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Effect of Airflow on Thermal Comfort in a Naturally Ventilated University Classroom

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ABSTRACT: The health, productivity, and learning capacities of the people who use a classroom are greatly impacted by the indoor thermal conditions. Airflow short-circuiting, draft discomfort, and uncomfortable temperature stratification are just a few of the issues that can arise from inadequate air distribution in a classroom. The Classroom ESABSF was selected for the airflow analysis on thermal comfort in a naturally ventilated university classroom. The selection was based on the indoor thermal environmental conditions measured and simulated. The Classroom ESABSF, which measures 24 x 25 x 5m (length x width x height), with a north-south orientation along its length. A corridor connects the room's eastern and southern sides to a main entrance door, and portions of the room's east and south faces feature glass louvers, each with six operable windows. During the studies, several window opening configurations and locations were employed to examine the variance in the room's ventilation characteristics. Ten simulations were run, with five including occupancy and the other five without occupancy. The average air temperatures and velocities were anticipated and observed at a level of 1.1 meters above the floor. Average air temperatures and velocities in the classroom, which were 1.1m above the floor, were measured and predicted. The Classroom ESABSF recorded (with occupancy) relative humidity, indoor air temperature, and indoor air velocity, PMV, PPD, and thermal sensation of 32.55ºC, 0.95m/s, 62.72, 97%, and hot, 29.01ºC, 0.95m/s, 78.45%, 69% and slightly warm, respectively for the dry and wet seasons. The unoccupied Classroom ESABSF recorded relative humidity, indoor air temperature, and indoor air velocity, PMV, PPD, and thermal sensation of 31.08ºC, 0.88m/s, 59.63, 81%, and warm, 28.43ºC, 1.02m/s, 85%, 49%, and cool, respectively, for the dry and wet seasons. The study concluded that an increase in air flow decreases the indoor air temperature, relative humidity, and radiant temperature. The occupied classroom was uncomfortable during both the dry and wet seasons as compared to the unoccupied classroom. The study recommended that architects make all efforts (wall-to-window ratio) at the design stage to increase air flow in naturally ventilated classrooms. The number of students in a classroom should be calculated according to the total floor area of the classroom to avoid overcrowding of the classroom.

Keywords: *Thermal comfort, Natural ventilation, Air flow. Simulation, Classroom, and Air Temperature.*

Introduction

Students' health, productivity, and capacity to learn are all significantly impacted by the indoor temperature conditions in a classroom (Geng et al., 2017; Jastaneyah et al., 2023; Krajcík et al., 2012; Tronchin et al., 2018). A classroom's inadequate air distribution can lead to several issues, such as draft discomfort, airflow short-circuiting, and uncomfortable temperature stratification.

(Jurelionis et al., 2016; Krajcík et al., 2012; Shao et al., 2017). Students who experience thermal discomfort in classrooms may become restless, distracted, headachey, and exhausted, all of which can lower productivity (Ahadzie et al., 2021; Roelofsen, 2002). Ephraim (2020) and Jastaneyah et al. (2023) assert that a classroom's indoor temperature has a substantial effect on students' ability to learn. High air temperatures in classrooms impair a person's ability to think and move, which is problematic in tropical regions (Jastaneyah et al., 2023; Johansson et al., 2018). Haddad (2016) and Jastaneyah et al. (2023) assert that because students spend more time in classrooms, they must be thermally comfortable. In most school classrooms, high air temperatures during times of high thermal load are a regular worry; nonetheless, they may cause pupils' academic performance to decline (Bayoumi, 2021). Planning for improved thermal conditions has been suggested by several studies (Alghamdi et al., 2023; Mba et al., 2022; Olgyay et al., 2016; Waseem & Talpur, 2021; Widera, 2021; Xu et al., 2021; Zoroğlu Çağlar & Zorer Gedik, 2022).

According to Olgyay et al. (2016), a classroom's interior temperature should be between 23 °C and 29 °C with a relative humidity of 30 to 70% in tropical settings. The ideal temperature range for structures in tropical regions, according to Rahadian and Sulistiawan (2020), is between 18°C and 29°C, with a maximum humidity of 80%. Additionally, Rahadian and Sulistiawan (2020) suggested that classrooms' indoor air velocity not surpass 1.5 m/s. ANSI/ASHRAE guideline 55-2005 states that classroom temperatures should be between 23°C and 26 °C for summer comfort (Mora & Bean, 2018). Specifically, Rahmillah et al. (2017) and Utkucu and Sözer (2020) asserted in adaptive comfort research that a building's comfort zone is 2 °C above a neutral temperature.

2. Literature review

2.1 Natural Ventilation

Natural ventilation is the process of replacing air in any room to give great indoor quality without the need for artificial means (Medina et al., 2021). The comfort, health, and well-being of the people who live there are directly impacted by the ventilation conditions in that space (Al-Sharif et al., 2021). The use of natural ventilation in building designs has grown in importance (Gan et al., 2022; Koranteng et al., 2021). It can be utilized to remove heat from an area, provide outside air, and lessen contaminants and odors (Akadiri et al., 2012).

