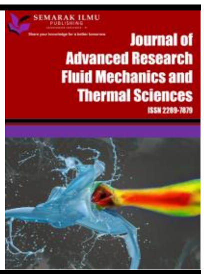
SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



Airflow Distribution of Hall and Classroom as Temporary Evacuation Centers: A Case Study in Melaka

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ARTICLE INFO

Article history:
Received 24 May 2022
Received in revised form 23 September 2022
Accepted 1 October 2022
Available online 25 October 2022

Keywords:
Airflow distribution; Temporary Evacuation Centers; air velocity

ABSTRACT

During floods, the Malaysian Department of Welfare (JKM) oversees the opening and assigning of victims to evacuation centres. Public buildings such as school classrooms and community halls act as Temporary Evacuation Centers (TEC) that can last up to two weeks. The foldable tents will be provided to each family at the evacuation centres to assure that the victims have personal space. For privacy and separation, they were confined in a temporary tent with only a few fans from the building to keep their comfort. Therefore, the thermal comfort level within the temporary tent is usually affected by the airflow distribution from naturally ventilated buildings from building layout and design. In this study, two independent public buildings were hall (School A) and a classroom (School B) in Melaka, Malaysia, were investigated to simulate the airflow distribution accordingly. In-situ air sampling measures were performed using indoor air sampling techniques for 24 hours to measure the air velocity, air temperatures, and relative humidity in the building. Airflow distribution throughout the floor was used to simulate the airflow with the Computer Fluid Dynamics (CFD) model to identify the airflow direction. The average airflow rate between Schools A and B was 0.19 ms^{-1} and 0.27 ms^{-1}, respectively, after the data collection. Meanwhile, the average air temperature between Schools A and B was 30.3℃ and 29.4℃, respectively. Therefore, School B's classroom layout is the best model for forecasting airflow rate, air velocity, and temperature for the evacuation center.

1. Introduction

Malaysia has been hit by a series of significant floods in recent decades due to the natural and human forces caused. Malaysians are a riverside people by nature, as their early dwelling areas evolved along the banks of the peninsula's major rivers [1]. Floods have become the norm for many Malaysians because of natural reasons such as excessive monsoon rainfall, severe convective rainstorms, inadequate drainage, and other local variables [2]. According to the World

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https://doi.org/10.37934/arfmts.100.2.157168

Meteorological Organization (WMO), flood is the third most lethal natural hazard, with several lives lost and property damaged [3]. Flood is caused by a combination of environmental factors like heavy rain, storm surges, insufficient drainage infrastructure, and dam structural failures [4]. Therefore, the flood problems in Malaysia caused by the monsoon and flash floods continue even though the government has implemented various structural and non-structural plans to reduce their effects [5]. Malaysia's government initiated the Natural Disaster Management and Relief Committee (NDMRC) in 1972 to coordinate flood relief operations at all levels of government, including national, state, and district, with the joint goal of minimizing flood damage and avoiding human death [6].

Evacuation centers are designated as safe havens for displaced persons due to specific situations, such as catastrophes (natural hazards such as floods, hurricanes, and fire, where people must leave their own homes due to its risks). Evacuation facilities are designed to handle people who have been exposed to such dangers [7]. Evacuation is necessary when a flood occurs, especially in populated areas. Malaysia Department of Welfare or Jabatan Kebajikan Masyarakat (JKM) Malaysia will be responsible for organizing victims in the evacuation centres. The Social Welfare Department was established in April 1946. Within a period of 72 years, JKM has evolved through many phases in fulfilling its role in national development. From its involvement with major problems caused by the Second World War, the role and functions of the department have expanded to include prevention and rehabilitation services of social issues and community development. As one of the government agencies with an important role in social development, Melaka's state government has identified 46 flood-prone sites across three districts. The preparedness steps for floods have been implemented to deal with the tragedy in the future. Melaka Tengah and Jasin districts have 15 areas, whereas Alor Gajah has 16 areas. In addition, there were 92 Temporary Evacuation Centers (TEC) found, with a capacity of nearly 26,000 victims [8]. In Malaysia, there are more than 5000 gazette evacuation centres throughout the country that can accommodate about 1.6 million victims [9]. Table 1 indicates the list of evacuation centers in Melaka that were officially selected from JKM Melaka. These TEC are frequently used by the victims during the evacuation.

