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NUMERICAL ANALYSIS OF WINDCATCHERS CAPACITY TO PREVENT THE SPREAD OF COVID-19 IN CLASSROOMS

[1]Ibrahim Usman Haruna, [1]Mohammed Hassan Idris and [1]Muhammad Idi Tikau

[1.] Department of Mechanical Engineering, Federal Polytechnic Mubi

Corresponding Author Email Address: heldabuk@yahoo.com; +234 803 116 5647

Abstract

Introduction of fresh outdoor air into classrooms and advancing the indoor air qualities are among the concrete layered strategies for mitigating the spread of the SARS-CoV-2 virus (COVID-19). The introduction of outdoor fresh air into classrooms through the window openings using natural ventilation is poor due to low wind speed, inadequate window geometry, and perhaps the blocking of airflow paths by obstacles. The erratic nature of grid supply and the operational cost of running generating plants for continuous use of ceiling fans in classrooms are impractical. Furthermore, the use of refrigeration-based air conditioning system is associated with high investment and operational costs, poor indoor air quality, high energy consumption, and negative impact on the environment. In this study, the potential of wind-catcher in improving ventilation and indoor air quality in classrooms to checkmate the spread of COVID-19 was numerically investigated. A hypothetical model of the wind-catcher integrated into a classroom was developed using solid works software. The indoor air quality (IAQ) in the classroom in terms of the mean age of air (MAA) and air change effectiveness (ACE) in the occupants' breathable zone was numerically determined using computational fluid dynamics (CFD) during the dry season in March and wet season in August. The temperature in the classroom in these seasons was also numerically determined. The MAA, ACE, and temperature in March were determined to be 31.83 seconds, 1.23 and 25.4℃ respectively while, in August were 43.57 seconds, 1.09 and 23.9℃ respectively. These values of MAA and ACE in both wet and dry seasons indicate that the IAQ in the classroom integrated with the wind-catcher is enough for mitigating the transmission of COVID-19 based on the guidelines of the ASHRAE Epidemic Task Force for schools and universities. Therefore, school authorities are implored to adopt the technique of equipping classrooms with wind-catchers for minimizing the spread of coronavirus among school children.

Keywords: COVID-19, Wind-catcher, MAA, ACE, CFD

INTRODUCTION

2019 saw an outbreak of the coronavirus illness around the world (Liu et al, 2020). The transmission risk of the novel severe acute respiratory syndrome 2 (SARS-CoV-2) was first confirmed by the National Health Commission of the Republic of China (Wang & Du, 2020), and later by the Centre for Disease Control and prevention. The outbreak of the dreaded COVID-19 had practically brought the world to almost standing still. Virtually all sectors were paralyzed by the lockdown as a result of the outbreak.

The education sector, like other sectors, was seriously affected by the COVID-19 lockdown. All schools were closed and students were forced to stay at home. A healthy building is among the risk reduction strategies recommended by World Health Organization (WHO) and UNICEF provided guidelines for preventing the spread of COVID-19 in schools (IASC, 2020). The concrete layered strategies recommended for mitigating the spread of COVID-19 in school buildings include but not limited to the following:

i. Increase outdoor air ventilation
ii. Filtration of indoor air
iii. Use of plexiglass as a physical barrier
iv. Improving the indoor air quality
v. Installation of no-contact infrastructure
vi. Surfaces should always be kept clean
vii. Bathroom hygiene should be improved