In addition to lowering construction and operating costs related to the acquisition and use of mechanical equipment, designing for natural ventilation may also boost building occupant productivity by improving the indoor environment and connecting to the outdoors (Gan et al., 2022; Koranteng et al., 2021; Rodríguez-Muñoz et al., 2018). According to Bellos et al. (2016), Dankyi & Koranteng (2012), Ikechukwu et al. (2019), Popovich et al. (2021), Santer et al. (2005), Singh & Holla (2021), and others, the most important elements for natural ventilation are climate adaptability, window orientation, and movable windows. Cross-ventilation and water evaporation systems are two examples of how to create air in hot, dry areas (Akadiri et al., 2012; Anand et al., 2017; Ikechukwu et al., 2019; Popovich et al., 2021). Natural ventilation is a passive ventilation technique used to bring in fresh air and eliminate dangerous pollutants from the interior space.

(Abdullah & Alibaba, 2022; Ji et al., 2011; Schweiker et al., 2019; Toe, 2018). Natural ventilation's passive design can use less energy than mechanical ventilation systems because it guarantees occupants have consistent Indoor Air Quality (IAQ) and acceptable thermal conditions (Ahmed et al., 2021; Emmerich et al., 2001; Jomehzadeh et al., 2017; Nikas et al., 2010; Soebiyan, 2018; Utkucu & Sözer, 2020; Wang et al., 2017). Through windows, doors, or internal building apertures, natural ventilation is created by heat, wind, diffusion forces, or a combination of these factors (Abdullah & Alibaba, 2022a; Chen et al., 2021; Rahadian & Sulistiawan, 2020). Aside from the building's shape and interior design, window location and exposure to sunshine are two crucial elements of well-designed natural ventilation (Bawakyillenuo & Agbelie, 2020; Lu et al., 2017; Rahadian & Sulistiawan, 2020).

Air movement is also a result of a pressure differential brought on by separate or combined buoyancy and wind forces (Mihlayanlar et al., 2017; Sakiyama et al., 2021; Toe, 2018). Because temperature, wind direction, and wind velocity can all fluctuate frequently, calculating natural ventilation is more challenging (Mihlayanlar et al., 2017). Along with these factors, the size and shape of the apertures can also have an impact on the pressure difference and, consequently, the ventilation rate (Erebor et al., 2021; Sara, 2021; Wen et al., 2022). Literature portrays natural ventilation as a result of both external and internal factors (Erebor et al., 2021; Sara, 2021; Wen et al., 2022). External variables include things like building orientation, urban form, and microclimate conditions. Internal issues include opening configurations (window-to-wall and window-to-floor ratios), louver angles in apertures, and the floor plan (Bledi et al., 2011; Pathirana et al

2.1.1 Wind-Driven Ventilation

Leeward and windward side pressure differential brought on by wind forces results in wind-driven ventilation (Gough et al., 2018). The leeward side refers to the façade's face that does not directly experience wind force, whereas the windward side refers to the façade's face that does (Chapman, 2018). Wind-driven ventilation includes cross-ventilation, which results when a wall faces or is close to another wall with two or more apertures, and one-sided ventilation, which only happens when apertures are on the same wall (Bayoumi, 2018; Roslan & Rodzi, 2017).

2.1.2 Ventilation on One Side Only

When the room door is closed, a single façade of a building with basic rooms is usually open outdoors. When a building just has one wall with apertures that interact with outside air to provide local ventilation, one-sided ventilation emerges (Ahmed et al., 2021; Singh & Holla, 2021; Wang et al., 2017). One-sided openings should be properly placed and proportioned because the rebellious nature of the wind creates fluctuating airflow in the one-sided ventilation approach, which can result in less airflow than cross-ventilation (Bayoumi, 2021; Singh & Holla, 2021; Zhai et al., 2015). Additionally, the combined windows area ought to make up about 5% of the floor. The width of the wall containing one window must be 2.5 times that of the floor area (Ahmed et al., 2021; Singh & Holla, 2021).

2.1.3 Cross-Ventilation

Compared to the single-sided ventilation method, this approach makes more use of pressure variations between the windward and leeward sides (Zhang et al., 2022). Cross-ventilation occurs when a building has several openings on various façades, whether they are facing or adjacent walls, and each wind movement causes a pressure differential between two sides (Ahmed et al., 2021). The air is moved from the windward side to the leeward side in this manner (Gou et al., 2018). Cross-ventilation should be controlled to eliminate pollutants and internal heat because it can only be effective and sufficient at a depth of the building (Kajjoba et al., 2022; Sara, 2021). The depth of the building can be up to five times the ceiling height for wind-driven cross ventilation (Kajjoba et al., 2022; Sara, 2021). When windows are open, cross-ventilation typically takes place (Kajjoba et al., 2022).