Table 1
Official evacuation centres in Melaka

No	Zone	Evacuation center	Latitude	Longitude	Capacity
1	Dun Kota Laksamana	SJK(C) Notre Dame	2.207292	102.241472	200
2	Dun Kota Laksamana	Sek. Ke. Bukit Cina	2.203547	102.256462	200
3	Dun Kota Laksamana	Balai Raya (Bilik Bacaan) Kg Chetti	2.200567	102.238427	30
4	Dun Kesidang	Sek. Men. Gajah Berang	2.202811	102.240864	400
5	Dun Kesidang	Sek. Men. Katholik	2.206764	102.241449	400
6	Dun Kesidang	Sek. Men. Notre Dame Convent	2.207537	102.242444	400
7	Dun Kesidang	Sek. Keb. Methodisc (ACS) Kesidang	2.204937	102.236442	200
8	Dun Kesidang	Sek. Keb. (P) Methodist 1	2.204265	102.233924	200
9	Dun Kesidang	Sek. Keb. (P) Methodist 2	2.204265	102.233844	200
10	Dun Kesidang	Sek. Ren. Jenis Keb. Tengkera 1	2.203678	102.232202	150
11	Dun Kesidang	Sek. Keb. Limbongan	2.208581	102.220463	150
12	Dun Kesidang	SK Taman Merdeka	2.270917	102.236571	800
13	Dun Kesidang	SJK(C) Malim, Melaka	2.237005	102.224989	300
14	Dun Banda Hilir	Balai Raya Kampung Bukit Cina	2.307923	102.172604	80

Public buildings commonly play a significant role in emergency shelters for flood victims. However, the statistical weather analysis in terms of building design for warm and humid climates indicated that Malaysia experiences high solar intensity for a long duration, such as the monitoring of heatwave reached (daily maximum temperature 35℃-37℃) was occurred on the northern side of the peninsula [10]. The overheating condition is not as severe as in hot–dry climates, and it is exacerbated by the high humidity and little diurnal temperature change [11]. Moreover, with the acceleration of urbanization of tropical climates in recent years, the building density in traditional urban blocks has become higher in humid and dry areas. This condition leads to the deterioration of the natural disaster in urban areas in Malaysia such as Kelantan, Terengganu, Pahang, etc [12]. On the other hand, higher building density restricts the potential of natural ventilation in summer. Therefore, it increases the difficulty of thermal comfort and Indoor Air Quality (IAQ) improvement in the blocks [13].

Two main factors, high air temperature and relative humidity, affect occupants' health and comfort while staying in the TEC, especially in buildings with poor ventilation systems [14,15]. In addition, due to the year-round monsoon rains, evacuation becomes essential when flooding occurs in populations [16]. According to this condition, the new allocation of evacuation centres in Malaysia is based on the building's capacity to withstand the flooding. Owing to the high number of evacuees, the victims are in small rooms or frequently overcrowded halls. Certain basic requirements must be established before determining evacuation centers, such as ventilations, building characteristics and numbers of the victim, etc [6].

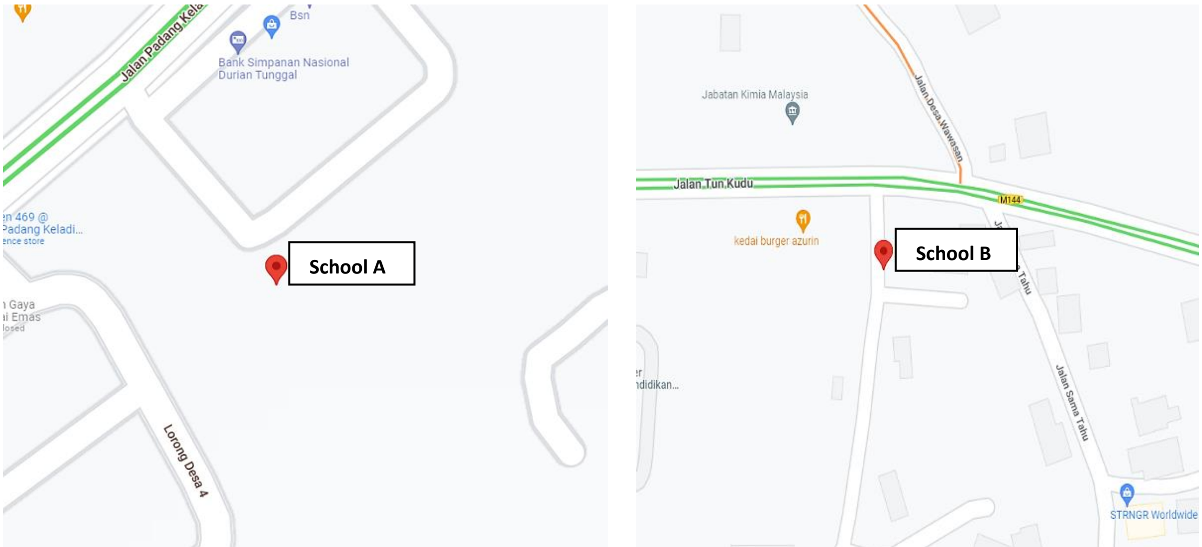
Multi-purpose halls, indoor arenas, and government facilities are frequently used based on the flood situation and prone areas. However, in Malaysia, school buildings have historically served as the primary evacuation site because they are often the only readily accessible structure in cities that can handle many people at once [17]. Temporary shelter in Malaysia is mainly applied as an emergency life-saving initiative that can last up to two weeks [18]. In fact, the victims were placed in a temporary tent for privacy and separation, with only limited fans available [19,20].

