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Evaluating the impact of classroom design and orientation on the indoor environment quality in Egyptian schools.

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Keywords

Indoor environment quality'(**IEQ**);

Thermal comfort **(TC)** ;

Indoor air quality (IAQ) ;

The expected percentage of dissatisfaction **(PPD)** ;

The predicted mean vote **(PMV).**

Abstract

Indoor environmental conditions in classrooms affect students' health and academic performance. Studies have proven that the quality of the indoor environment is important in classrooms. Indoor environmental quality (IEQ) is represented in achieving thermal comfort, indoor air quality, visual comfort, as well as acoustic comfort. The research aims to determine the extent to which the shape and orientation of the classroom in Egypt affect the quality of its internal environment, and the thermal performance, as well as achieving good ventilation for the classroom. The research conducted an environmental simulation for the classroom in Cairo, Alexandria, and Aswan using the environmental simulation program Design Builder. To study the extent to which the design, shape and orientation of classroom openings in accordance with the design standards of the Educational Building Authority affect thermal comfort and air velocity in the classroom in selected study areas in Egypt. The model has been calibrated via field measurements in a standard classroom. The research found that the expected percentage of dissatisfaction (PPD) inside the classroom in Aswan is higher than the PPD for the classroom in Cairo by a rate exceedingly 40%. The predicted mean vote (PMV) for the classroom in Cairo is the best during the school months, as its ranges from zero to less than (+1 and -1). The classroom with the southern orientation in Alexandria represents the lowest in (PPD) in the school months from (December to May), as decreases by 20% compared to the classrooms in the other directions in Alexandria.

1. Introduction

Educational spaces can be defined as the environment where teaching and learning processes take place. The environmental conditions in classrooms play critical roles in students' health, performance, behaviour, and productivity [1-3]. Students and teachers spend about 4 to 8 hours per

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day during weekdays in classrooms, which represents one-third of their total time [4, 5] .As education levels rise, students require higher levels of concentration and more thinking.

The main goal of any building is to reduce the negative effects of the external environment on its occupants, by creating a healthy, comfortable and productive indoor environment. Therefore, many studies and literature have focused on studying the impact of the quality of the internal environment on the academic achievement and performance of school students [6]. As well as on the negative impact of the internal environment on the health of students, as the quality of the internal environment of the building interacts dynamically with its users and affects them physiologically and psychologically [7].

Unhealthy buildings, that have inadequate ventilation and various external pollutants in the long term, are very harmful to their users and can cause various types of diseases. Unhealthy classrooms lead to student absence and negatively affect the educational process. [8], [9] Therefore, the design considerations of the classroom are an important factor in improving the performance of the internal environment in it according to the different environmental and climatic characteristics and considerations.

It is evident that the performance of the indoor environmental quality (IEQ) depends on external environmental factors such as outdoor air quality, outdoor temperature [10], wind speed, humidity, outdoor noise and lighting intensity levels.[11], [12], [13] .The indoor environmental quality (IEQ) in buildings includes indoor air quality (IAQ), acoustic comfort (AcC), thermal comfort, lighting and visual comfort (VC) [4] .In addition to other factors such as colour, visual effects, vibrations, solar gains, safety factors and unexpected hazards that may have an impact on the personal comfort.

To improve IEQ inside a classroom, it is necessary to focus on visual, thermal and ventilation conditions which are important to achieve physical comfort for students and improve their performance and academic understanding. Most of the studies conducted in Egypt on educational classrooms included measuring and evaluating the air quality in the classroom and the amount of pollutants [14]. Among them a study that also addressed the self-assessment of the environmental performance of government primary schools in the hot dry climate in Egypt, through questionnaires without any measurements or environmental simulations [15].

numerus previous studies also addressed the evaluation of the acoustic performance of classrooms in educational buildings [16]. In addition, some studies focused on examining the indoor comfort conditions as well as energy consumption inside classrooms in Egypt to determine the extent of the impact of natural lighting on energy consumption, as well as the amount of cooling inside the building[16] .

Therefore, this research focuses on verifying the indoor environmental quality (IEQ) inside the classroom according to the design standards approved by the Egyptian Educational Buildings Authority. The impact of the design and position of openings in classrooms on thermal performance in different climatic regions in Egyptian schools is studied according to design considerations of the classroom, such as thermal comfort and natural ventilation.

The objective

This research aims to find to which extent the classroom that is designed according to the standards of the Educational Buildings Authority achieves the quality of the internal environment. In addition to examining the effect of the shape, the design and the position of the openings in the classroom according to the Educational Buildings Authority on the environmental performance (that is reported via thermal comfort and the natural ventilation) in the classroom in the different climatic regions in Egypt. Also, the impact of different orientations of the classroom on the thermal performance and thus the quality of the internal environment is tested.

Methodology*:*

The research* methodology *is as follows:

Firstly, the theoretical aspect: deals with identifying the quality of the indoor environment and its constituent elements inside buildings, such as thermal comfort and indoor air quality, in addition to visual comfort and acoustic comfort. In addition to discussing the design foundations of the classroom in schools in accordance with the standards of the Educational Building Authority, identifying the most important influences that affect the quality of the internal environment in the classroom.

Secondly, the applied aspect: The Design Builder environmental simulation program is used to analyze the environmental performance of the classroom, where the measurement is done inside a classroom with fixed dimensions and two opposite external facades containing the openings of the classroom. The simulation model has been calibrated via comparing its outcome (air temperature) to the air temperature obtained from field measurement in two typical classrooms.

Air temperature, PMV (the predicted mean vote) and PPD (the predicted percentage of dissatisfied) are measured and analyzed to determine the thermal comfort inside the classroom. Air movement is also measured in three climatic regions in Egypt (Aswan - Cairo - Alexandria) to determine the extent of the design's compatibility according to the standards of the Egyptian Educational Buildings Authority in the four main directions (north - south - east - west) with the internal environment quality in the classroom.

2. Indoor environment quality (IEQ)

Indoor environmental quality is defined as the quality of the built environment of any indoor space in relation to the well-being and health of the occupant who uses that space. It is composed of several factors and various sub-domains that affect human life inside the building, namely indoor air quality (IAQ), acoustic comfort (AcC), thermal comfort (TC), and visual comfort (VC).

In addition to the quality of the working environment, furniture orientation, electromagnetic waves, vibrations, and other related factors [17]. The four most important factors are Indoor Air Quality (IAQ), AcC (Acoustic Comfort), TC (Thermal Comfort), and VC (Visual Comfort). This is shown in **Fig1**. [18].

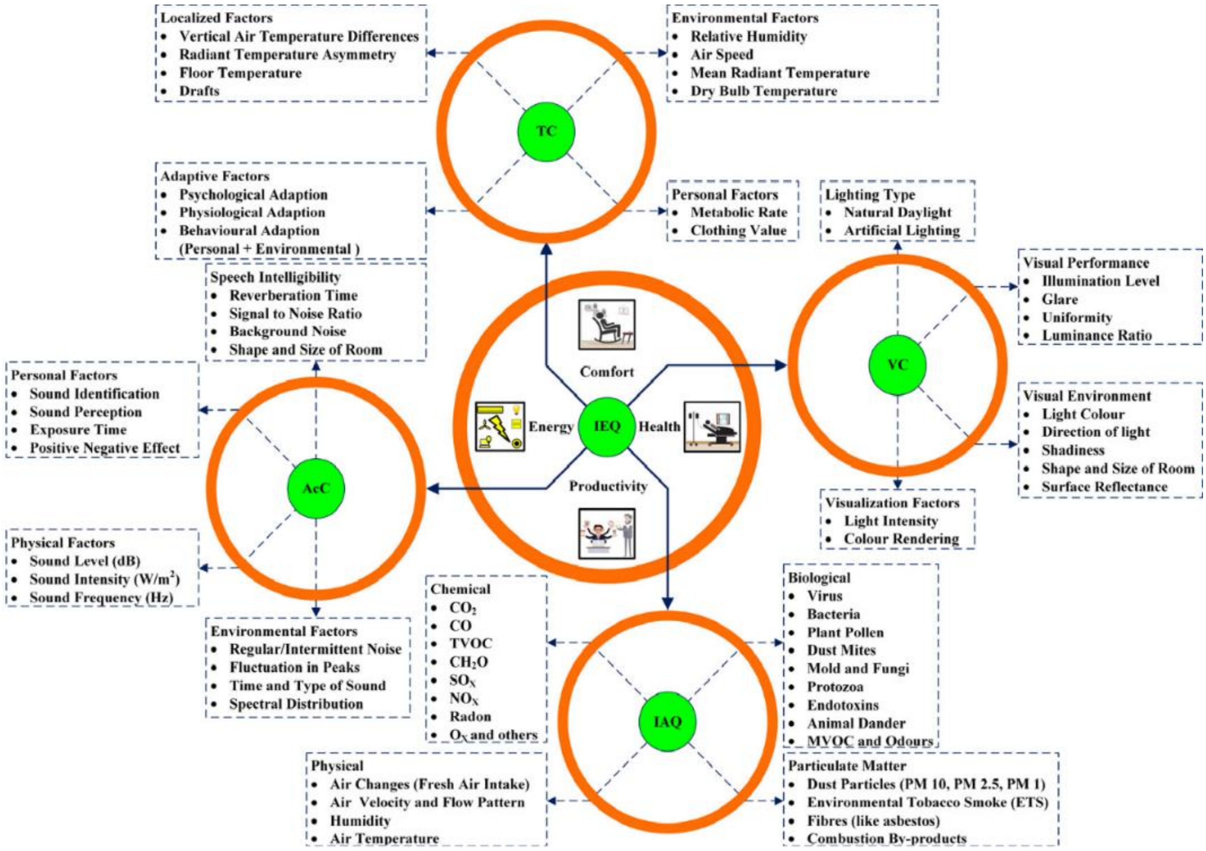


Fig1. IEQ parameters and associated sub-parameters. [18]

This is evident in the following general equation, which explains the components of indoor environmental quality without weights, equation (1). [18]

$$\mathbf{IEQ = TC + VC + IAC + AcC} \qquad (1)$$

Where IAC is indoor air comfort and is a combination of IAQ (**Indoor Air Quality) and** ventilation. (AcC) acoustic comfort, (TC) thermal comfort, and (VC) visual comfort.