According to Wahab et al. (2018), cross-ventilation occurs horizontally and necessitates a wind flow produced by pressure differentials. Cross ventilation is the most efficient technique to employ in situations where the temperature variations between interior and outdoor environments are negligible, since buoyant forces would not be as effective (Aflaki et al., 2021). Building walls are crucial in the process of creating air pressure ventilation. According to Aflaki et al. (2021), high pressure is produced when the windward side of a building's walls restrict airflow, whereas the leeward side of the building experiences lower pressure than the windward side.

As a result, air flows from the windward side of an aperture in the walls, which has positive pressure, to the leeward side, which has negative pressure (Aflaki et al., 2021; Baeumle, 2019).

2.1.4 Ventilation Driven by Buoyancy

Another force that naturally ventilates interior areas is buoyancy. Thermal buoyancy-driven ventilation, also known as stack ventilation, is an airflow caused by the temperature differences between indoor and outdoor air, which also creates a density differential (Gan et al., 2022; Michalak, 2022). Warm air is drawn within and released at higher apertures, or rather outlets, by the pressure differential caused by density variance (Dogan & Kastner, 2021; Hox, 2015). Atriums and chimneys are frequently utilized components to improve ventilation driven by buoyancy (Michalak, 2022). Depending on the variations in air pressure between two locations at various heights, buoyancy-driven ventilation travels vertically (Wahab et al., 2018).

For stack ventilation to be effective, two key dynamics are the temperature differential between outdoor and internal air and the height difference between openings (Adom et al., 2018; Aflaki et al., 2021). However, the wind effect may be more significant than the buoyancy effect in stack ventilation since even a small quantity of wind flow results in air pressure distributions on the building envelope that impact the airflow (Michalak, 2022). Using a validated CFD model, Hussain and Oosthuizen (2013) investigated pressure variations brought on by heat variations in a building containing an atrium. The study's simulations showed that when buoyancy-driven ventilation is used, external air floods into the interior and mixes with indoor air.

According to the study, ventilation time and the difference in temperature between indoors and outdoors affect ventilation performance (Hussain & Oosthuizen, 2013).

2.1.5 Significance of Natural Ventilation

An efficient and sustainable technique to get fresh, natural air into indoor spaces is through natural ventilation. As residents spend more time indoors, indoor environmental factors become more significant (Campano et al., 2019; Singh & Holla, 2021). The interior environment's air quality is a crucial component, and it can become uncomfortable if things like body odor, CO_2, and volatile organic compounds (VOCs) build up (Sara, 2021; Sykes, 2017; Talarosha et al., 2020). Another issue to control for greater sustainability is energy efficiency. According to this term, natural ventilation promises both energy efficiency and air quality (Ahadzie et al., 2021; Bawakyillenuo & Agbelie, 2020).

2.2 Thermal Comfort Factor

Six factors determine the appropriate thermal environment's thermal comfort for a representative inhabitant of the selected zone (Motamedi et al., 2017). These six factors should be taken into account when determining the zone's tolerable thermal comfort levels, which vary over time. Air temperature, radiant temperature, air speed, and humidity are all aspects of the thermal environment (Kaja & Srikonda, 2019). Metabolic rates and clothing insulation are traits of the zone's inhabitants (Safwan, 2020).

2.2.1 Metabolic rate and clothing insulation

The variances in metabolic rates among humans depend on a number of factors, such as exercise level, age, gender, and health. The amount of heat generated by the average person's skin surface area while they are seated and at rest is 58.2 W/m^2, or units of met, which is how the metabolic rate is expressed. The pace at which a person's metabolic processes transform chemical energy into heat and mechanical work per unit of skin surface area is known as their metabolic rate (ASHRAE, 2017).

"The quantity of thermal insulation worn by a person that has a major impact on thermal comfort" is the definition of clothing insulation (ASHRAE, 2017). The fabric and thickness of clothes can maintain the body's heat balance or avoid overheating, while the amount of clothing worn influences the body's thermal equilibrium and heat loss. The application of this standard is significantly influenced by the concept of thermal comfort, or clo. 0.155 m2K/W is equivalent to one clo.

2.2.2 Air temperature

Boverket's building regulations (BBR), which encompass all technical specifications of construction operations in Sweden, provide necessary provisions and general principles when establishing a new structure. Section BFS 2011:6 of the BBR standards requires that buildings and their infrastructure be constructed to satisfy the thermal comfort of the occupied zone. While the lowest temperature in inhabited zones of residential areas should not be less than 18 °C, the highest temperature in healthcare and workplace settings should not be more than 26 °C, and the lowest temperature should not be less than 20 °C (Alsmo & Alsmo, 2014; Rahadian & Sulistiawan, 2020).