A series of dedicated and well-designed relief shelters should be seriously considered a long-term flood disaster management strategy. This study aimed to investigate the airflow distribution and temperature of the evacuation centers based on the original profile of selected public buildings. The data analysis and simulation results could assist the responsible authorities in selecting the best TEC while facing any natural disasters in the future.

2. Methodology

2.1 Site Measurements

The primary data was obtained from two source locations. The resources and information were provided by Malaysia Welfare Department (JKM), specifically in Melaka state. These buildings were officially selected as Temporary Evacuation Centers (TEC) during the flood that occurred in the Melaka district. According to this study, there were two types of public buildings, such as school hall (School A) and school classrooms (School B), in two different experimental locations. The coordinates between Schools A and B were 2.2287° N, 102.3090° E, and 2.3111° N, 102.2817° E, respectively. Schools A and B were 14.5 km away from normal traffic. According to JKM Melaka, the school with a hall will identify as School A, whereas classrooms will identify as School B. Both schools were in the same state. Figure 1 illustrates the accurate location between Schools A and B.



(a) (b)

Fig. 1. School location (a) School A (b) School B.

2.2 Site Monitoring

The physical characteristics of the buildings were obtained through physical measurements such as external wall area, operable windows area, building properties, etc. Both schools used the ground floor for observation and experiment. The designed parameters and basic information were exactly based on the original profile. These profiles were measured from the experimental location, as shown in Table 2 and Table 3. Malaysia's Ministry of Health (MOH) has developed a COVID-19 prevention and management guideline in flood relief centers that starts from evacuating victims to these centers to the process after completion of placement at the flood relief centers. Tents, facilities, and self-hygiene items were provided in the guidelines. The capacity of each Temporary Evacuation Center (TEC) is arranged according to COVID-19 management guideline [19]. During the pandemic period, visitors were not allowed to visit the selected Temporary Evacuation Centers (TEC) were difficult to visit due to movement control order (MCO). The indoor and outdoor air properties were captured using the official air measuring instruments as indicated in Table 4.

Table 2
Building parameters

Schools	Building volume per (m^3)	Building types	Amount (unit)	Floor level	Capacity (person)
A	7320.62	Hall	1	Ground	100
B	203.49	Classroom	2		20

Table 3
Building facilities & characteristics

Building List	Windows		Doors		Tents			Ventilation
Schools	Size (m^2)	Quantity (unit)	Size (m^2)	Quantity (unit)	Volume (m^3)	Quantity (unit)	Material	Natural-ventilated
A	2.24	16	3.717	16	9.382	28	Nylon	
B	3.2	4	3.77	2		2		