2.1. Thermal Comfort (TC)

Thermal comfort (TC) is the mental state that expresses the level of satisfaction with the surrounding thermal environment [19]. Thermal comfort TC depends on four environmental factors: relative humidity (RH), mean radiant temperature (MRT), dry air temperature (DBT), and air speed, along with two personal factors, clothing rate and metabolic rate [18].

Two well-accepted models for predicting the thermal comfort TC of any building are Predictive Mean Voting (PMV) and an adaptive model known as thermal balance model or laboratory model [19]. The PMV model was developed by Povl Ole Fanger in the 1970s, and it works well for air-conditioned (AC) buildings [20]. The International Organization for Standardization (ISO-7730) considers the (PMV) model to be its thermal comfort model[21].

The European thermal adaptive comfort standard BS EN 15251 is based on ASHRAE 55, where the comfort temperature is calculated through the equation (2) [21].

$$\mathbf{T_c = 0.31\ T_{pma(out)} + 17.8} \qquad (2)$$

It is a linear regression of indoor comfort temperature (Tc) and outdoor air temperature (Tpma (out)).

2.2. Indoor Air Quality (IAQ)

The air quality in and around a building is known as indoor air quality [21]. Indoor air quality depends on humidity, ventilation rate, and air temperature. In addition to many gases, biological pollutants, and the presence of particles that affect air quality [22] , [23].

The influencing factors are represented by a group of factors (physical, chemical, biological and particulate) and dynamic interactions. External pollution greatly affects the quality of indoor air in buildings with natural ventilation. [24].

Ventilation affects indoor air quality as it is the process of replacing stale indoor air with fresh outdoor air and maintaining air movement inside the building. There are two main ways to address indoor air quality problems in buildings: one is to increase the ventilation rate inside the building, and the other is to reduce or control sources of air pollution inside and outside the building.[17].

Since natural ventilation can improve thermal comfort, there are two common methods for providing natural ventilation. **First**: Ventilation is from one side, which means there is only one window in one wall. **Second:** If the room has two windows in two parallel walls, cross ventilation will be done through the intersecting windows. Many studies and designers have used cross ventilation to provide natural ventilation in the building [25].

Many studies have reported that high temperatures are the most common problem in classrooms. Therefore, many researchers have worked to study the interaction of humans with their environment and the effect of their body heat on the increase in building temperature. These results led researchers to determine a minimum air speed to provide a comfortable place according to the environment and climate to which it belongs [25].

2.3. Visual comfort (VC)

Visual comfort represents the well-being of the occupants of an architectural space that is influenced by the visual environment surrounding the building and is self-accessible[18] . Visual comfort is affected by natural daylight, lighting level, light uniformity, and light colour [26], [27]. Discomfort usually occurs due to glare, non-uniform lighting, and the lack of appropriate levels of required lighting intensity, which affects students' performance in the classroom [28].

Previous studies have shown that daylit places improve people's overall health [29], as the lack of visual comfort affects students and causes some symptoms such as frequent headaches, eye strain, and poor eyesight in the classroom.[30], [31].

2.4. Acoustic Comfort (AcC)

Acoustic comfort (AcC) refers to the quality of a building and its ability to protect its residents from ambient noise and provide them with a better and safer acoustic environment, through which they can communicate easily[18]. Acoustic comfort in an occupied space usually depends on a combination of factors: sound pressure levels, sound frequency, source distance, sound absorption, isolation, and reverberation time (RT). Noise can be classified into five types: constant, fluctuating, tonal, and intermittent noise. Speech intelligibility mainly depends on reverberation time (RT) and signal-to-noise ratio (SNR) [18].

Since the internal environment quality with its four elements (thermal comfort - air quality - visual comfort - auditory comfort), it is employed to evaluate the environmental performance for the classrooms. The paper focuses on discussing and analysing the design foundations of classrooms in schools approved by the Egyptian Educational Buildings Authority and the most important influences that affect the quality of the internal environment in the classroom. This will be done via studying the extent of the impact of its design on the thermal comfort and ventilation in the different climatic regions in Egypt. The tool used for achieving these goals is by environmental simulation of a standard classroom via Design Builder.

3. Classroom design requirements in schools in Egypt [32] .

According to the design standards of the Egyptian Educational Buildings Authority, the most important design considerations for the classroom are found to be:

The classroom area is not less than 42 m^2, with the student's share of the classroom area not less than 2 $m^2$for schools that implement special curricula, and 1.4 $m^2$for language schools. The length of the classroom does not exceed 9 m, and this represents the maximum distance between the seat of the last student and the blackboard.[32] As for the area of classroom openings (windows), it must exceed than 18% of the classroom area distributed on both sides of the classroom.[32]

The width of the classroom door should not be less than 1 meter, and the height of the window session should be greater than 1.1 m.[32] For natural lighting in the classroom, it is preferable to be to the left of the students.

As for the general orientation of the classroom in schools, what is permitted is the northern direction, and it is possible to deviate 25 degrees to the east and west from the north. If this condition is impossible, other directions can be allowed while providing full shading of the openings by sun visors.[32]

It should be noted most of the Egyptian schools' classrooms are designed to these design requirements, irrespective on orientation for the classrooms, as the school building is oriented in any of the four directions according to the school's location and its specifications only.

4. Case study

This research deals with the following case study of the classroom according to the design requirements of the Egyptian Educational Buildings Authority in three Egyptian regions: Aswan - Cairo - Alexandria.

4.1.Description of the case study

The environmental performance of the school classroom is analyzed according to the designs of the Educational Building Authority using the environmental simulation program "Design Builder".

The dimensions of the classroom were determined to be consistent with the requirements of the Educational Buildings Authority and what is applied, so that the dimensions of the classroom are 7.5 * 5.6 = 42 m^2. As for the dimensions of the openings, they are designed in the models approved by the Authority as follows:

The dimensions of the ventilation openings in the classroom are 1.55*2.60 m^2.

The classroom contains three windows, two on the student's left overlooking the street, and one opening in the corridor on the opposite wall, as shown in **Fig 2**.A

Note that the window is positioned 1.1m above the room floor, the width of the window is 2.6m and the height of the window is 1.55m. The openings consist of four aluminum sections (two of them are fixed and the other are sliding) in addition to four fixed lower leaves. Note that the glass is single,

white, transparent, and 6 mm thick. The doors in the classrooms are 1 meter wide and 2.20 meters high, and the total height of the classroom is 3.30 m.
Note that the classroom whose environmental performance was measured using the Design Builder environmental simulation program is located on a middle floor inside the school and between repeated classrooms. It has one facade facing the outside and the other facing the corridor for movement leading to the classrooms. Heat exchange takes place through the external walls and their openings. As for the walls adjacent to other classrooms and the ceiling and floors adjacent to other classrooms, they do not allow heat exchange (adiabatic), as show in **Fig 2.B**

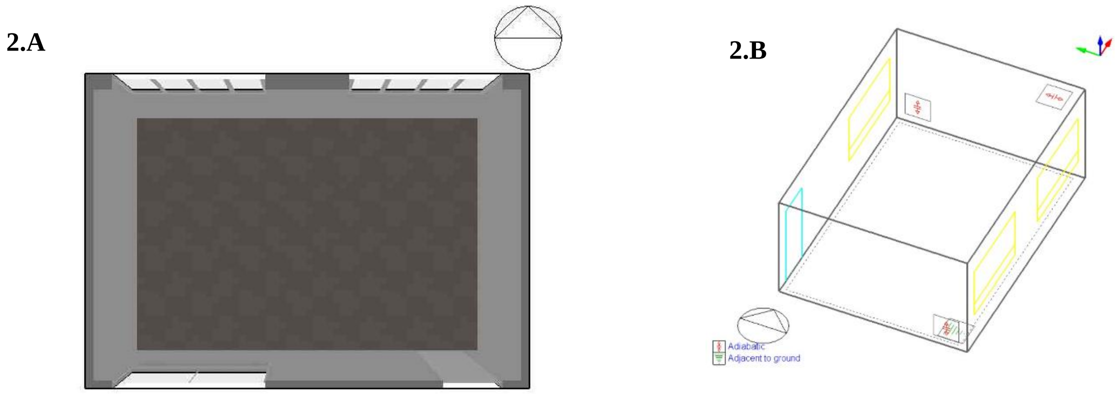


Fig 2. The classroom in Design Builder program
(A) Plan of classroom in Design Builder (B) heat exchange settings .