The European Standard for Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting, and Acoustics (EN 15251) offers design guidelines for thermal comfort for interior climate. Different levels of indoor air temperature expectations are indicated by three categories in EN 15251.

2.2.3 Mean radiant temperature

"The temperature of a uniform, black enclosure that exchanges the same amount of heat through radiation with the occupant as the real enclosure," according to ASHRAE (2017), is the definition of mean radiant temperature. This suggests that the mean radiant temperature represents the impact of the surface temperature in any zone on the thermal comfort of the occupants. Reflected solar radiation through the surfaces of HVAC-equipped buildings has significantly altered the thermal comfort of the occupants (Chaudhuri et al., 2018).

The heat stress and thermal comfort indices can be evaluated using the data on variances and how they affect thermal comfort, which means radiant temperature provides. On the other hand, interior thermal studies have assumed that the temperature inside is the same, disregarding the mean radiant temperature. The complex measurement methods were the reason for this mistake (Chaudhuri et al., 2018).

2.2.4 Airspeed

One of the most important aspects of indoor thermal comfort, indoor air speed, has a big influence on the people who live there since it is directly tied to air temperature and thermal perception. As a result, there is a greater heat exchange between the zone's occupants and the surrounding air due to its higher velocity. When the velocity is rather high in a cold climate, ASHRAE (2013) recommends limiting it to less than 0.20 m/s in inhabited zones that use HVAC systems to lower the risk of draft in indoor climates.

The airspeed in the occupied zone should be less than 0.15 m/s during the winter months when heating is required, under Swedish Boverket's mandatory requirements and general guidelines (BBR). The air speed in the occupied zone should be less than 0.25 m/s during the summer months when cooling from the ventilation systems is needed.

2.2.5 Relative humidity

Relative humidity is a crucial factor in interior thermal comfort and human health. According to surveys by Alsmo and Alsmo (Alsmo & Alsmo, 2014), almost 70% of employees in workplaces, schools, and other facilities experienced dry air throughout the winter. According to studies, the indoor climate's relative humidity has an impact on people's health, with poor relative humidity conditions being associated with higher rates of allergies and respiratory infections (Alsmo & Alsmo, 2014).

Maintaining relative humidity of between 40% and 70% will reduce the likelihood of viruses and bacteria in the indoor air spreading, as shown in Figure 2.6. The relationship between relative humidity and temperature is inverse, meaning that as air temperature rises, relative humidity decreases (Alsmo & Alsmo, 2014; Rahmillah et al., 2017). The relative humidity is particularly low during the winter when outdoor air is brought into to warm the interior atmosphere (Alsmo & Alsmo, 2014). The minimum indoor relative humidity level is not included in ASHRAE (2017), and this standard does not refer to a minimum humidity level.

3. Materials and Methods

The Classroom ESABSF was selected for the airflow analysis on thermal comfort in a naturally ventilated university classroom. The selection was based on the indoor thermal environmental conditions measured and simulated.

3.1 The University Classroom with Natural Ventilation (Classroom ESABSF)

Figure 1 depicts a Google map location, a 3D view, and a schematic diagram of the Classroom ESABSF, which measures 24 x 25 x 5m (length x width x height) with a north-south orientation along its length. A corridor connects the room's eastern and southern sides to a main entrance door, and portions of the room's east and south faces feature glass louvers, each with six operable windows. During the studies, several window opening configurations and locations were employed to examine the variance in the room's ventilation characteristics.

Figure 1 Google map location, 3D views, and a schematic diagram of the Classroom ESABSF

3.2 *Assumptions of CFD Prediction*

The following assumptions were made in the CFD prediction:

Heat sources: The heat generated by the room's equipment and the solar heat gained through the south-facing glazed portion were thought to be evenly distributed throughout the floor. Artificial lighting close to the ceiling was perceived as a uniformly distributed heat source.

Challenges: The Classroom ESABSF tables and columns were modeled as barriers. The inhabitants were regarded as impediments to the generation of heat (100 W per person).

Supply air: Assuming normal and uniform distribution across the openings, the air velocity at the supply openings was computed from the measured air flow rate.

3.3 *Simulation Runs*

Ten simulations were run, with five including occupancy and the other five without occupancy. Table 1 displays the average air temperatures and velocities that were anticipated and observed at a level of 1.1 meters above the floor. Average air temperatures and velocities in the classroom, which were 1.1m above the floor, were measured and predicted. Figure 2 shows the schematic diagram of the Classroom ESABSF with occupants/obstructions in position.

Table 4.30 shows that the mean indoor air velocity and indoor air temperature values measured from the Classroom ESABSF and predicted by the simulation are reasonably accurate. For indoor air velocity and indoor air temperature, the mean discrepancy between the predictions and measurements is less than 4% and 1 ^{o}C, respectively.