Table 4
Air sampling instrument specifications

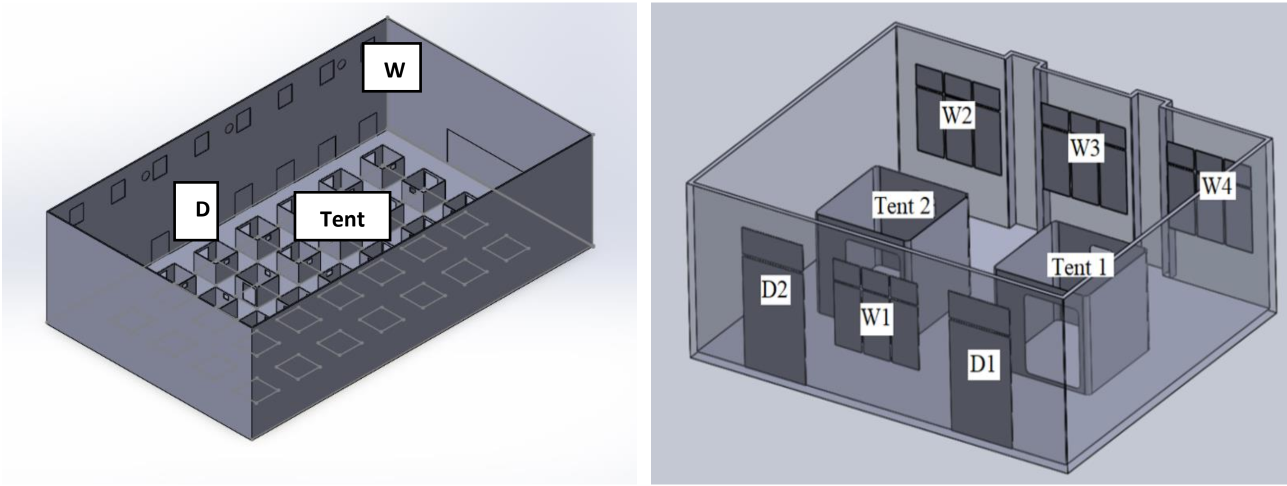
No	Instruments	Parameters	Brand & Model	Accuracy and resolution
1	VelociCalc (Multi-function Ventilation Meter)	• Airflow rate/air speed • Air temperature	TSI 9565-P	Velocity Speed: 0.1-25.0 $m/_s$ Accuracy: ±(1.5%)reading Resolution: 0.01 $m/_s$ Temperature °C= 5 to 45°C Resolution: 0.1 Accuracy: ±2°C
2	Vane Digital Anemometer	• Airflow rate/air speed • Air temperature	PROFESSIONAL INSTRUMENTS 87A-EN-02	Velocity Speed: 0.00 - 30.00 ms^{-1} Resolution: 0.01 ms^{-1} Threshold: 0.3 Accuracy: ± (5% + 0.1 ms^{-1}) Temperature °C= -10°C - +45°C Resolution: 0.1 Accuracy: ±2°C

The air velocity or distribution of airflow measured with the Professional Instruments vane digital anemometers is particularly precise in the range between 0 and 2 ms^{-1}. The temperature and relative humidity were measured by the VelociCalc 9565-P air velocity meter. Its indoor temperature and relative humidity ranges are 0 to 33℃ and 19% to 99% (RH) for relative humidity. The sampling points were set to be more than 1.5 m away from the workstations and at the work plane of each indoor space taken to be 1.2 m from the floor level. The data were also taken at 5-minutes intervals during the typical working hours of the space users, which is between 8 am and 8 pm per 24 hours [21]. There were a few evacuation tents set up in order to operate the experimental studies. Each of the schools took 3 days for experimental studies to obtain accurate measurement and data collection [22]. Figure 2 presented our study's investigation and data collection during a site visit to both environments.

(a) (b)
Fig. 2. Site measurements (a) School A (b) School B

The collected data were analyzed using One-Way ANOVA analysis and regression models between both schools for each day. In Each temporary evacuation center was simulated to understand the airflow distribution. Therefore, the simulation results are presented in detail after the observations have been done during the experiment.

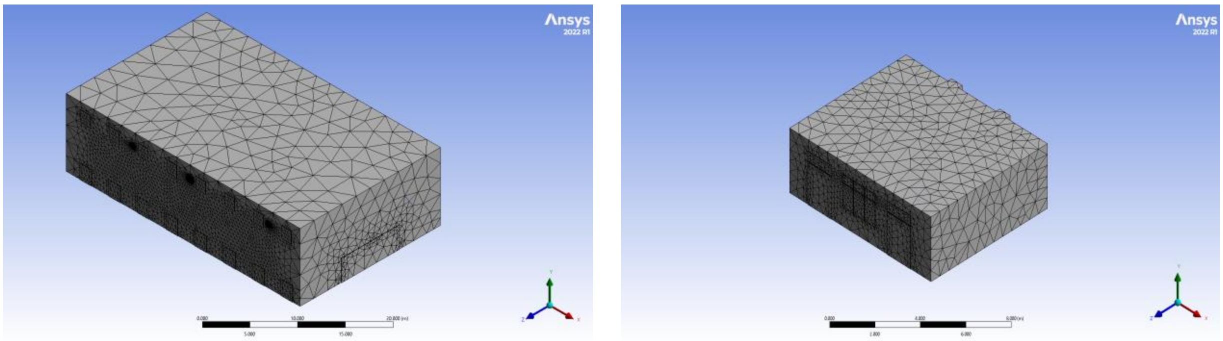
According to Figure 3(a) and Figure 3(b), D defined as door entrance of the building whereas W defined as the windows of the building which allows the entrance of the distributed airflow. School A has only one unit of the building whereas School B has three classrooms in three floors in a building. School A has one unit of hall, while School B has one unit of classroom in each floor. Both 3D models were created with Computer Aided Design (CAD) Solidworks software, as illustrated in Figure 3 above, in terms of allowing viewers to understand the presented buildings that are currently available. Both layouts were created based on the original profile stated in Schools A and B accordingly.