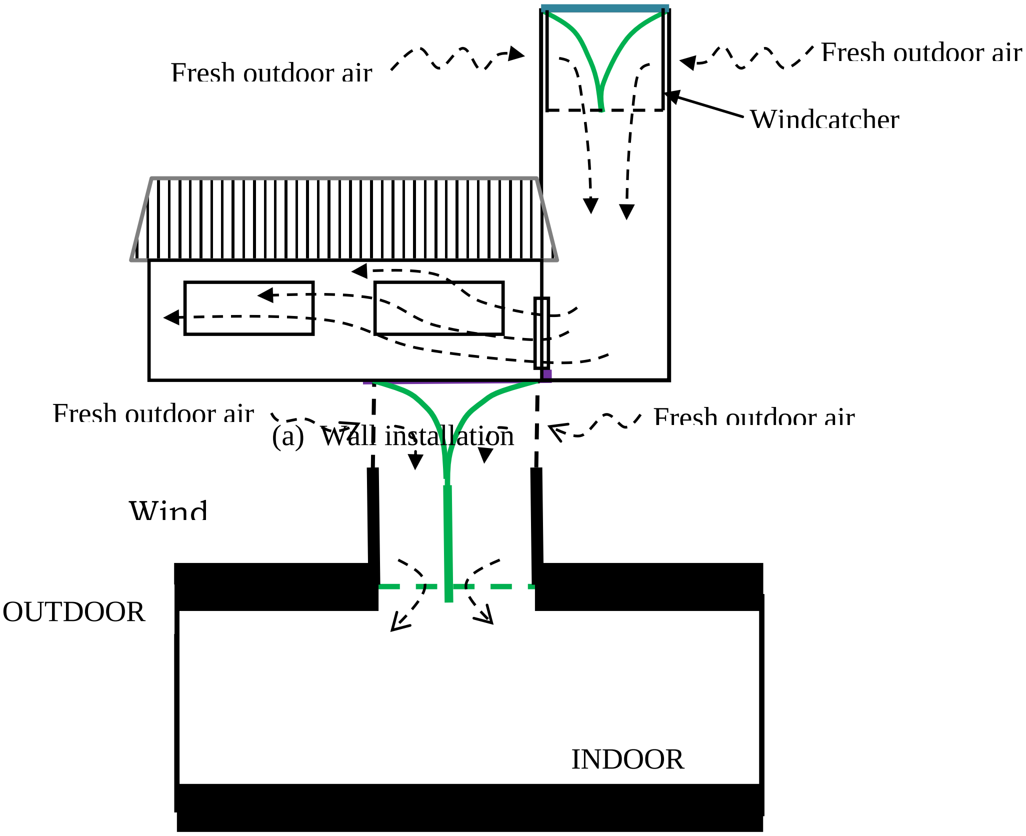
The increase in the introduction of outdoor air and the enhancement of indoor air quality are among the aforementioned layered strategies for the mitigation of the building inhabitants from the inhalation of contaminated aerosols. Aerosols are microparticles with a diameter smaller than $5\mu m$, containing pathogens, which having been released in the air, are transported by the flow of air current, thus been able to cause diffusion even at a considerable distance (Feng et al, 2020). A study has shown that the SARS-CoV-2 virus remains practical in aerosols for about three hours (Feng et al, 2020). This implies that adequate air ventilation in the classrooms may be able to reduce the concentration of the dreaded virus per unit volume of indoor air. Furthermore, improving the indoor air quality in the classroom enables the occupants to breathe healthy air free of coronavirus.

In developing countries like Nigeria, the use of refrigeration-based air conditioning systems for the provision of adequate airflow in buildings is encountered by so many challenges. Among these challenges is the epileptic nature of grid supply, high investment, running and maintenance costs (Benkari et al., 2017). Furthermore, the conventional air-conditioning system has a low indoor air quality due to the recirculation of air with the partial fresh air replacement and also, harms the environment (Marcel et al., 2020). The window-to-wall (WWR) of most classroom windows are between 10% to 17% (Sani, 2918) and this range of WWR is below the standard WWR of 22%-24% recommended by ASHRAE Standard-55 (2010) for thermal comfort in buildings under natural ventilation settings. Also, achieving good indoor air quality in the classroom is impeded in low wind situations and the blockage of the window openings by external objects such as buildings, trees, etc. Mechanical ventilation using ceiling fans, apart from relying on the epileptic grid supply, cannot remove warm air in buildings and also add to the cooling load due to the heat that emanates from the fan motor and the friction between fan blades and air molecules (Cengel, 2002). Therefore, the need to use a sustainable ventilation system in classrooms during this COVID-19 epidemic is imperative. Windcatcher is one of these sustainable ventilation systems.