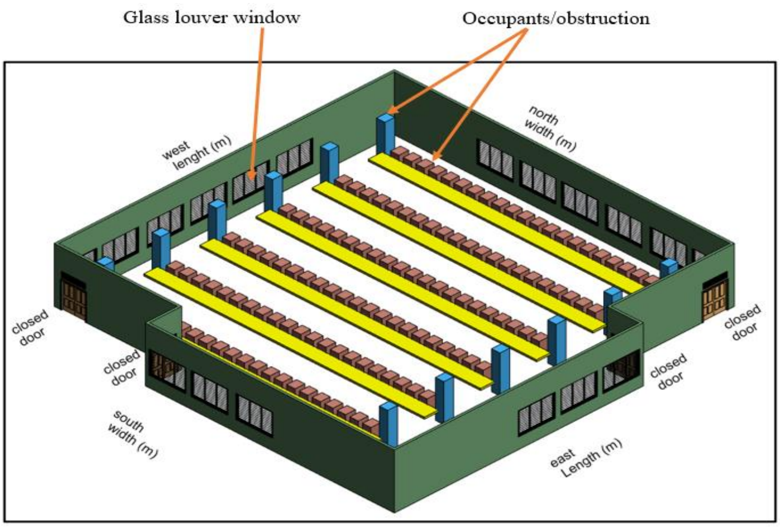

Figure 2 Schematic diagram of the Classroom ESABSF with occupants/obstructions in position.

4. Results

A naturally ventilated university classroom (Classroom ESABSF) for the dry and wet seasons was used for the airflow and thermal comfort predictions. The Classroom ESABSF was selected for the analysis based on its performance according to the CEB Thermal Comfort Tool. The Classroom ESABSF recorded (with occupancy) indoor air temperature, indoor air velocity, relative humidity, PMV, PPD, and thermal sensation of 32.55^{o}C, 0.95m/s, 62.72, 97%, and hot, 29.01^{o}C, 0.95m/s, 78.45%, 69% and slightly warm, respectively for the dry and wet seasons. The unoccupied Classroom ESABSF recorded an indoor air temperature, indoor air velocity, relative humidity, PMV, PPD, and thermal sensation of 31.08^{o}C, 0.88m/s, 59.63, 81%, and warm, 28.43^{o}C, 1.02m/s, 85%, 49%, and cool, respectively, for the dry and wet seasons.

The expected indoor air temperature and indoor air velocity distributions for the two scenarios that were covered with occupancy (case 1-5) and the other without occupancy (case 6-10) are displayed in Table 1 and compare the expected temperatures and velocities with the occupied and non-occupied values for the two scenarios for the two seasons (dry and wet). The corresponding supply velocities are 2.00 and 1.10m/s, and the airflow rates for cases 1 and 6 are 3.62 and 6.43 air changes per hour, respectively. All the windows in the Classroom ESABSF were completely open in all cases. Air entered the classroom ESABSF through the nine windows of the south-west wall and exited through the other nine windows in the north-east. Table 1 shows that predictions and measurements correspond quite well, except for the projected values near the supply window, which were somewhat higher for velocity and lower for temperature in the classroom. The assumption regarding the velocity direction at the supply opening was efficient. It is possible that the supply air velocity was not perpendicular to the opening region as predicted. In actuality, the wind directions during the study moved towards the south-west for all cases.

Additionally, Table 1 shows that while the measured values were almost uniform, the anticipated indoor air temperatures for the occupancy case ranged from the lowest near the supply opening to the highest close to the occupants. This is due to a comparatively significant discrepancy between the room bulk temperature, particularly the body temperature used in the prediction, and the air temperature supply. Because the measurement was taken at a few different locations, it could not capture the entire range of variances. Compared to the occupied classroom, the anticipated indoor air temperature in the vacant classroom shows a smaller variance (Table 1) and greater agreement with the occupied classroom. Once more, the difference between the occupied and non-occupied classroom velocities is greater. Assumptions and uncertainties in important parameters like the dispersion of heat sources in space and the size and direction of supply air velocity could explain these differences. However, the predictions were deemed good when compared to field observations, which are far more intricate and, most importantly, controllable than those in, say, scale or laboratory models. The expected proportion of dissatisfaction for the two scenarios shown in Table 1 was 97% and 9% for the dry and wet seasons for the occupied, with corresponding non-occupied values of 81% and 4% for dry and wet seasons, respectively. The PPD for the wet season for both occupied and unoccupied classrooms was well below the acceptable 20%. The PMV was recorded as hot and neutral during the dry and wet seasons, respectively, for the occupied classroom and warm and neutral during the dry and wet seasons, for the unoccupied classroom. The Classroom ESABSF did not adhere to ASHRAE Standard 55-2023 during the dry season for the occupied and unoccupied and hence was thermally uncomfortable. Figure 3 shows simulation results from the Classroom ESABSF during the dry and the wet seasons.