4.2. description of environmental simulation program “Design Builder”

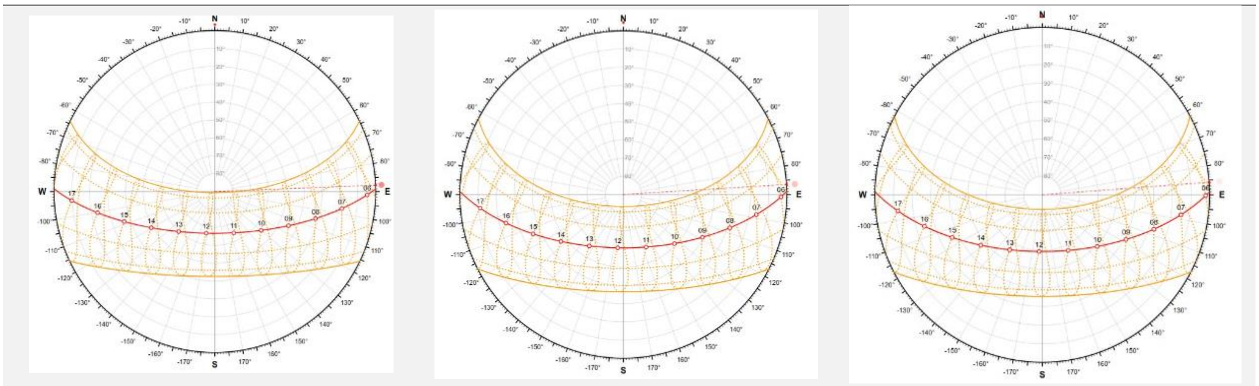
Design Builder environmental simulation program is a reputable program used to deal with environmental problems and remediation of buildings. It provides detailed data on air temperature, air flow and energy consumption in and around buildings using the Energy Plus and Computational Fluid Dynamics (CFD) packages for general purposes. [33].
Design Builder relies on Energy Plus to measure energy, carbon, lighting, thermal comfort, air temperature, radiant temperature, and air velocity[34].
It even extends Energy Plus capabilities. Architects, engineers, and designers may model, simulate, and improve the energy performance of buildings with its user-friendly interface through its 3D modeling of building layouts. Professionals may make better informed decisions early in the design process thanks to this software, which results in more sustainable and energy-efficient structures. It is considered a unique software tool for creating and evaluating building designs.[33]
Design Builder combines rapid 3D building modeling and dynamic energy simulation with ease of use. “Design Builder” is employed as it provides flexible engineering input and comprehensive material libraries in addition to proven accuracy in estimation of thermal performance.
It can estimate Predicted Dissatisfaction Percentage (PPD) and Predicted Average Vote (PMV) for analysis and evaluation. The analysis is evaluated under seven different conditions according to ASHRAE 55: Hot (+3), Warm (+2), Very Warm (+1), Neutral (0), Very Cold (1), Cool (2), Cold (3). The PMV/PPD scale contributes to the evaluation of thermal comfort and the PPD essentially gives the percentage of people expected to experience local discomfort. [33]

Many studies and research focused on examining its validity and accuracy of its simulation results. In [35] , the authors showed that the Design Builder simulations of annual energy consumption in an office building deviated by only 1.6% from the field measurements they conducted. In [36], the authors target was the validation of the simulation results of Design Builder software. So, they modeled a two-rooms in a courtyard house via it while they did field measurements for the real building to estimate the amount of heat gain in the building. Their findings assured the accuracy of the Design builder results differed from the field measurements by less than 10% in their experiment. On testing the accuracy of estimating a roof thermal performance for a classroom in a tropical zone via Design Builder, the authors in [37] found that the deviation from the practical measurements didn't exceed 2.4%. Hence, the validity and acceptable accuracy of using Design Builder in estimating thermal performance issues for indoor environments such as inside classrooms is evident.

4.3. The simulation scenarios

The research examines three locations Aswan, Cairo and Alexandria, **Fig 3** represents the solar path for the three cities respectively. Environmental performance is measured within the classroom in the three selected locations, in the four main directions (north - south - east - west).

The paper deals with measuring environmental performance by measuring thermal comfort inside the classroom, air temperature, as well as the amount of natural ventilation in it, using the environmental simulation program "Design Builder".



ASWAN **CAIRO** **ALEXANDRIA**

Fig 3. The solar path of Aswan, Cairo and Alexandria

4.4. The weather data in case studies

4.4.1. Aswan weather data

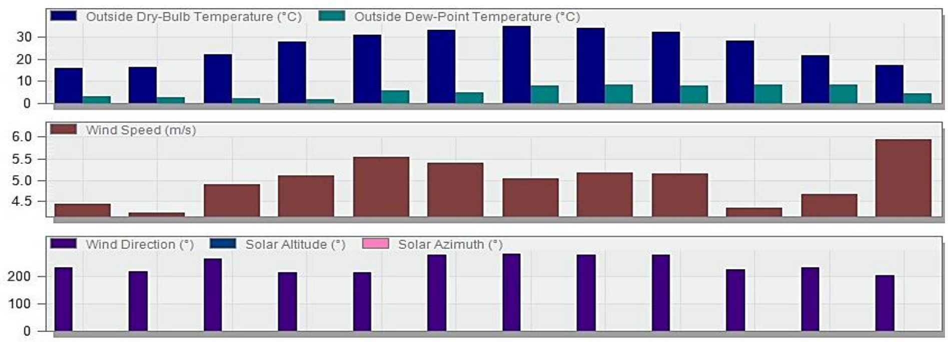


Fig 4. Aswan weather data

DMS Lat	**24° 5' 20.1768'' N**
DMS Long	**32° 53' 59.3880'' E**

Weather data of Aswan as shown by the Design Builder program. It shows that the air temperature in the shade reaches its maximum in July, reaching 34.8, while its lowest value reaches 15.89 in January. The air speed ranges from 4 to 5.5 m/s, as shown in **Fig4**. [33]

4.4.2. Cairo weather data

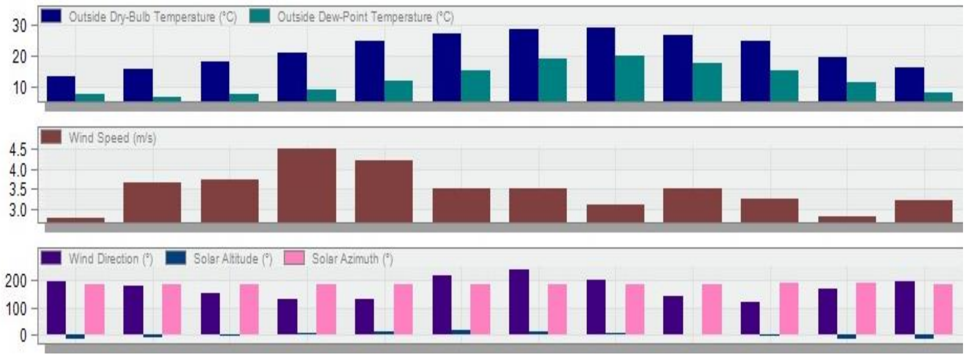


Fig 5. Cairo weather data

DMS Lat	30° 1' 59.9988" N	Weather data of Cairo showed that the maximum air temperature in August reaches 29.24o c, while the lowest in January is 13.75o c. The air speed ranges from 2.7 to 4.5 m/s, as shown in **Fig 5**. [33]
DMS Long	31° 14' 0.0024" E	

4.4.3. Alexandria weather data

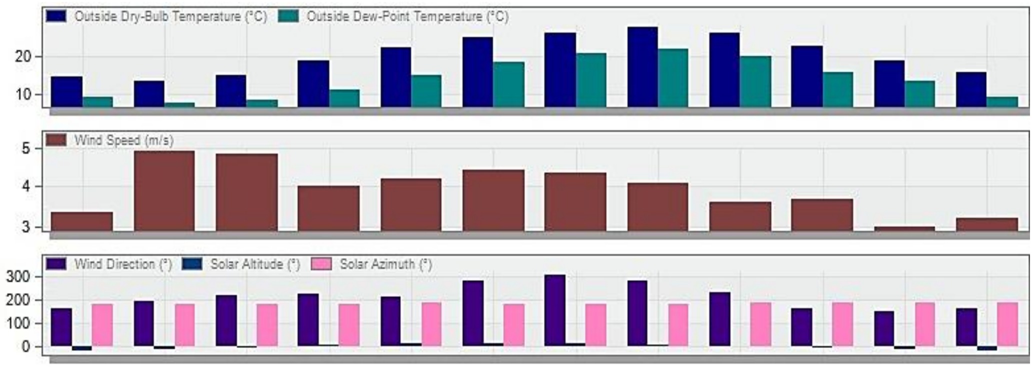


Fig 6. Alexandria weather data

S Lat	31° 12' 20.7108" N	Weather data of Alexandria showed that the maximum air temperature in August reaches 27.28o c, while the lowest in January is 14.67o c. The air speed ranges from 3.2 to 4.41 m/s, as shown in **Fig 6.** [33]
DMS Long	29° 55' 28.2936" E	

4.5. The simulation program input and data entry for base case

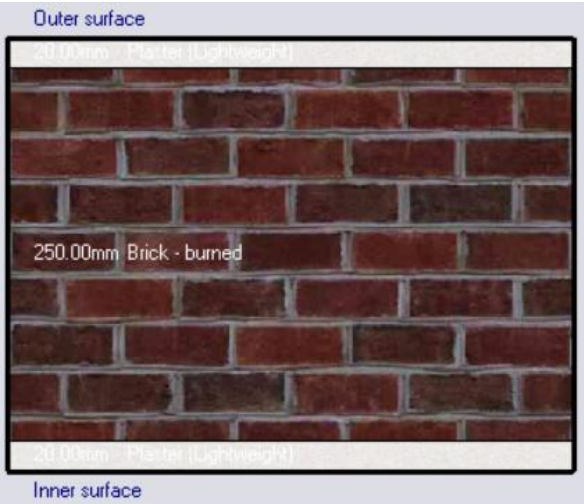
The measurement is done inside the classroom in the three selected regions (Aswan - Cairo - Alexandria), during school hours from 7 am to 14 pm, except Friday. The measurement was made using the environmental simulation program Design Builder to measure the extent to which the design of the classroom and the position and area of its openings affect the quality of its internal environment, in the four main directions (north - south - east - west).

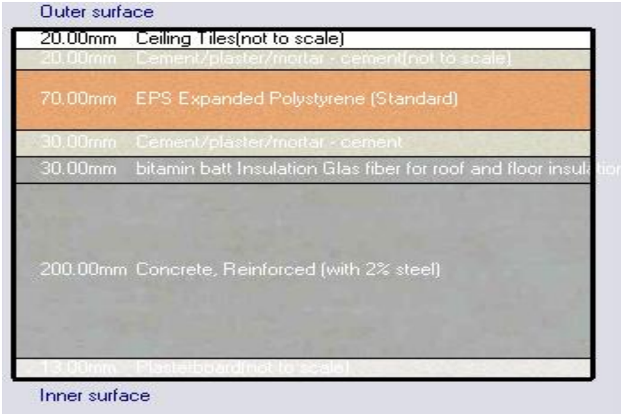
It is worth mentioning that the analysis of the thermal performance results considers only the school months while the simulation program reports the PMV and PPD all the year.