The wind catchers are architectural elements used for natural ventilation. They generally take the form of small towers installed on top or side buildings to draw fresh air from outside into a building, providing natural ventilation and enhanced indoor air quality (Hosseini et al., 2016). Compared to the conventional air conditioning system, they don't require a power supply for their operation, are environmentally friendly, have low investment and running costs, have low or no maintenance cost,, and can work throughout the day. The location of the windcatchers at an elevated level enables them to capture high velocity and clean air and then channel it to the interior of the buildings.

Principle of Operation of Windcatcher

The principle of operation of windcatcher natural ventilation system is mainly based on wind-driven ventilation and buoyancy (stack) effect (Coles & Jackson, 2007; Hughes, Calautit, & Ghani, 2012). During the day time, the movement of wind at an elevated level above the roof level creates positive pressure on the windward side of the structure and at the same time produce negative pressure on the leeward side. This pressure difference is highly sufficient to deliver fresh outdoor air to the space and at the same time extract warm and stale air out (Iyengar, 2013) (Hughes & Cheuk-Ming, 2011). During the night-time, in the absence of air movement or in low wind conditions, the windcatcher operates like a thermal chimney (Sayigh, 2013; Mahyari, 1996) in which it utilizes the air temperature gradient between inside and outside of a building. Whenever the outdoor air temperature is considerably lower than the indoor air temperature, the pressure difference and air density gradient of the internal and external air masses make the low dense indoor to rise and expel through the windcatcher leeward side; simultaneously, fresh, cool, and dense air descends through the windward side of the devices (Mahmoudi, 2009). Figure 1 (a and b) shows window and roof installed windcatchers to buildings.



(a) Wall installation

(b) Roof Installation

Figure 1: Windcatcher Installed to Buildings

It is worthy to note that the impact of wind pressure driven flow is more effective than buoyancy driven force by about 76% (Masrous et al., 2012).

Therefore, the installation of windcatchers to classrooms will enhance the introduction of clean and adequate air into classrooms which can along with other concrete layered strategies mitigate the spread of COVID-19.

METHODOLOGY

A hypothetical model of the students in a classroom was developed using solid works software as shown in Figure 2. The classroom model has dimensions of $20m \times 10m \times 4m$.