The Classroom ESABSF only adhered to ASHRAE Standard 55-2023 and was comfortable during the wet season of occupied and unoccupied periods. The higher the airflow and the air change, the lower the indoor air temperature of the classroom, as shown in Table 1.

Table 1. Predicted and measured mean indoor air velocities and indoor air temperature in the Classroom ESABSF (1.1m above the floor).

Occupied					
No	**Air change rate (1/hr)**	**Velocity(m/s)**		**Temperature (ºC)**	
		Wet	**Dry**	**Wet**	**Dry**
1	3.62	2.00	1.88	26.21	32.45
2	4.56	1.54	0.85	26.32	31.18
3	5.32	0.98	0.92	25.89	30.13
4	1.56	0.95	0.89	25.76	33.04
5	4.57	1.01	0.88	26.08	30.25
Mean		***1.12***	***0.95***	***26.05***	***32.55***
PPD				7%	97%
PMV				-0.14 (neutral)	3 (hot)
Unoccupied					
No	**Air change rate (1/hr)**	**Velocity(m/s)**		**Temperature (ºC)**	
		Wet	**Dry**	**Wet**	**Dry**
6	3.62	1.10	1.09	22.84	30.04
7	4.56	1.14	1.13	23.92	30.01
8	5.32	1.16	0.98	21.11	31.45
9	1.56	0.89	0.91	22.32	30.09
10	4.57	0.98	0.89	22.98	30.01
Mean		***1.04***	***0.90***	***22.63***	***30.02***
			PPD	4%	81%
			PMV	-0.11 (neutral)	1.9 (warm)

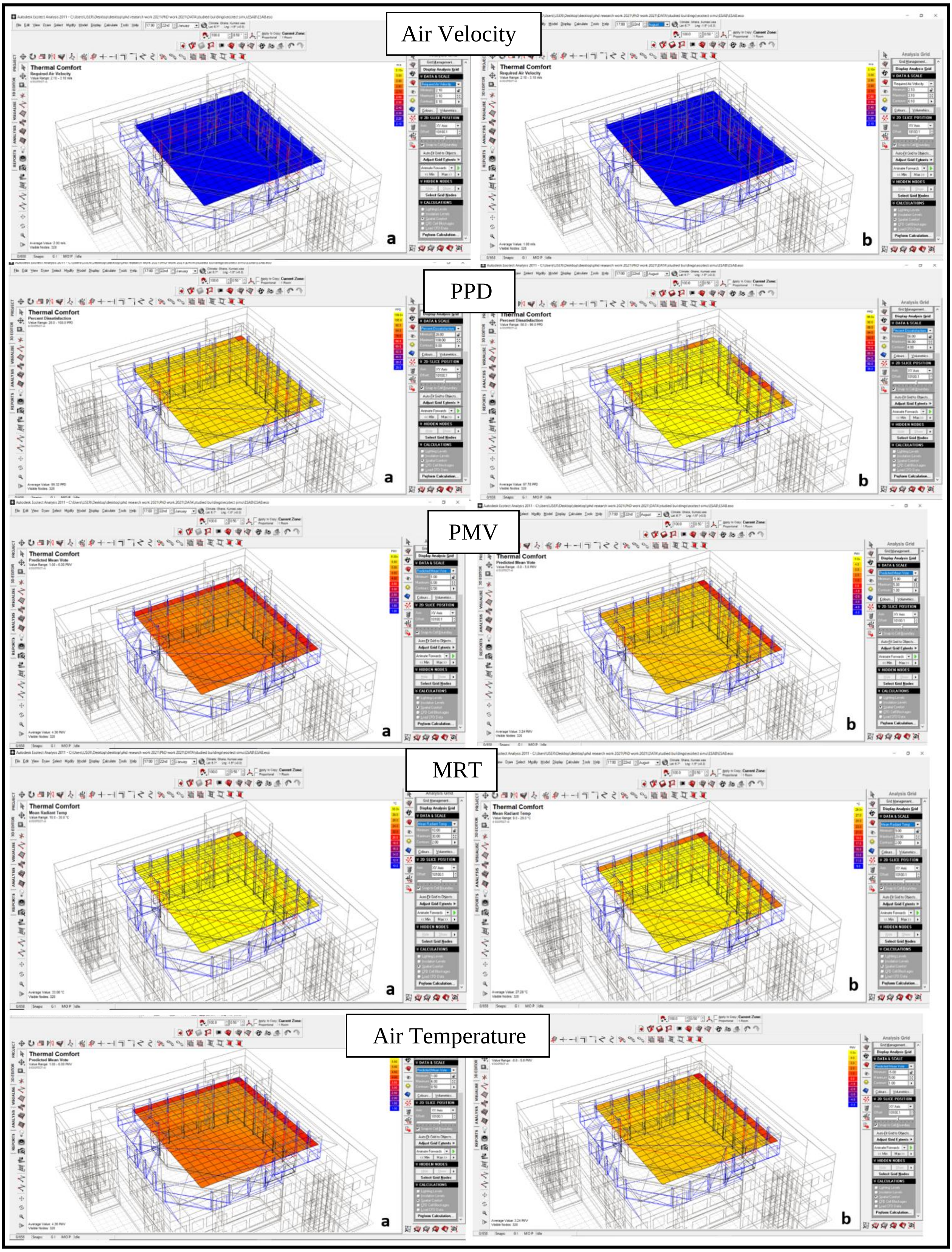

Figure 3 Results from the simulation (a) dry season and (b) wet season (Classroom ESABSF)