The characteristics of the classroom envelope are represented by external walls 25 cm thick, in addition to 2 cm thickness of finishing material. As for the glass for the windows, it is transparent, 6 mm thick, as shown in **Table 1.**

Table 1: Base case envelope

Base case envelope:	Walls	Roof	Windows
Layers	plastering 0.02m	Ceiling tiles: 0.02m	**Generic clear 6mm**
	Brick burned 0.25m	Cement -plaster-mortal: 0.02m	
	plastering 0.02m	EPS expanded polystyrene: 0.07m	
		Cement -plaster-mortal: 0.03m	
		Bitumen batt insulation: 0.02m	
		Concrete reinforces (2% steel): 0.2m	
		Plaster board: 0.013m	
U-Value(w/m2-k)	**1.4**	**0.318**	**3.835**





It should be noted that the input parameters and classroom specifications are the same for all simulation scenarios except the geographical data and weather data that differ for each city where the classrooms are located.

4.6. Validation (Model Calibration)

The results obtained from the environmental simulation program design builder for the study model were verified by calibrating the model. Field measurements were made in a typical classroom according to the design standards of the Educational Buildings Authority and compared with the results of the environmental simulation program design builder.

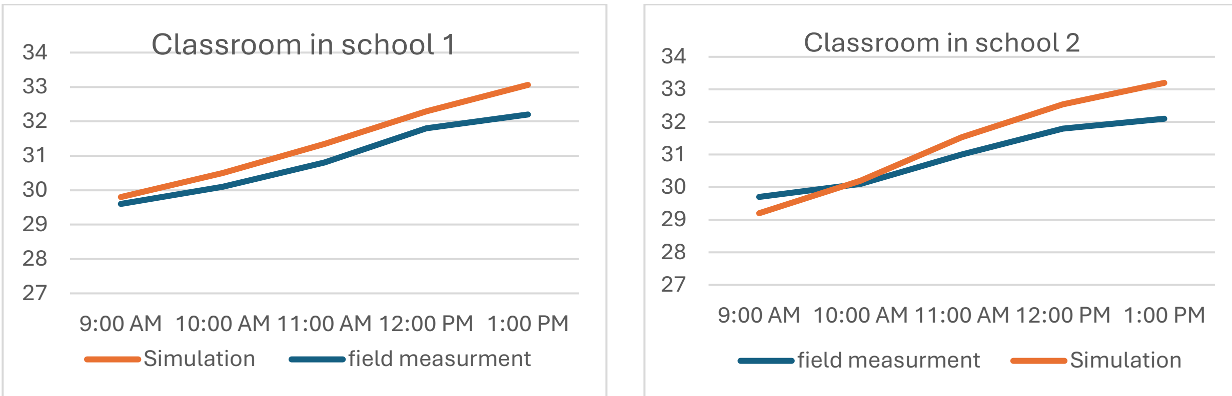
Air temperatures have been actually measured in two classrooms in Tanta city, where the researcher has the possibility of field measurement in (a classroom at Al-Rafei Language School in Tanta (school1)with a north orientation as shown in **Fig 7** and a classroom at Tanta Preparatory School for Girls (school 2) with a west orientation as shown in **Fig 8**) , on the third floor of an intermediate classroom between other classrooms, on two different days (September 1, 2024 and September 4, 2024, respectively).

The field measurements have been compared with the air temperature that has been measured by the same model for the classroom in Tanta city in both directions using the environmental simulation program design builder. A weather station has been used to measure the air temperature from 9 am to 1 pm in the two classrooms.

Fig 7. School 1: Al-Rafei Language School in Tanta -North orientation

Fig 8. School 2: Tanta Preparatory School for Girls – West orientation

Comparing the temperatures obtained from the simulation program Design Builder with the field measured temperatures in the two classrooms showed a variation of 0.6-2.67% in the classroom at School 1, and a variation of 0.33-3.42% in the classroom at School 2 during the measurement periods (from 09:00 am to 13:00 pm) as shown in Figure (9) and (10) respectively. This shows an acceptable variation when the difference is within 5% [38], [39].



(a) A north oriented classrom in school 1 (b) A south oriented classrom in school 2

Fig 9: Obtained air temperature from field measurement and simulation for typical classrooms oriented in the north direction (a) and west direction (b)

5. Result & discussion

Via employing the environmental simulation program "Design Builder", this research focuses on measuring thermal comfort and air movement inside the classroom during the different months of the year, especially during the hours of study attendance.

The PPD, PMV, and air movement are analyzed for the four directions (north - south - east - west) in the three study areas (Aswan - Cairo - Alexandria). This is to reveal the impact of the difference in the study area as well as the orientation of the classroom on the quality of the internal environment, while maintaining a fixed design of the classroom in terms of its position in the school and the area and location of its openings in accordance with the design standards of the Egyptian Educational Buildings Authority. The details of the simulation outcomes analysis is introduced in the following discussion.

5.1.Thermal comfort

The thermal satisfaction of students is determined by measuring PMV (the predicted mean vote) during the months of the year in the four orientations, for Aswan, Cairo, and Alexandria.
In addition, the PPD (the predicted percentage of dissatisfied) is measured, as it represents an indicator that determines the quantitative prediction of thermally dissatisfied students. Moreover, the air temperature inside the study samples in the four directions is measured.

5.1.1. Comparing different orientations of the classrooms in the study cases.

A. Aswan.

Regarding the predicted mean vote (PMV) during the months of the year in Aswan, as shown in **Fig 10**, and by examining it for the school classroom in Aswan, it is noticed that the peak PMV occurs in July as expected and its value is 3.86, 3.95, 4.35, and 4.44 for the orientations: North, South, East, and West respectively, with the least PMV value for the northern orientation.

When focusing on the school months (from September to June), it is found that the PMV in the northern orientation in Aswan ranges from -0.8 to 3.2, and the southern -0.4 to 3.3, while in the eastern and western orientations it ranges from -0.7 to 3.6. This confirms that the amount of thermal dissatisfaction in Aswan is very high, especially in the school months (May - June - September - October), where the PMV reaches more than 2 in the four directions.

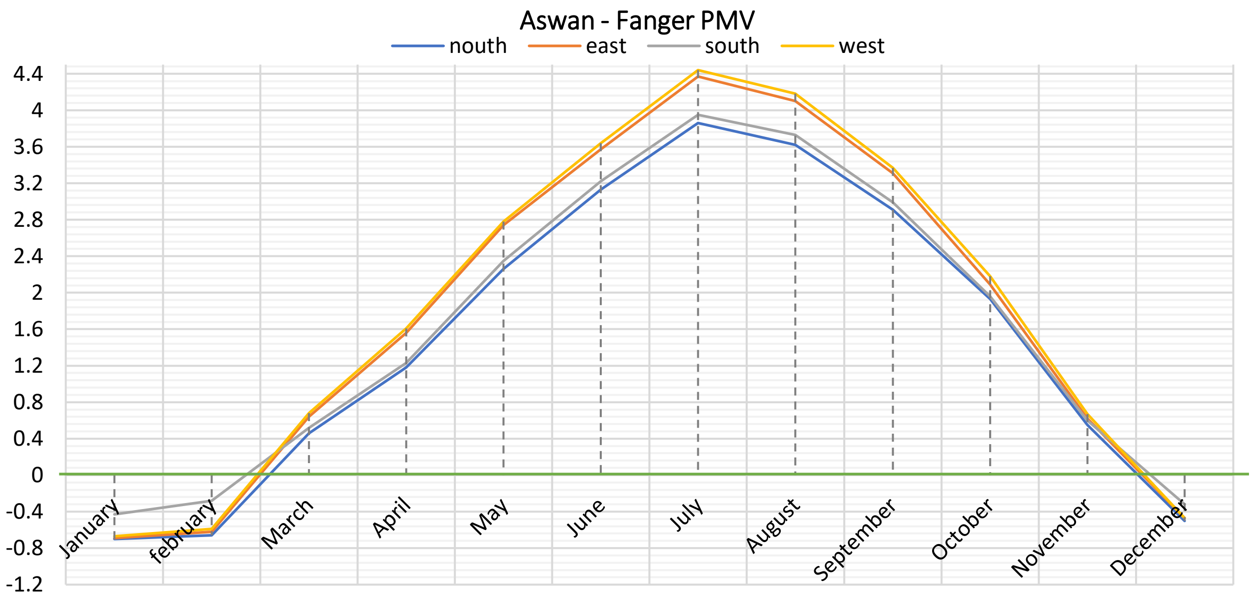


Fig 10. Aswan Fanger PMV

As for the predicted percentage of dissatisfaction (PPD) in Aswan as shown in **Fig 11**.-During the months of the year in the four directions, it is found that it represents the highest rates of thermal

dissatisfaction within the classroom among all study areas. The PPD reaches higher than 50% in the eastern and western orientation of the classroom (from April to October).
The PPD in the northern orientation of the classroom in Aswan ranges (from 24% - 84%) during the school months. While the PPD in the western orientation ranges (from 23% to 91%) in the school months, which confirms that the classroom design does not achieve thermal satisfaction for students in Aswan, especially in the west and east orientations.