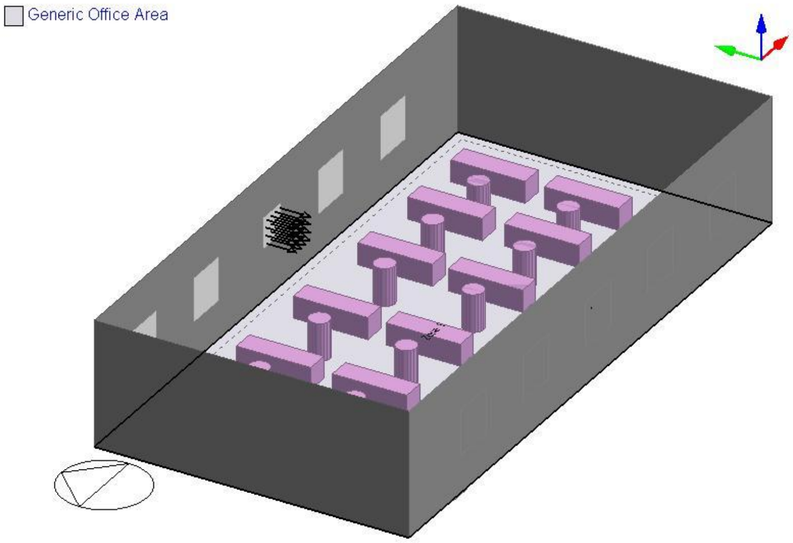


Figure 2: Hypothetical Model of the Classroom Equipped with Windcatcher

Weather Data

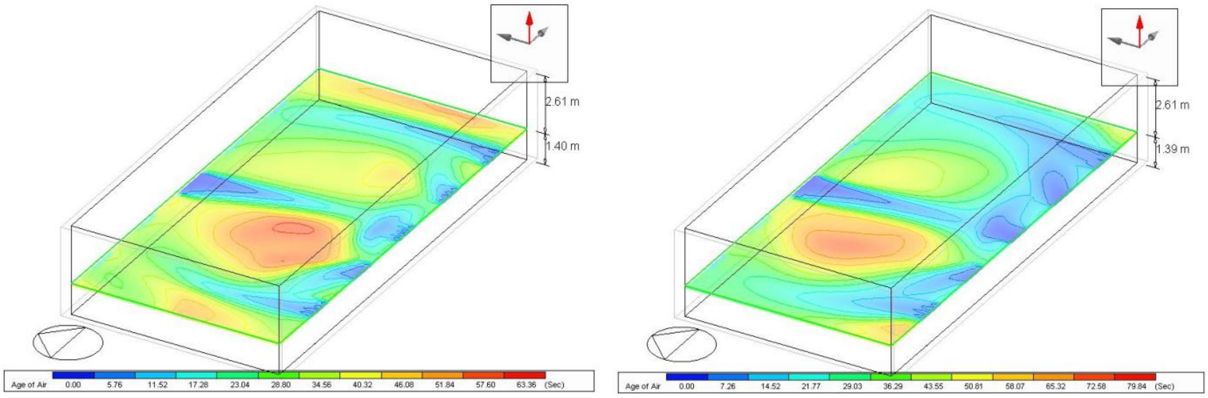
Past weather data for 15 years (2014-2019) were obtained from World Meteorological Organization (WMO, 2011). These weather data were averaged over 15 years to be used in the CFD simulation. The pertinent weather data considered in this study were temperature, relative humidity, and wind speed.

Computational Method and CFD Modelling

The computational method of the windcatcher integrated to the classroom was developed and then imported for CFD analysis. Then the appropriate boundary conditions and turbulence model are set. A computational model assuming steady incompressible flow under a turbulent flow regime was used to investigate the airflow, distribution, and thermal conditions in the hypothetical model.

Analysis of the Mean Age of Air (MAA)

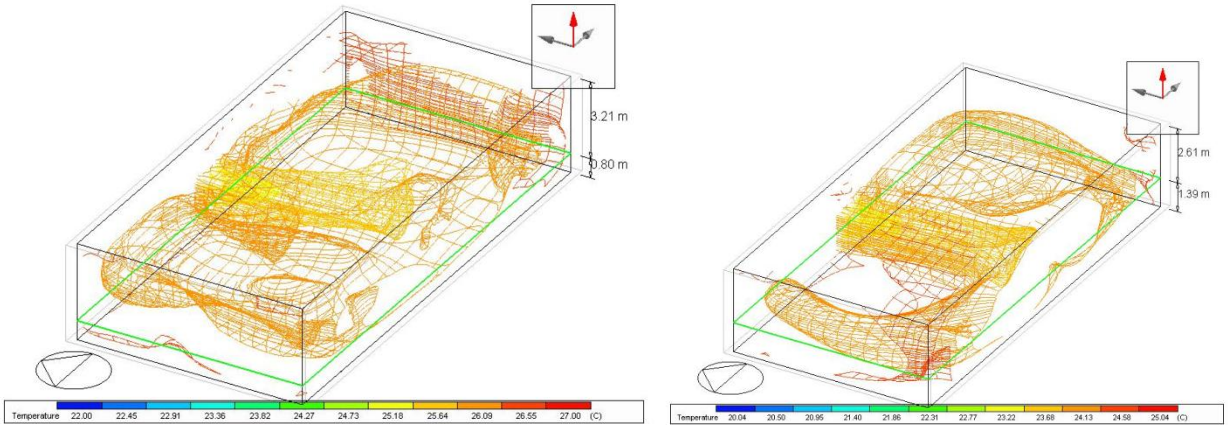
The MAA is used in indoor air quality studies for the evaluation of the supply air distribution in space. Therefore, its value reflects the flow characteristics of the air supply by the windcatcher. The MAA distribution in the classroom was numerically determined using CFD simulation during the dry season in March and wet season in August. The 3D contour plots of the MAA in the dry and wet seasons are shown in Figure 3 (a and b).