4.1 Descriptive statistics

Table 2 presents the descriptive statistics of the average thermal comfort level for both occupied and unoccupied classroom spaces, along with their corresponding seasons (dry and wet). The results indicate that the mean, median, and standard deviation for the occupied classroom were all higher than those for the unoccupied classroom. The mean value for the occupied classroom in the dry and wet seasons was 32.55 °C and 26.05 °C, respectively. The mean value for the unoccupied classroom in the dry and wet seasons was 30.02 °C and 26.05 °C, respectively.

Table 2 Descriptive statistics of annual energy consumption (kW/m2) and carbon emission

Season	Classroom State	N	Mean	Median	Std. Deviation
Dry Season	Occupied	5	32.55	8.2	1.04
	Unoccupied	5	30.02	4.65	1.21
	Total	5	8.50		1.24
Wet Season	Occupied	5	26.05	8.51	0.72
	Unoccupied	5	22.63	2.75	0.54
	Total	10	7.52		1.13

4.2 Analysis of Variance by using single-factor ANOVA

The ANOVA test results are displayed in Table 3. According to the ANOVA, the occupied classroom's mean temperature throughout the dry and rainy seasons was 32.55 ^{o}C and 26.05 ^{o}C, respectively. The mean yearly carbon output of the green building model was substantially lower than that of the conventional building model, according to the findings of the ANOVA test. It was discovered that the p-value of 0.00 was below the alpha threshold of 0.05.

Table 3 Single-factor ANOVA results of occupied and unoccupied classrooms in the dry and wet seasons

Season	Mean	F-value	P-value	F-critical
Occupied				
Dry season	32.55	8.12	0.00	4.35
Wet season	26.05	7.230	0.00	3.26
Unccupied				
Dry season	30.02	7.98	0.00	4.11
Wet season	22.63	6.76	0.00	3.10

4.3 Correlation Analysis.

The correlation between the study's variables of air velocity, air temperature, relative humidity, and radiant temperature is displayed in Table 4's correlation matrix (Pearson Correlations). Table 4 displays the relationship between air temperature and air velocity. Air velocity and air temperature have a substantial negative correlation, as seen by the r-value (-0.942) and p-value of 0.000. This suggests that the temperature of the air in the classroom drops as the air velocity rises. The relationship between air velocity and relative humidity is displayed in Table 4. Air velocity and relative humidity have a substantial negative correlation, as seen by the r-value (-0.851) and p-value of 0.000.

Relative humidity falls as air velocity rises. Table 4 displays the relationship between air temperature and radiant temperature. There is a significant negative correlation between air temperature and radiant temperature, as indicated by the r-value (-0.921) and p-value of 0.000. The radiative temperature in the classroom drops as air velocity rises.

Table 4 Correlation Matrix (Pearson Correlations).

		Air Temperature	**Relative Humidity**	**Radiant Temperature**
Air Velocity	Pearson Correlation	-0.942	-0.851**	-0.921**
	p-value	0.000	0.000	0.000
	N	5	5	5

** = Correlation is significant at the 0.01 level (2-tailed).

4.1 Model Summary^b of the regression analysis

The multiple regression model explained 96.2% of the variance in thermal comfort by environmental variables (air velocity, air temperature, radiant temperature, and relative humidity), according to Table 5's corrected R2 value of 0.962. Environmental factors were independent variables that accounted for 95.7% of the observed variability in thermal comfort (R2 = 0.962, Adjusted R2 = 0.957). This suggests that the environmental variable provides a positive explanation for the variation in thermal comfort. Between 1 and 3, the Durbin-Watson statistics were 1.721. The independence of errors was examined using the Durbin-Watson statistics. As 1.721 is less than 3 and larger than 1, the independence of observation was satisfied.

Table 5 Model Summary[b] of the regression analysis.