(a) (b)

Fig. 3. Building layout (a) School A (b) School B

Ansys Workbench combines simulation data to create more accurate models. This software simplifies simulation by centralizing simulation data in one place. Figure 4 indicated the mesh models of each building layout such as hall and classroom. To achieve the aims, each temporary evacuation centers (TEC) should be simulated to ensure reviewers understand the airflow distribution in the specific buildings.



(a) (b)

Fig. 4. Mesh model (a) School A (Hall) (b) School B (Classroom)

Table 5 indicated the setup process of the parameter in Ansys software. In order to validate the data collection, several parameters need to be set up while handling the simulation analysis [22]. The energy equation was included to drag the inlet airflow from outside into the indoor environment. Both data simulated with laminar flow. The medium content in the simulation is air constant. The density was 1.225 kgm^{-3} and its gravitational force was in -9.81 ms^{-2}. The inlet airflow for school A and B were 0.20 ms^{-1} and 0.47 ms^{-1} respectively. On the other hand, the air temperature in school A and B were set to constant which was 300 Kelvin (K).

Table 5
Parameter setup in Ansys Workbench

Models	School A		School B	
Energy	Yes		Yes	
Viscous	Laminar		Laminar	
Fluid	Air		Air	
Boundary conditions	Inlet	Outlet	Inlet	Outlet
Position	Doors	Windows	Windows	Doors
Velocity (ms^{-1})	0.20	0.18	0.47	0.43

3. Results
3.1 Data Analysis

Figure 5 illustrates the average velocity and temperature distribution in Schools A and B 24 hours a day. As Figure 5(a) indicated, the air velocity in School A was higher than in School B in every part of the day. The average velocity between School A and B was 0.19 ms^{-1} and 0.27 $ms^{-1,}$ respectively. Meanwhile, the average air temperature between School A and B was slightly similar, which were 30.3°C and 29.4°C, as illustrated in Figure 5(b).

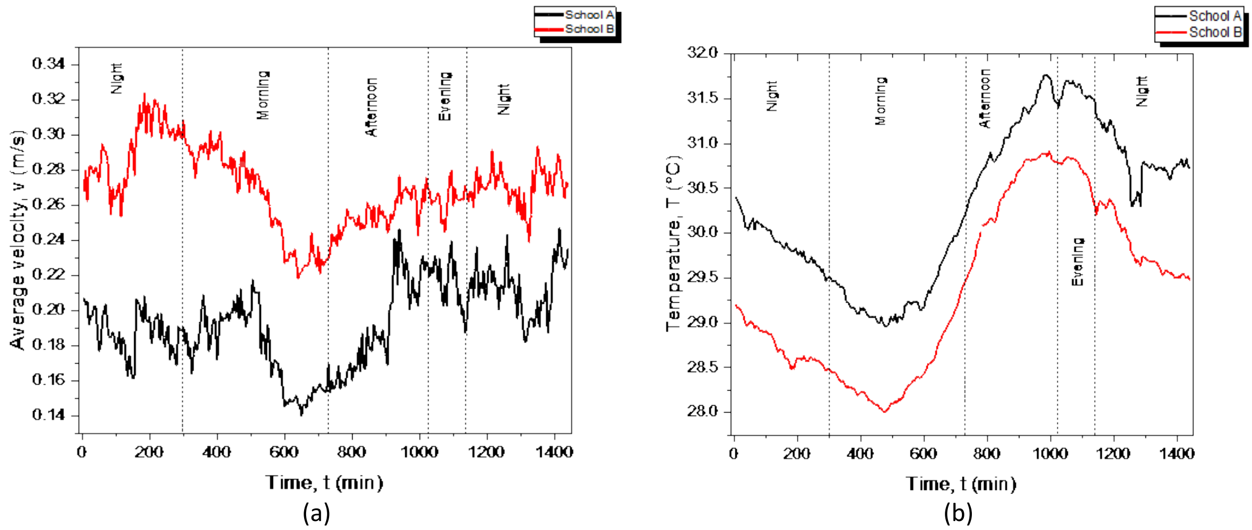


Fig. 5. Time interval is taken in relation to velocity and temperatures between Schools A and B (a) Average velocity and (b) Average temperature

According to the Malaysian Meteorological Department of the Ministry of Environment and Water, Melaka's long-term weather trend has been no rain in the morning, afternoon, or night. As a response, the real-time measurements were taken in regular weather conditions [23,24]. Both schools had lower air velocity and higher air temperature in the afternoon session starting from 12 pm to 5 pm due to the climate changes in Malaysia during the monsoon seasons. School B has the coolest environment to become a temporary evacuation center (TEC) compared to School A due to its environmental airflow and temperature. School B has the highest airflow speed and lowest air temperature, which were 0.22 ms-1 and 30.9°C. On the contrary, the environment in School A is warmer than in School B due to its low airflow speed and air temperature, which were 0.14 ms^{-1} and 31.8°C, respectively.