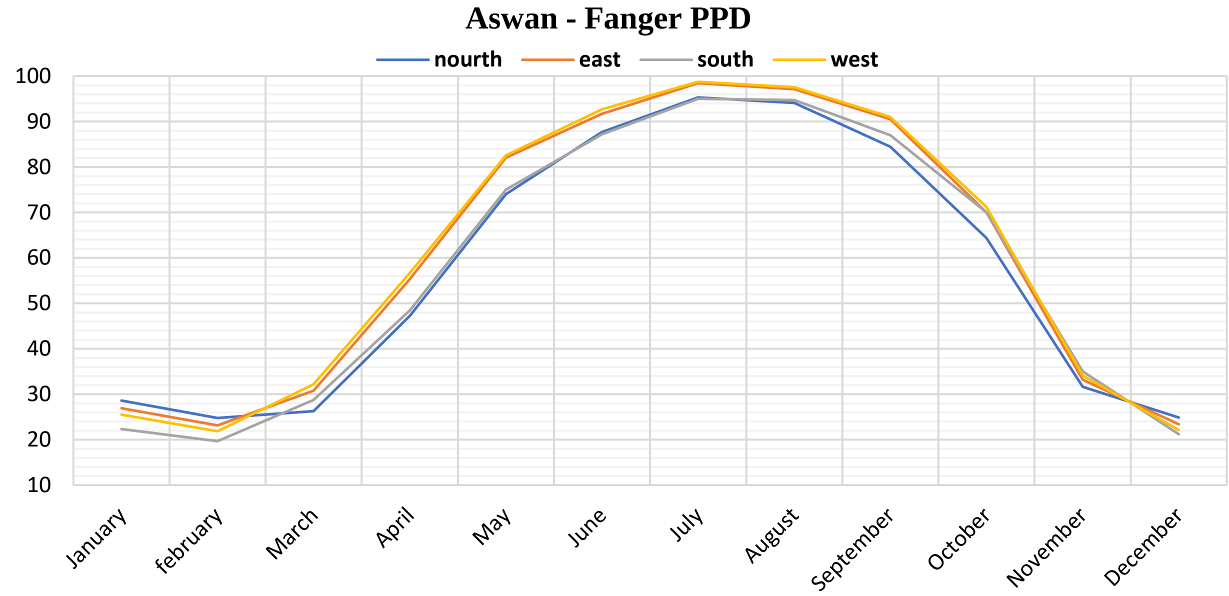


Fig 11. Aswan Thermal comfort Fanger model PPD

B. Cairo

Regarding the predicted mean vote (PMV) during school months in the four directions, in Cairo, as in **Fig 12.** It is found that the PMV represents the best value in the northern direction of the classroom, as the PMV ranges between (+1 and -1) in about 7 months of the year in the northern orientation (from February to May, and the months of November and December). It is followed by the southern orientation of the classroom, then the eastern and western orientations, as the classroom with the western orientation represents the highest PMV amount, i.e. above 2 from June to September. This confirms the effect of classroom orientation on thermal comfort.

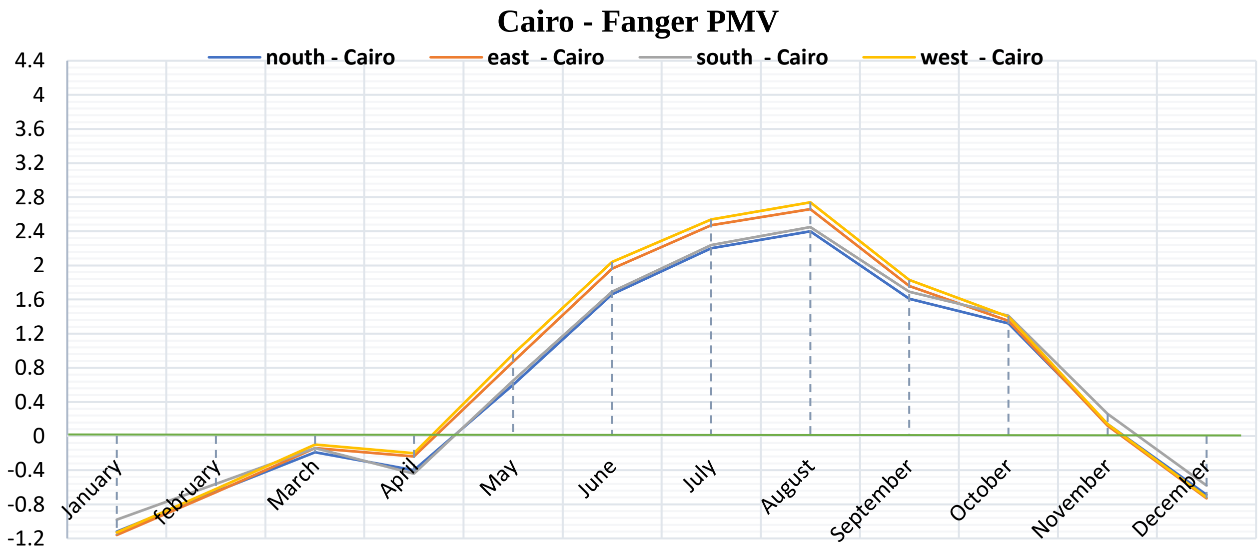


Fig 12. Cairo Fanger PMV

As for the predicted percentage of dissatisfied (PPD) in the four directions in Cairo: As shown in **Fig13**, it is found that the PPD reaches more than 50% in Cairo in four months (from June to September) in the classroom in the four directions. The northern orientation of the classroom represents the lowest level of student dissatisfaction, as the PPD range in months of study presence in the classroom (from 20% to 50%), followed by the southern orientation and then the eastern orientation. The western orientation represents the highest PPD, as it ranges in the school months from (20% to 61%).

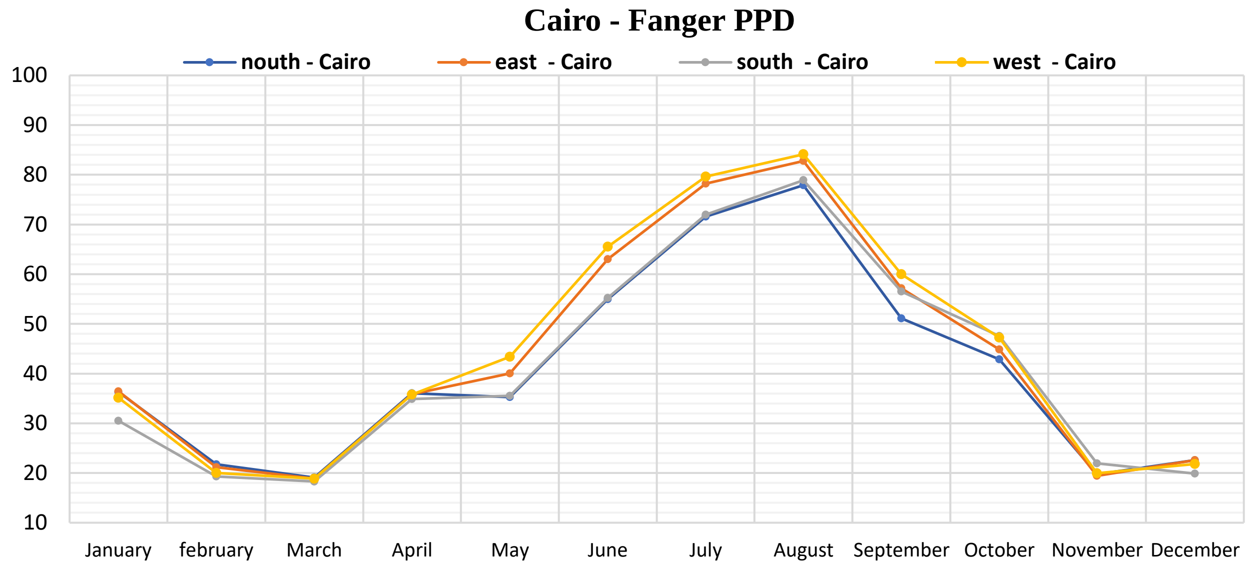


Fig 13. Cairo Thermal comfort Fanger model PPD

C. Alexandria

Regarding the predicted mean vote (PMV) in Alexandria, as shown in Fig 14, it is found that (PMV) ranges between (-1.18 to 1.35) in the northern direction of the classroom in school months. The PMV in the western direction of the classroom ranges between (-1.18 to 1.57) in school months. This confirms that (PMV) in Alexandria in the four directions of the classroom does not exceed 2. The PMV decreases in the winter months and reaches less than -1 from January to April, which are within school months. This will negatively affect the thermal comfort of students during the classroom.

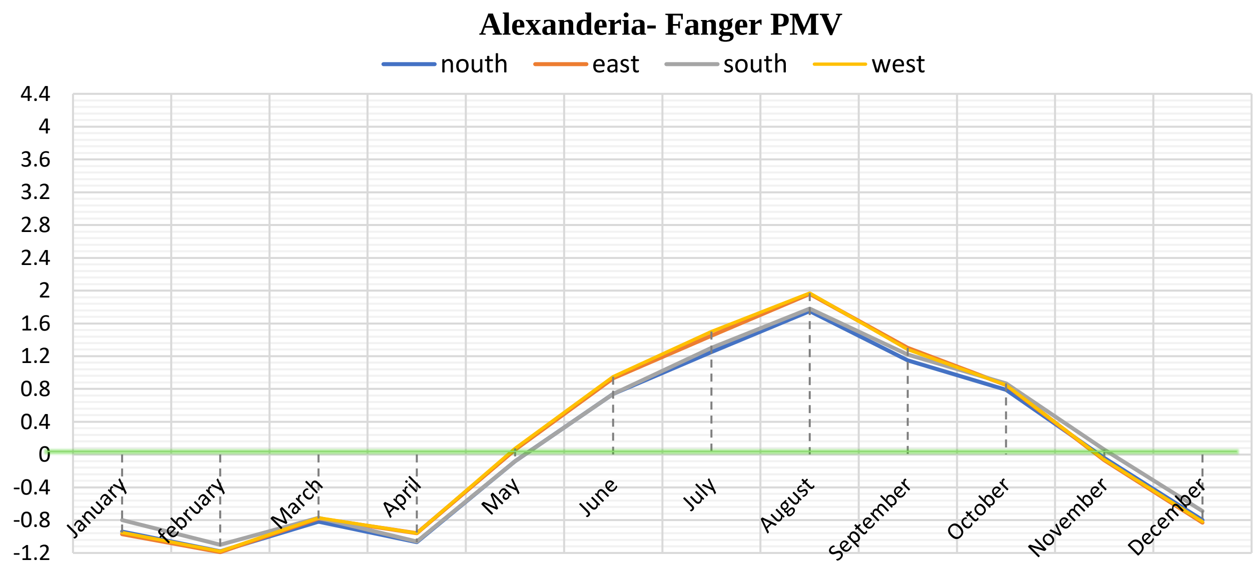


Fig 14. Alexandria Fanger PMV

As for the expected percentage of dissatisfaction (PPD) in Alexandria as shown in **Fig 15,** it is found that. The northern direction of the classroom represents the lowest percentage of student dissatisfaction, as PPD ranges in the months of study presence in the classroom (from 15% to 37%), followed by the southern-oriented classroom, then the eastern classroom. As for the western direction, it is the highest in PPD, as it ranges in the months of study from (14% to 44%). It also shows an increase in the PPD during the winter months, as it approaches 30-40% in winter. Therefore, it can be concluded that the classroom in the southern orientation in Alexandria represents the lowest in the school months from (December to May), as it decreases by 20% compared to the classrooms in the other directions in Alexandria.