Model	R		R Square (R^2)	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.934[a]		0.962	0.957	0.576	1.721

a. Predictors: (Constant), Air Velocity, Air Temperature, Radiant Temperature, Relative Humidity
b. Dependent Variable: Thermal Comfort

5. Discussions

The Classroom ESABSF recorded (with occupancy) indoor air temperature, indoor air velocity, relative humidity, PPD, PMV, and thermal sensation of 32.55°C, 1.12m/s, 62.72%, 97%, and hot, 26.05°C, 0.95m/s, 78.45% and 7% and neutral, respectively for the dry and wet seasons. The Classroom ESABSF, when not occupied, recorded an indoor air temperature, indoor air velocity, relative humidity, PMV, PPD, and thermal sensation of 31.08°C, 0.90m/s, 59.63%, 81%, and warm, 28.43°C, 1.04m/s, 85%, 4% and neutral respectively for the dry and wet seasons. The results obtained imply that, unless a higher airflow rate makes up for it, the indoor temperature may be higher than what is considered thermally comfortable when the outside temperature is significantly higher. Therefore, if discomfort in space is to be avoided in a hot climate, some steps may need to be taken to provide enough air, preferably cool air, without creating an excessive draft. In cold season, the inlet windows should be adjusted to limit the inflow of air into the space to maintain indoor thermal comfort, which is standard procedure.

An additional forecast was created for the conditions described in case one, but without occupancy, to examine the impact of occupants on airflow and thermal comfort. Figures 6.1 and 6.5 display the temperature distribution and airflow pattern in this instance. Occupants' thermal comfort has a significant impact on the temperature distributions and airflow patterns in the classroom. The presence of occupants raises the temperature of the air near the body and causes an air plume to rise around the head as a result of body heat. Like other obstructions, the occupant affects and reroutes airflow. The diversion happens because of the buoyant force caused by the temperature differential between the body and the surrounding air, in addition to the separation of air as it flows over the body. The temperature of exposed flesh is approximately 32.45 °C, whereas the temperature of clothing might range from 27 to 30 °C. As a result, compared to those with occupancy, the temperature in the occupied zone decreased by 1 °C and the velocity by 10% when the inhabitants were absent from the classroom. The distribution of comfort indices is inherently impacted by the inhabitants since they alter the indoor environment. However, the overall effect of occupancy on the predicted thermal comfort is minimal due to the simultaneous decrease in indoor air temperature and indoor air velocity. For instance, the average PDD in the occupied zone dropped from 97% with occupancy to 81% during the dry season, and without occupancy dropped from 7% to 4% during the wet season. Naturally, this change may be rather significant in some spots in the classroom, especially in and around the area where occupants were located.

The simulation was developed to predict airflow and thermal comfort in naturally ventilated rooms given data on critical parameters such as supply air velocity and temperature. In a warm, humid climate, windows positioned correctly can offer adequate thermal comfort, and natural ventilation can be used to create a comfortable environment in a hot region, depending on the supply—exit configuration, people density, and room architecture. A naturally ventilated room's temperature and airflow patterns are greatly influenced by the arrangement of its occupants.

The study by Lamberti et al. (2021) showed that in order to improve interior environmental conditions and student well-being in classrooms, more research into the connection between architectural features and thermal comfort is required. For their study, Koranteng et al. (2019) used a survey and quantitative methodology. Using the Mahoney Tables, their study evaluated the subjective heat impressions of people in workplaces, classes, and residential hallways. A total of 214 valid questionnaires were used in the analysis. 58% of residents in each of the three residence halls selected the comfort band, indicating negative emotions, according to the survey (Koranteng et al., 2019). Koranteng et al. (2019) discovered that votes for warm sensations (44%) were more than votes for cool sensations (29%). According to Cheng et al. (2022), the building's air flow was well received and satisfied ISO 7730's Categorical B standards. However, the risk of chilly feet is the main reason why stratum ventilation for winter heating may result in the pain of warm heads and/or cold feet.

6. Conclusions

According to this study, airflow has a great impact on thermal comfort in university classrooms with natural ventilation. By boosting convective heat escape from the body, proper air flow improves occupant comfort, especially in warmer climates. The findings demonstrate that acceptable comfort levels can be maintained without the use of mechanical air conditioning, provided natural ventilation is efficiently captured through thoughtful window location and design. However, it was also noted that drafts from excessive airflow, especially during colder months or when air movement is irregular, can result in local discomfort.

The simulation revealed a generally favorable reaction to more airflow during hot weather, highlighting the significance of adaptive thermal comfort models that take users' capacity to adapt to changing environmental circumstances into consideration. The significance of managing air distribution to avoid stagnation and ensure constant ventilation throughout the classroom was further supported by a CFD study.

7. Recommendations

The study recommended that architects make all efforts (wall-to-window ratio) at the design stage to increase air flow in naturally ventilated classrooms.

The number of students in a classroom should be calculated according to the total floor area of the classroom to avoid overcrowding of the classroom.

To improve airflow, place movable windows on opposing sides (cross ventilation) and make use of window designs that give you control over the airflow's direction and strength.

To help with stack ventilation, include clerestory windows or high-level openings, and to optimize natural air exchange, design with the direction of the prevailing wind in mind.

Supplement natural ventilation during low-wind conditions with fans to maintain air movement, and fans should be adjustable to allow occupants control and enhance perceived comfort.

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