In a similar approach to the relationship between temperature and air velocity, the air velocity would affect the air temperature in the temporary evacuation centers (TEC) during the time spends. In short, School B has the best environment for the victims during the evacuation due to several facts, such as the number of opening positions and the area of the location [25].

Table 6 indicates the analysis results of coefficients regression models. In the case of the velocity regression model, the airflow rate decreases as the time taken changes in each part of the day, such as morning, afternoon, evening, and night sessions. Therefore, the average air temperature and velocity are directly proportional to the part where the time ambient air or ambient/recirculated air is blown into the specific location. The ANOVA results in Table 7 revealed that the prediction model was 3×10^{-165}, which is statistically significant with ($p<0.05$) for all models. By calculating the data explained by the model, a similar approach was carried out by Goicoechea and López [26] and Ibrahim *et al.,* [27], the air change rate in the study was highly significant prediction of air change per hour (ACH) can be done with the independent variables which is (temperature changes). The overall analysis results, such as the model's explanatory power of the data and the p-value, indicated that School B is the optimal model for predicting the greater airflow rate of the air velocity and temperature at the site compared to School A [27].

Table 6
(Velocity) Data Analysis (One-way ANOVA)

Velocity						
Model		*df*	*SS*	*MS*	*F*	*P*
School A	Regression	1	9141711	9141711	64.35909	2.69×10^{-14}
	Residual	286	40624089	142042.3		
	Total	287	49765800			
School B	Regression	1	6014730	6014730	39.31819	1.32×10^{-9}
	Residual	286	43751070	152975.8		
	Total	287	49765800			

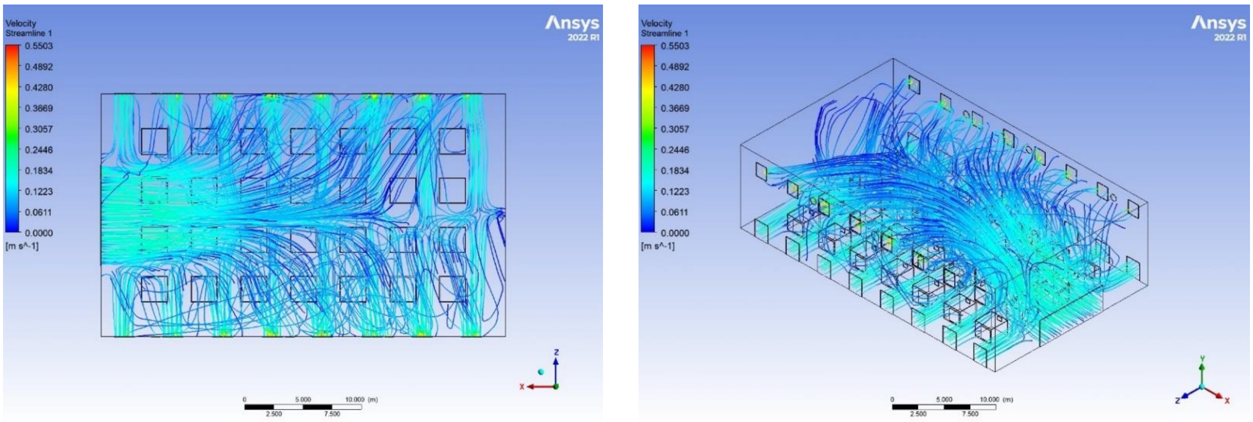
Table 7
(Temperature) Data Analysis (One-way ANOVA)