(a) Dry Season (b) Wet Season

Figure 3: 3D Contour Plot of the MAA

The temperature inside the classroom in the dry season in March and wet season in August were also analysed using the CFD numerical simulation and the 3D contour plots of the temperatures inside the classroom model in this seasons are shown in Figure 4 (a and b)



(a) Dry Season (b) Wet Season

Figure 4: 3D Contour Plot of Temperature in the Classroom Model

Analysis of Air Change Effectiveness (ACE) in the Classroom

The ACE in the classroom was numerically evaluated in the breathing zone of the occupants. The breathing zone of the occupants of the classroom has the coordinate $X = 10.000, Y = 4.343, Z = 7.121$, and is shown in Figure 5.

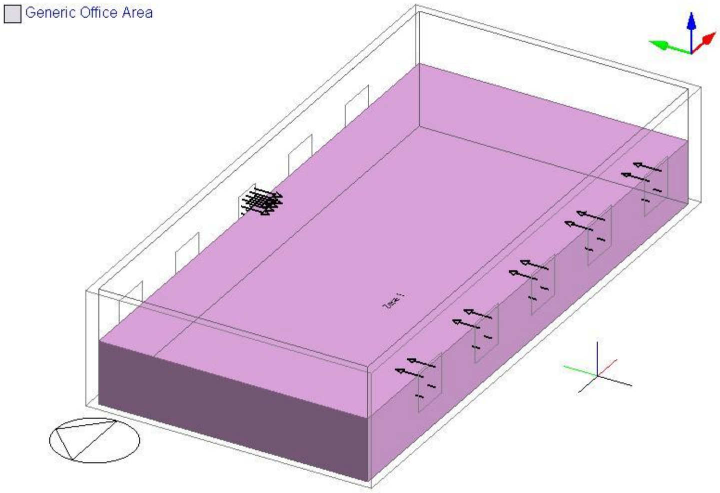


Figure 5: Breathable Zone of Occupants in the Classroom

RESULTS AND DISCUSSION

Figure 3 show that the MAA in the month of March and August were 31.83 seconds and 43.57 seconds respectively. This means that during both dry and wet seasons the resident time of the air in the classroom is very small. This implies that the resident time of the air of the classroom assuming to be contaminated with COVID-19 is very short and therefore, the contaminated air will quickly be expel out the windows of the classroom.

The ACE in the classroom occupants' breathable zone in both dry and wet seasons were 1.23 and 1.09 respectively. This implies that the quality of air in the breathable zone of the occupants in both seasons has met the requirement of ASHRAE Standard-55, 2010. According to ASHRAE Epidemic Task Force on COVID-19 in schools and universities, the minimum required ACE of 0.5 should be maintained in the breathable zone of the occupants. It is evident here that the ACE in both seasons are greater than 0.5 which is an indication that the air in the breathable zone is of high quality. Furthermore, the values of ACE in both seasons indicate the windcatcher supplies air directly into the occupants breathable zone. This agrees with the work of ASHRAE Standard-55 (2010) who stated that supplying outdoor air directly into occupants' breathable zone gives the value of ACE greater than unity.

From Figure 4, the temperatures in the classroom during the dry and wet seasons were 25.4℃ and 23.9℃ respectively. This shows that during both seasons the indoor temperatures were within the thermal comfort zone. According to ASHRAE Standard-55, 2010, human beings wearing normal clothing are thermally comfortable at temperature range of 23℃-27℃.

CONCLUSION

The potential of using windcatcher to mitigate the spread of the deadly coronavirus in classrooms during the dry and wet seasons was numerically investigated. Employing the recommended protocols for the mitigation of COVID-19 in schools and universities by WHO, UNICEF, NCDC, and ASHRAE Epidemic Task Force, the numerical results of the MAA and ACE in both seasons indicate that the windcatcher is capable of slowing the spread of COVID-19 and at the same time maintaining a comfortable temperature in the classroom. Therefore, school authorities are implored to embrace this technology in mitigating the spread of COVID-19 in classrooms.

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