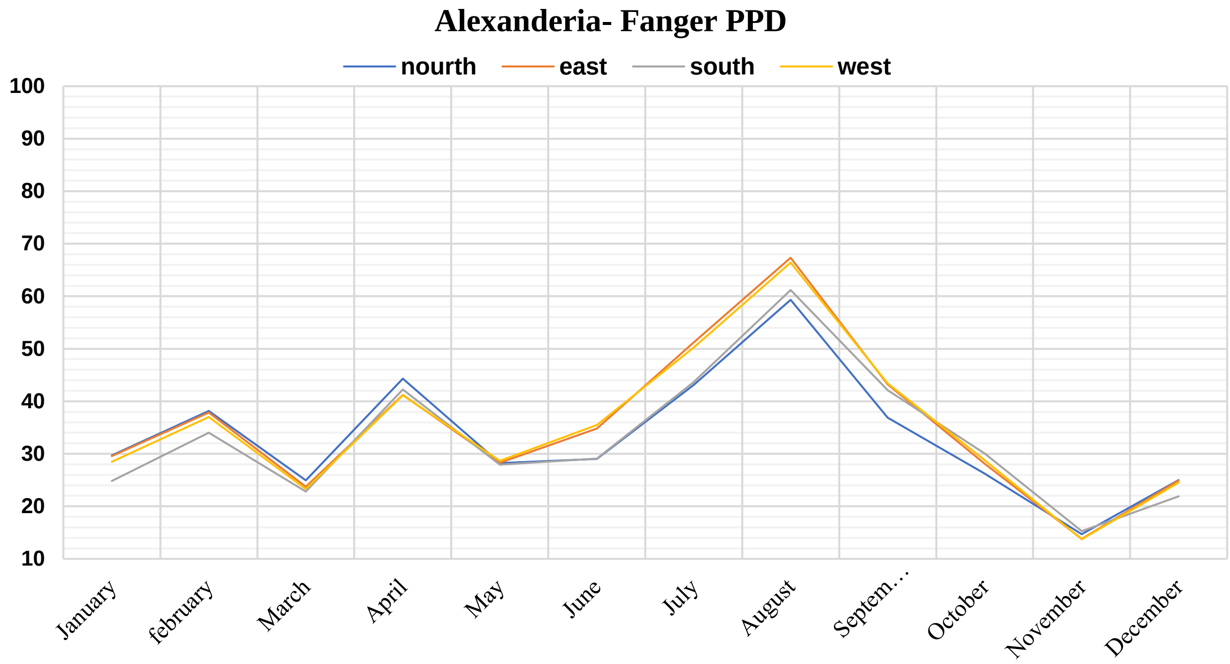


Fig 15. Alexandria Thermal comfort Fanger model PPD

5. 1.2. Comparative analysis of the results of the three case studies (Aswan - Cairo - Alexandria)

A. Air temperature

The air temperature inside the study samples in (Aswan - Cairo - Alexandria) in the four directions is shown in **Fig 16**. The air temperature inside the classroom in Alexandria represents its lowest rate, as it is less than 19^{o} C from December to March. The temperature inside the classroom in Alexandria in winter is lower than the thermal comfort rates.

For Cairo, the air temperature inside the classroom ranges from 22^{o} C to 29^{o} C for about 7 months of the year, in school months.

While in the city of Aswan, the air temperature inside the classroom is higher than 30 ^{o}C for about 7 months i.e. from April to October, which confirms that the design of the classroom in Aswan in the four directions is thermally unsuitable as the air temperature in it rises above the thermal comfort rates, which requires environmental treatments for the classroom's envelope and openings to improve the air temperature inside it.

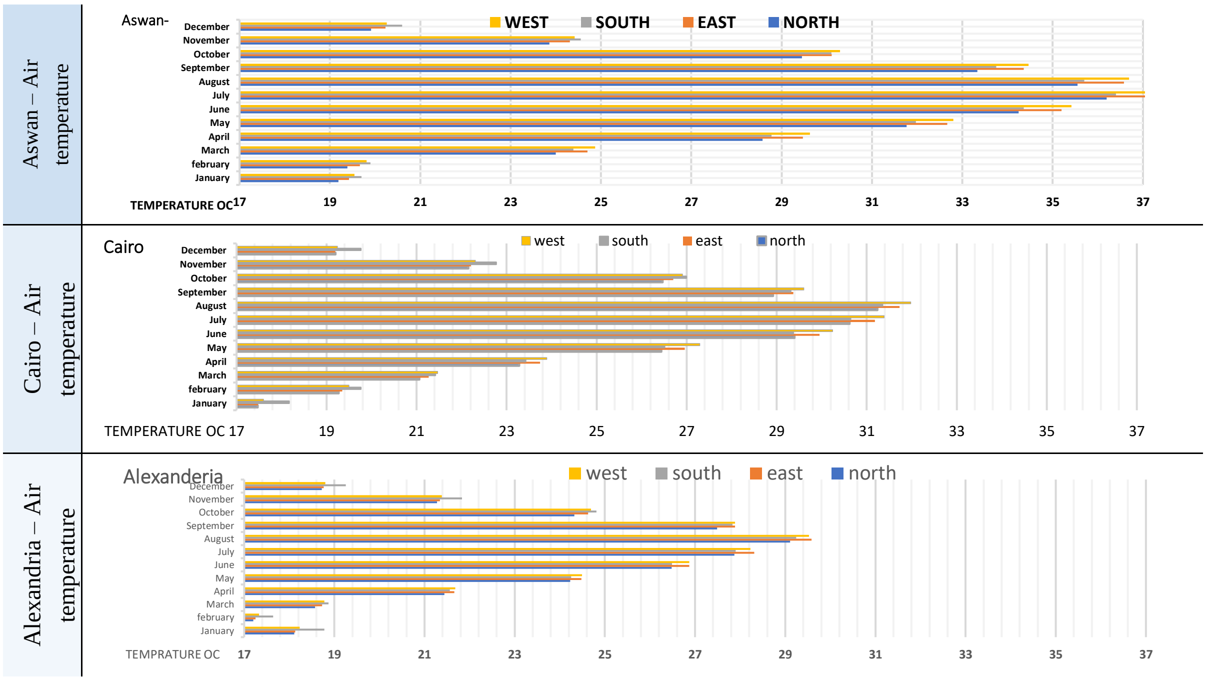


Fig 16. (Aswan – Cairo -Alexandria) Air temperature

B. Fanger PMV Comparative Study

By comparing the level of thermal satisfaction of students (PMV) in the classroom in Aswan, Cairo, and Alexandria in the four main directions, as in **Fig17**, the following findings have arisen:

It is found that PMV rates in Alexandria range between (+1 and -1) for about 8 months of the year. For Cairo, they range between (+1 to -1) for about 7 months and are considered close to zero, especially during the school months. As for Aswan, the PMV value falls between (+1 and -1) from (November to March), i.e. 5 months of the year, while PMV exceeds 2 from (May to October).

The PMV value in the Aswan classroom also exceeds 4 in the summer, which confirms the intensity of the heat in the Aswan classroom designed according to the standards of the Educational Buildings Authority. It also confirms the need for environmental treatment of the classroom in Aswan to achieve thermal satisfaction for students. The research has found that the predicted mean vote (PMV) for the classroom in Cairo is the best during the school months, as its ranges from -1 to +1 passing through zero.