Temperature						
Model		*df*	*SS*	*MS*	*F*	*P*
School A	Regression	1	22695501	22695501	239.78	1.07×10^{-39}
	Residual	286	27070299	94651.39		
	Total	287	49765800			
School B	Regression	1	23452555	23452555	254.91	1.82×10^{-41}
	Residual	286	26313245	92004.35		
	Total	287	49765800			

df: degree of freedom, SS: Sum of squares, MS: Mean square

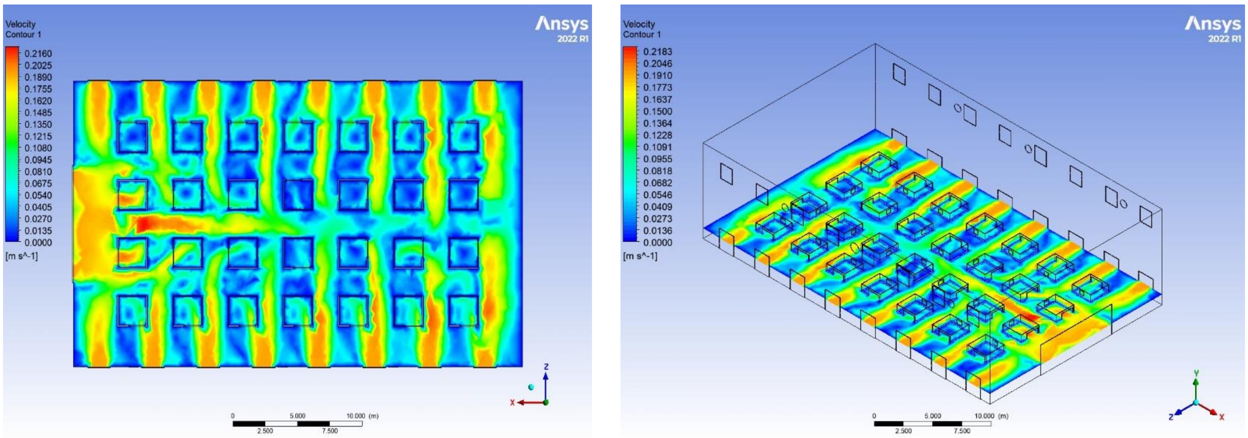
3.2 School A

Figure 6 below shows the velocity streamlined view, and Figure 7 shows the contour views of measured air velocity of the evacuation center with tent installed in School A. The direction of wind flow started from the bottom doors and flowed to the windows above with wind speed between 0.13 ms^{-1} and 0.19 ms^{-1}. The speed of airflow at the center of the building was between 0.12 ms^{-1} and 0.16ms^{-1}.



(a) (b)

Fig. 6. Ground floor (with tent) (a) Stream view 1 (b) Stream view 2

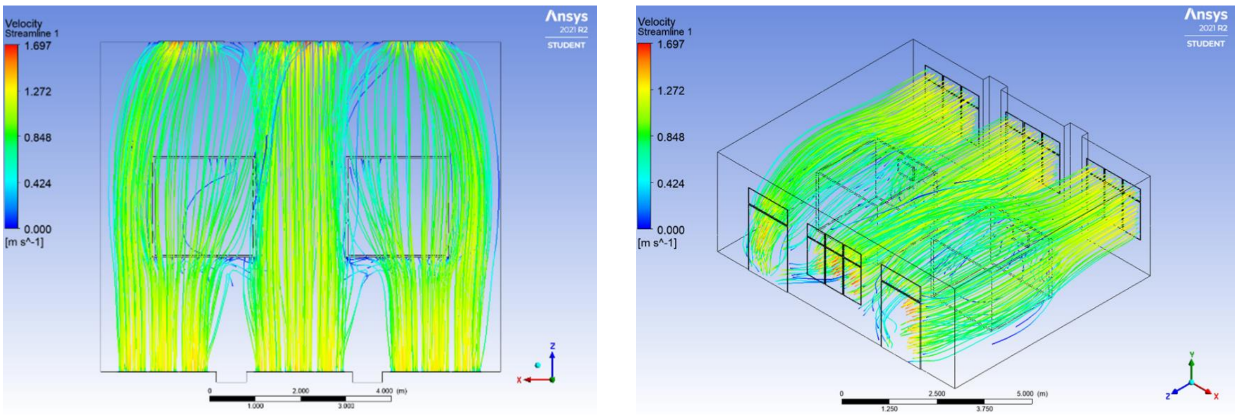


(a) (b)

