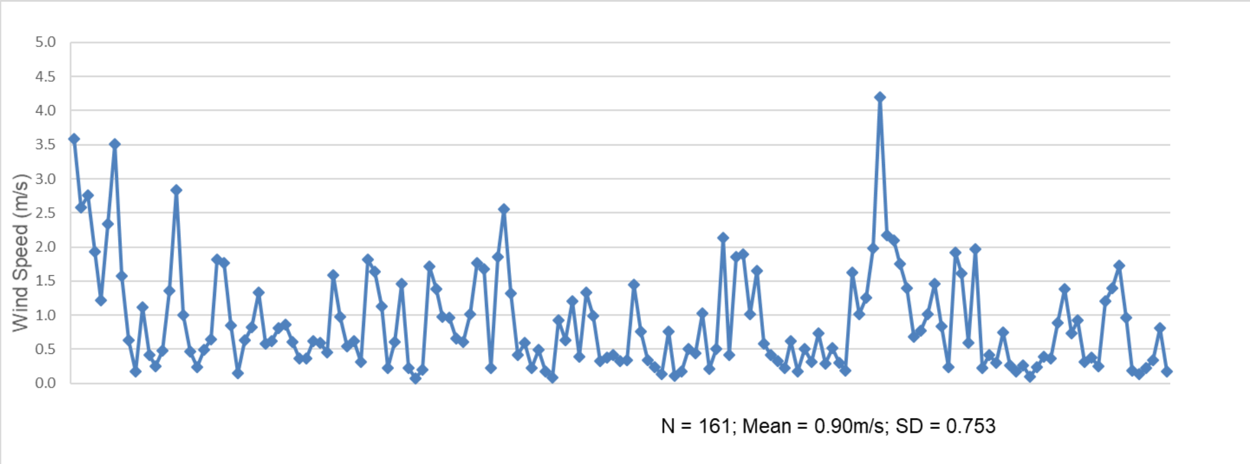


Figure 3 Shorter wing (S/wing) outdoor wind speeds

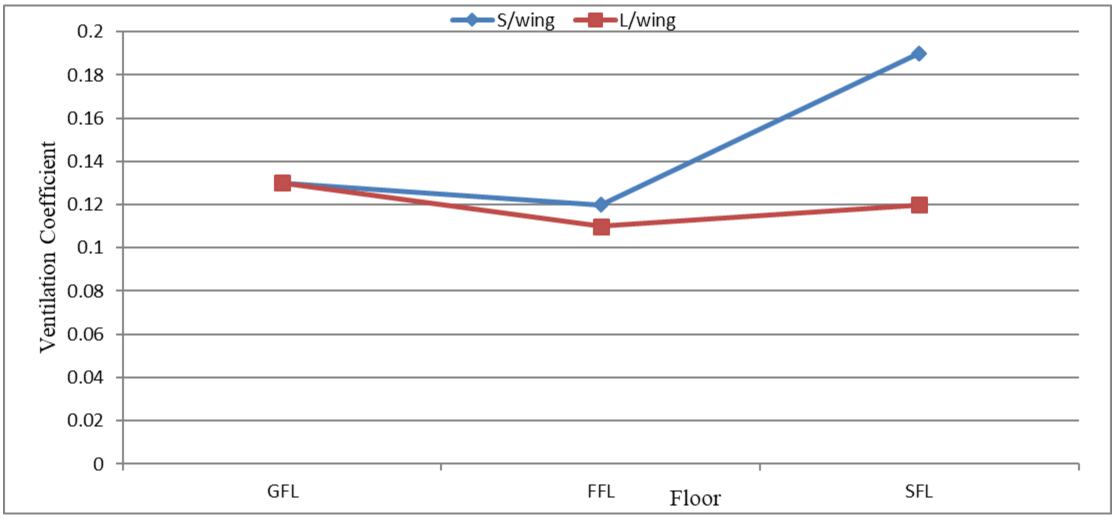
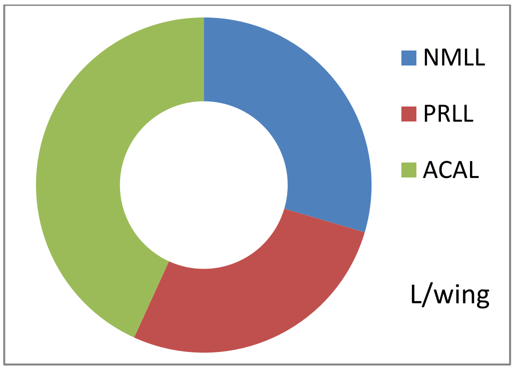


Figure 4 Derived ventilation coefficients in the study classrooms



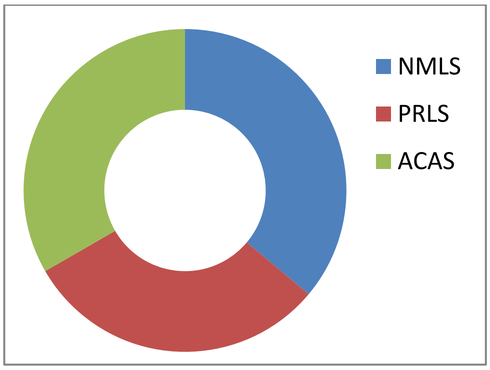


Figure 4 Study outdoor predominant wind directions relative to classroom external walls (NML = Normal; PRL = Parallel; ACA = Acute angle)

4.0 CONCLUSION

The effects of floor level and orientation differences on natural ventilation in two-storey school building classrooms were investigated in this study. The findings revealed some direct variation in natural ventilation (ventilation coefficient) with the floor level of the classrooms under investigation, which is more manifested in the two upper floors. However, the variation might not be significant. There is a need for further field studies on more suitable cases to ascertain the significance of this variation and the optimisation of floor levels for orientation-based wind-driven ventilation. It noted that the application of casement rather than sliding windows in classrooms on all the floors would enhance natural ventilation in the building and similar buildings in the study area. Further field studies need to be conducted on more suitable cases (higher floor levels) to ascertain the level of significance of this variation and the optimisation window area base on floor levels for orientation-based wind-driven ventilation.

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