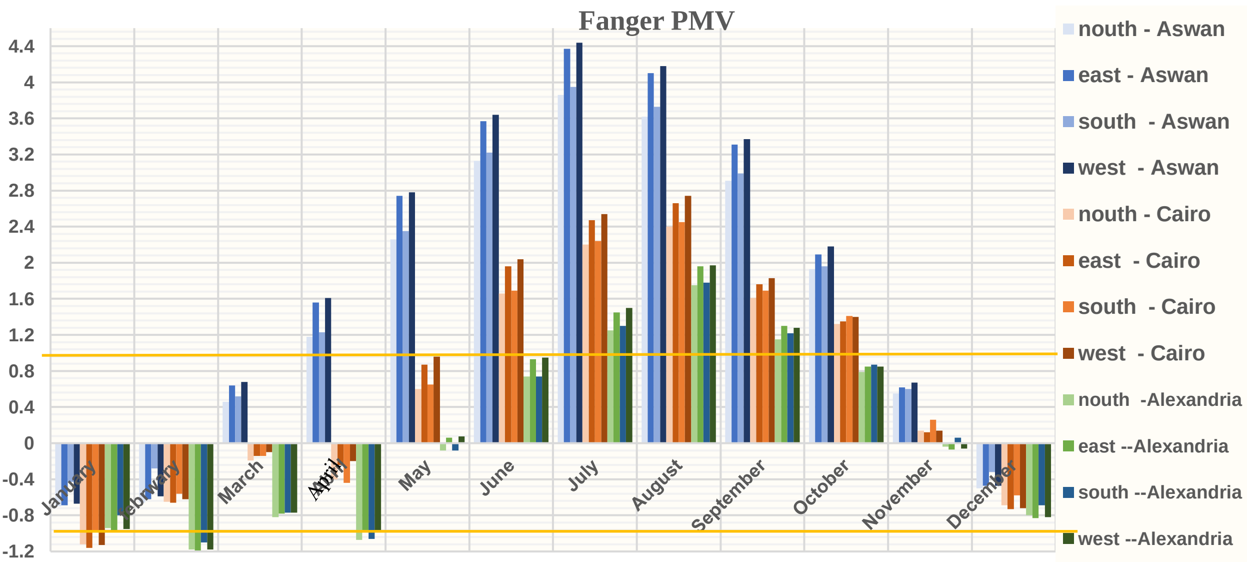


Fig 17. (Aswan – Cairo -Alexandria) Fanger PMV

C. Thermal comfort Fanger model PPD Comparative Study

By comparing the expected percentage of dissatisfaction (PPD) in the classrooms in Aswan, Cairo, and Alexandria, in the four directions, which is depicted in **Fig 18**, it is found that:

The percentage of thermal dissatisfaction (PPD) in Alexandria is lower than in Cairo and Aswan, except for some months in which temperature drops below the thermal comfort range (December - February - March - April). These are the months in which the classroom in Cairo has the lowest PPD in comparison to Aswan and Alexandria, and they are within the school months.

The (PPD) ranges in Alexanderia from 30-45% in most school months.

As for Cairo, PPD ranges from (20%-55%) in the northern orientation most of the school months, and from (20% to 65%) in the western orientation most of the school months.

As for classrooms in Aswan, PPD reaches more than 90% in the hottest summer months in the four directions. Thermal dissatisfaction exceeds 70% (from April to October) in the four study directions. The analysis of these results shows that the expected dissatisfaction rate (PPD) inside the classroom in Aswan is higher than the expected dissatisfaction rate (PPD) for the classroom in Cairo by more than 40% in the four directions during the months of the year,

which confirms the necessity of designing the classroom envelope and windows in Aswan city in a manner that is compatible with the thermal characteristics of the region to achieve acceptable environmental performance for students inside the classroom.

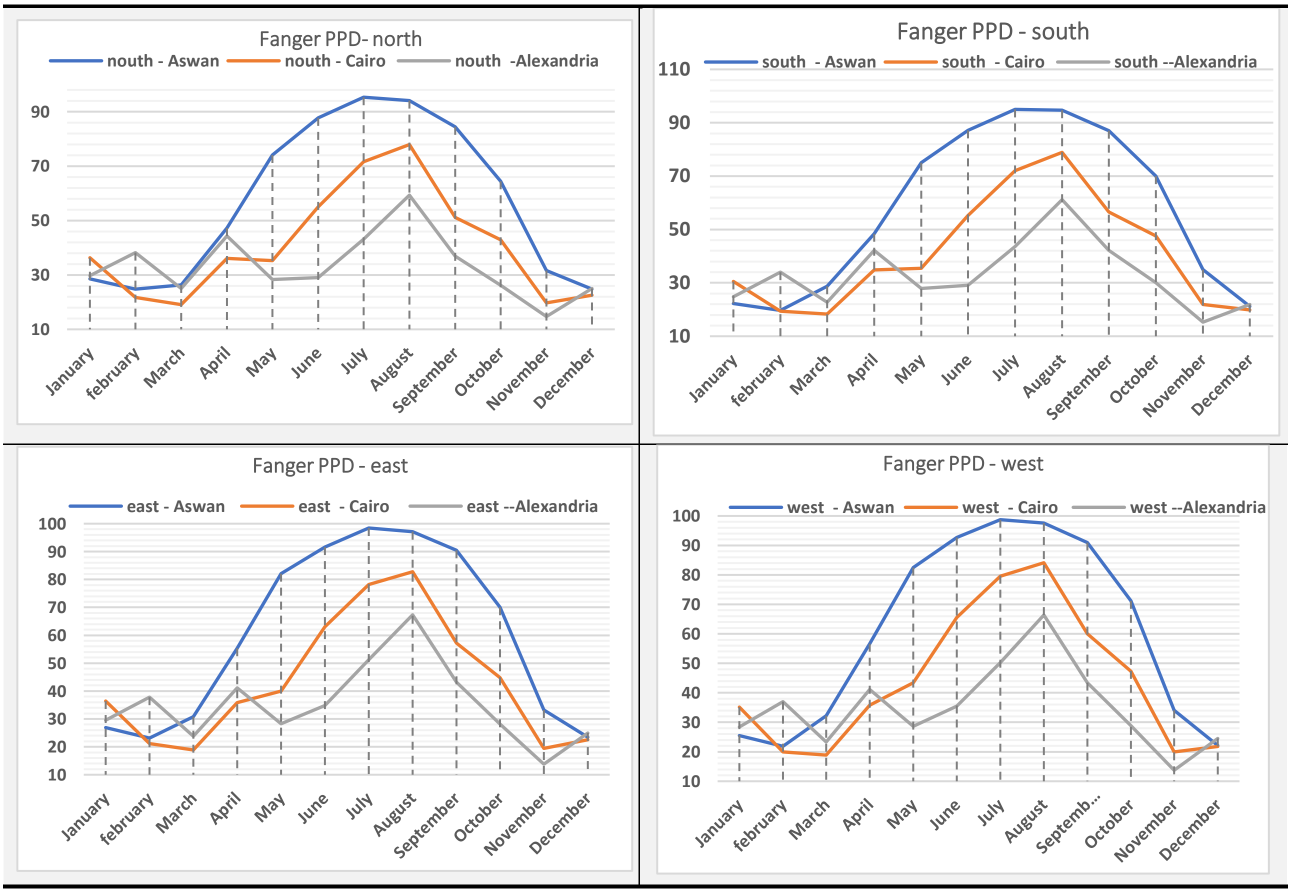


Fig 18. (Aswan – Cairo -Alexandria) Thermal comfort Fanger model PPD

5.2.Air movement

Air movement inside the classroom is one of the most important factors necessary to achieve good ventilation, as it expels the polluted air and obtains clean air**. Fig 19** shows the shape of the air movement inside the classroom in Aswan, Cairo, and Alexandria in the four directions, as shown by the environmental simulation program Design Builder.

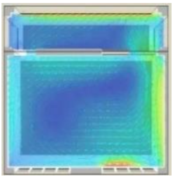
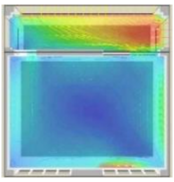
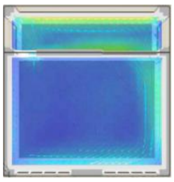
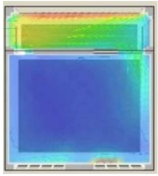
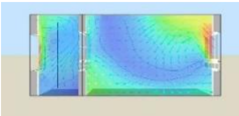
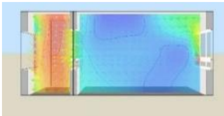
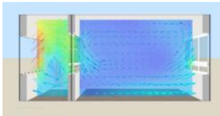
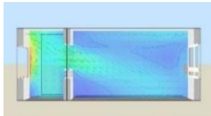
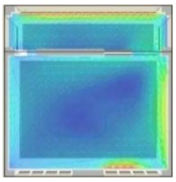
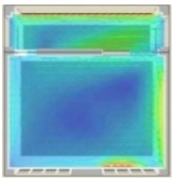
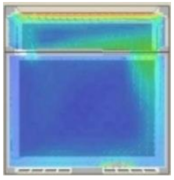
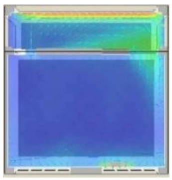
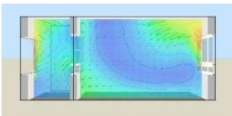
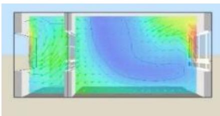
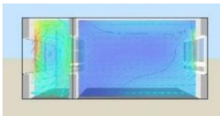
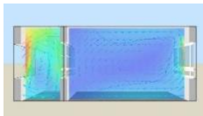
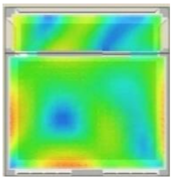
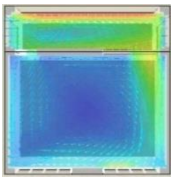
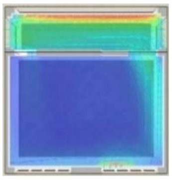
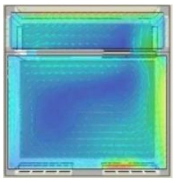
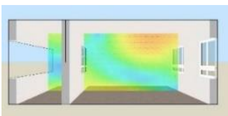
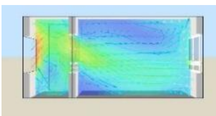
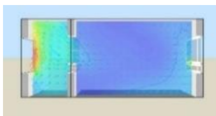
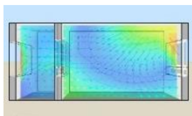
	North	East	South	West
Aswan				
				
	The air speed in the middle of the classroom ranges from 0.4 to 0.65 m/s in the middle of the classroom, while it reaches about 1.2 to 1.6 m/s near the windows.	The air speed inside the classroom ranges from 0.3 m/s, while it increases slightly at the windows to reach 0.7 m/s.	The air speed about 0.2 m/s inside the classroom, while the maximum air flow at the windows reaches about 0.6 m/s.	The air speed ranges about 0.3 m/s in the classroom, while it increases in the path of air movement between the windows to reach about 0.9 m/s.
Cairo				
				