Fig. 7. Ground floor (with tent) (a) Contour view 1 (b) Contour view 2

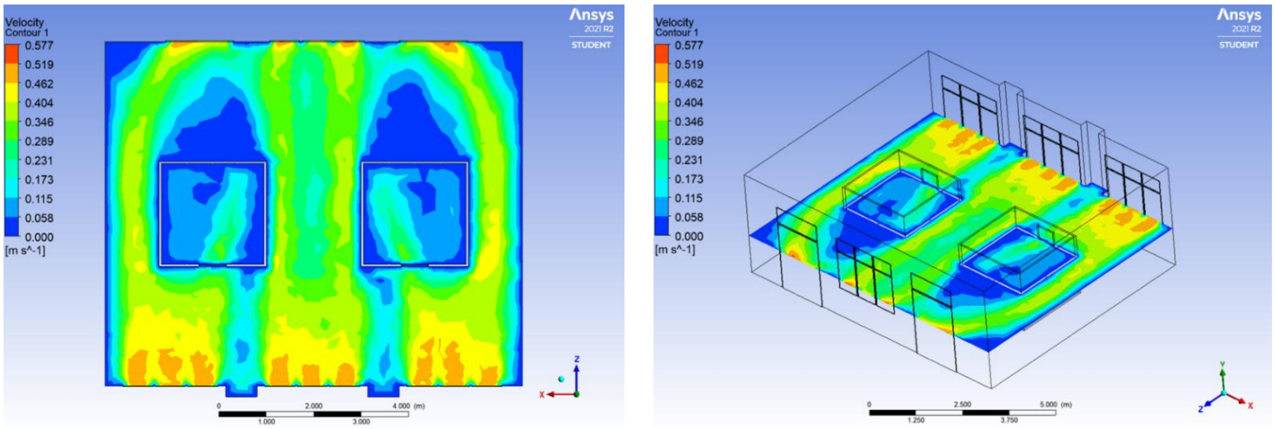
3.3 School B

Figure 8 and 9 show the streamline and contour views of the wind velocity of selected space with an installed tent, respectively. The measured airflow started from similar windows and passed through both tents before exiting door 1, door 2, and window 1 with different air velocities between 0.14 ms^{-1} to 0.56 ms^{-1}. Note that the wind speed inside the tent showed readings between 0.13 ms^{-1} to 0.29 ms^{-1}.



(a) (b)

Fig. 8. Ground floor (with Tent) (a) Stream view 1 (b) Stream view 2



(a) (b)

Fig. 9. Ground floor (with tent) (a) Contour view 1 (b) Contour view 2

3.4 Short Conclusion

The case is simulated to observe velocity and temperature fields. The contaminant concentration near the mouth zone/entrances is also observed. The contours of velocity, temperature, pressure, and concentration fields are taken around the room by creating a plane in a 3D volume [22]. The air velocity condition during the installation of the tent shows the same at each floor level because the wind condition inside the tent and concentrated on the side of the tent shows no wind movement in the area. As for the middle part of the tent, only the ground floor achieves the resistance set by DOSH, which is up to 0.289 ms^{-1}.

The result shows that the airflow distribution in School A (hall) will increase human comfort compared to School B (classroom). This statement is also agreed by Prakash and Ravikumar [28], which the airflow distribution does affect the level of comfort to humans or occupants due to the physical characteristics such as window position and geometry of the building located.

4. Conclusions

In the present work, an extensive data analysis has been made to study the comparison of airflow distribution between two different public buildings. Following conclusions are made as per the above study: Based on 3D finite element modeling of the original conventional building design, the obtained data showed how the air velocity flowed with respect to percentage volume during Computer Fluid Dynamics (CFD) analysis using FLUENT was considered. The work modeling, meshing, preprocessing, and analysis are performed in ANSYS R1 (2022). The victims from flood evacuation centers feel discomfort while staying in the evacuation center due to poor airflow distribution.

Therefore, the average air temperature and velocity are directly proportional to the part where the time ambient air or ambient/recirculated air is blown into the specific location. As per the above study, School B is maintained between temperature range from 28℃ to 29.5℃, and the air velocity was maintained high between 0.25 ms^{-1} and 0.28 ms^{-1}. In School B, the temperature range is maintained between 29.3℃ to 31.7℃. With the study of air distribution, School B has a better airflow distribution and cooler temperature compared to School A. However, this study has a limited scope which was conducted in schools in the Melaka area during the flooding season.

Therefore, there are several recommendations can be suggested to future researchers to improve the airflow in the evacuation center, and this will probably be able including

i. Observations can be conducted in other buildings rather than school buildings, such as hotels or residential areas on high ground in a similar state.
ii. Maximize the outdoor air in indoor spaces. The cheapest option is to increase outdoor airflow into the building by opening windows and doors.
iii. Use ventilating facilities to improve airflows, such as fans or Air-Conditioning & Mechanical Ventilation (ACMV) systems.
iv. Physical distancing between ACMV systems and outlet airflow in the buildings

Acknowledgment
The authors would like to acknowledge the financial support by Universiti Teknikal Malaysia Melaka (UTeM) under the short-term grant scheme (PJP) Universiti Teknikal Malaysia Melaka with reference number PJP/2020/FTKMP/PP/S01767.

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