	The air speed in the classroom ranges from 0.44 to 0.66 m/s in the middle of the classroom, while it reaches about 1 to 1.6 m/s near the windows.	The air speed in the middle of the classroom ranges from 0.3 to 0.44 m/s, while near the windows it ranges from 0.85 to 1 m/s.	The air speed reaches 0.3 m/s inside the classroom, while its maximum at the windows reaches 0.6 m/s.	The air speed ranges from zero to 0.3 m/s inside the classroom, while it reaches about 0.6 m/s near the windows.
Alexandria				
				
	The air speed increases, as it reaches more than 1 m/s inside the classroom, while near the windows it reaches about 1.75 m/s and more.	The air speed inside the classroom ranges from 0.44 to 0.9 m/s, while in the air movement path and near the windows it reaches 1.3 m/s.	The air speed inside the classroom ranges from 0 to 0.22 m/s, where the air inside the classroom feels still.	The air speed inside the classroom ranges from 0.4 to 0.6 m/s, while near the windows it reaches 1 to 1.31 m/s.
Air speed key				

Fig 19. Air Speed in the four orientations in (Aswan – Cairo -Alexandria)

The northern direction represents the best air movement inside the classroom for the three study samples (Aswan - Cairo - Alexandria), where the air speed reaches a maximum of 1 m/s to more than 1.5 m/s. The northern-oriented classroom in Alexandria represents the highest air movement, as the air speed in it reaches more than 1.75 m/s. The air speed inside the classroom in Cairo and Aswan ranges from 0.4 to 0.65 m/s, and its highest value near the windows reaches about 1.2 -1.6 m/s. Next is the classrooms with the eastern orientation, as the classroom in Alexandria is considered the highest in air speed, as it reaches inside the classroom from 0.44 m/s to about 0.9 m/s, while near the windows, and in the path of air movement, it reaches about 1.3 m/s.

It is found that the air speed inside the classroom in Cairo ranges from 0.3 to about 1 m/s, followed by the air speed in the classroom in the eastern direction in Aswan, where the highest speed reaches about 0.7 m/s. As for classrooms with a southern orientation, the air speed inside the classroom in Cairo ranged from 0.3 to about 0.7 m/s near the windows, followed by the classroom with a southern orientation in Aswan, where the air velocity inside ranges from 0.3 to 0.6 m/s near the windows. As for Alexandria, the air speed in the classroom in the southern direction is very weak, and ranges from zero to 0.22 m/s.

The classroom with western orientation in Alexandria is considered the best in terms of air speed in this direction, as its maximum speed reaches 1-1.31 m/s near the windows. As for Aswan, the air speed in the west direction ranges from 0.3 to 0.9 m/s. In Cairo, the maximum speed in the middle of the classroom reaches 0.3 m/s, and the highest speed near the windows reaches 0.6 m/s.

6. Conclusion

The PMV (the predicted mean vote) of the classroom according to the current designs used in schools, that is accredited from the Egyptian Educational Building Authority, is not suitable for the hot dry climate areas as it has been shown in Aswan city, where PMV reaches more than 1 in most school months of the year. Moreover, it rises to more than 4 in the summer months. It is also found that the northern orientation of the classroom in Aswan city is better than the rest of the directions, as PMV decreases by about 17% compared to the other classroom directions in the same city. As for the expected dissatisfaction rate (PPD) among students, it decreases by about 10% in the classroom with a northern and then southern orientation compared to the eastern and western orientations of the classroom in Aswan city.

The results also show that the expected percentage of dissatisfaction (PPD) inside the classroom in Aswan is higher than the PPD for the classroom in Cairo by approximately 40% in the four directions during all the months of the year, which confirms the necessity of designing the classroom envelope and its windows in the city of Aswan in a way that suits the thermal characteristics of the region to achieve the necessary thermal comfort during the school months. The predicted mean vote (PMV) for the classrooms in Cairo is the best during the school months as it ranges from -1 to 1.

The study also concluded that the thermal performance of the northern-oriented classroom in Cairo is the best in the study, because the air temperature ranges from 22°C to 29°C during the school months. Also, the expected percentage of dissatisfaction (PPD) in Cairo is lower than Alexandria from (December to April), i.e. in the winter months (during which the school is occupied by students), especially in the northern-oriented classrooms, where it reaches only about 20%. In addition, the air speed there ranges from 0.66 to more than 1 m/s.

For the classrooms in Alexandria, they are considered to have the best thermal performance in the summer (from June to October), especially in the northern orientation of the semester, where the expected percentage of dissatisfaction (PPD) is lower by 40% than its counterpart in Cairo. However, the classroom in the northern orientation in Alexandria needs to provide the necessary heating during the school months, especially in winter to achieve thermal satisfaction for the students. It is worth noting that the classroom with the northern orientation has good ventilation, as the air velocity in it reaches more than 1 m/s.

The research has found that the southern and northern oriented classroom in Alexandria is better in thermal performance than the classroom with an eastern and western orientation all the year. The classroom with the southern orientation in Alexandria represents the lowest expected percentage of dissatisfaction (PPD) in most of the school months from (December to May), as the PPD decreases by 20% compared to the classrooms in the other directions during winter in Alexandria. The air speed in the classroom with the southern direction in Alexandia is closest to rest (about 0.2 m/s) which necessitates a treatment for this classroom to improve air movement for improving ventilation inside the classroom.

The eastern and western facades in the orientation of the classroom have the highest impact on thermal discomfort in the examined areas, due to their exposure to solar radiation in a way that requires treating these facades according to the angle of the sun in each area and achieving protection from direct sunlight without affecting natural lighting and ventilation in the classroom.

Paying attention to the design of the classroom's outer shell and windows and orienting it according to the different climatic regions in Egypt helps in rationalizing energy consumption. Achieving thermal comfort, natural lighting and ventilation through passive design methods help reducing energy consumption in educational buildings in Egypt.

Hence it can be deduced that, the standard classroom design approved by the Egyptian Educational Building Authority is more suitable for Cairo in terms of PPD and PMV as compared to Alexandria and Aswan. Its thermal performance is greatly sensitive to the environmental conditions of the region where it is found. In Alexandria (north of Egypt), it suffers from low PMV and high PPD due to lower temperatures below the comfort values especially in winter and during school months, while in Aswan (South of Egypt), it also suffers from low PMV and high PPD due to the higher temperatures over the comfort values during school months and it becomes worse in summer. The classroom design is mostly suitable for Cairo (middle of Egypt). The following recommendations are necessary for resolving this issue and achieve better thermal performance for the classroom for north and south of Egypt.

Recommendation

- A regional design for the classrooms and the educational buildings should be developed. It should suit the climatic characteristics of each region in Egypt, to achieve thermal comfort for students and improve their educational performance.
- It is necessary to emphasize that the orientation of the classroom in the most appropriate direction for each region should be chosen according to the climatic characteristics, while adhering to the appropriate environmental treatments for each facade in the case of a change in direction

- It is necessary to deal with the classroom envelope in the Aswan city to provide the necessary thermal insulation to achieve thermal comfort for students, while providing appropriate shading in front of the openings in accordance with every orientation to protect against direct solar radiation, with the necessity of making strategies to achieve appropriate natural lighting inside the classroom.
- Emphasis on orienting the classroom in Cairo in the northern direction is important, because it achieves the best thermal performance and ventilation in that region. If the classroom is directed toward south in Cairo, good ventilation should be achieved inside the classroom to get rid of polluted air and provide appropriate ventilation for the students.
- Also, it is necessary to provide appropriate heating for the northern-oriented classroom in Alexandria to achieve good thermal comfort for students. More research should be done for achieving appropriate ventilation in the southern-oriented classrooms in Alexandria to achieve better ventilation in addition to proper thermal performance during the study months.

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تقييم تأثير تصميم الفصول الدراسية وتوجيهها على جودة البيئة الداخلية بالمدارس المصرية

الملخص

تؤثر الظروف البيئية الداخلية في الفصول الدراسية على صحة الطلاب وأدائهم الأكاديمي. أثبتت الدراسات أن جودة البيئة الداخلية مهمة في الفصول الدراسية، لما لها من تأثير كبير على صحة الطلاب الجسدية والنفسية. وتتمثل جودة البيئة الداخلية (IEQ) في تحقيق الراحة الحرارية، وجودة الهواء الداخلي، والراحة البصرية، وكذلك الراحة الصوتية.

يهدف البحث إلى تحديد مدى تأثير شكل واتجاه الفصل الدراسي في مصر على جودة بيئته الداخلية، والأداء الحراري، وكذلك تحقيق التهوية الجيدة للفصل الدراسي. أجرى البحث محاكاة بيئية للفصول الدراسية في القاهرة والإسكندرية وأسوان باستخدام برنامج المحاكاة البيئية Design Builder. وقد تمت معايرة النموذج من خلال القياسات الميدانية بفصل دراسي نموذجي.

دراسة مدى تأثير تصميم وشكل وتوجيه فتحات الفصول الدراسية وفقا للمعايير التصميمية لهيئة المباني التعليمية على الراحة الحرارية وسرعة الهواء في الفصول الدراسية في مناطق دراسية مختارة في مصر.

وتوصل البحث إلى أن النسبة المتوقعة لعدم الرضا داخل الفصل الدراسي بأسوان أعلى من النسبة المتوقعة لعدم الرضا للفصل الدراسي بالقاهرة بنسبة تتجاوز 40%.

يعد متوسط التصويت المتوقع (PMV) للفصل الدراسي في القاهرة هو الأفضل خلال الأشهر الدراسية، حيث يتراوح من صفر إلى أقل من (+1 و -1).

وتمثل الفصول الدراسية ذات الاتجاه الجنوبي بالإسكندرية الأقل في (PPD) في الأشهر الدراسية من (ديسمبر إلى مايو)، حيث تنخفض بنسبة 20% مقارنة بالفصول الدراسية في الاتجاهات الأخرى بالإسكندرية.