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The design efficiency of schoolyards on the thermal comfort in Egypt

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Abstract

Many studies have proven that outdoor education has an effective impact on the development of personal skills and learning outcomes of students, as the outdoor environment is directly related to the application of many cognitive, emotional, motor, and psychological areas. Schoolyards also affect students' health. The level of thermal comfort in the schoolyard is one of the most important indicators of students' satisfaction with their environment, which represents an important issue in the educational process because of its impact on the behavior and achievement of students within the school. Although children are more sensitive to weather and thermal environments than adults, few studies are focusing on the influence of schoolyard design standards on the outdoor thermal environment and its impact on children's thermal comfort. Therefore, 6 schools with different characteristics were selected in the city of Tanta, Egypt, to analyze the thermal performance of their courtyards. The Envi-net simulation tool was used to calculate T-air, MRT, surface temperature, and PMV as measures of outdoor thermal comfort, to determine the effect of design standards on the thermal comfort of children in schoolyards. The study concluded that thermal satisfaction in school courtyards with a north-south longitudinal axis is 20% higher than in school courtyards with an east-west longitudinal axis. The research suggested strategies for architects to enhance thermal performance of schoolyards by considering orientation, geometry, finishing materials, and landscape.

Keywords

Schoolyards; Thermal comfort; Air Temperature (Tair); Mean Radiant Temperature (MRT); Predicted Mean Vote (PMV); Tanta; design parameters.

1. Introduction

Schools are places where students spend most of their day; so, it is essential to provide them with a healthy and comfortable learning environment. Children spend approximately 25% of their school day in the schoolyard (Dascalaki & Sermpetzoglou, 2011), therefore it is important to pay attention to their physical, visual, and aural comfort besides the outdoor spaces on the school campus. There is a relationship between the size of the school and the health of students, as the sizeable area of the school provides more spaces for physical education, in addition to the presence of long walking distances for students. Such practices, in turn, improve students' health. They also represent essential spaces that provide students with enjoyable places to play, socialize, and relax .Most studies related to courtyards have focused on the impact of courtyards on buildings. A few studies discussed the school courtyard and focused on ventilation, the role of courtyard landscaping, noise control ...etc. There was a gap in the literature regarding the thermal effects of courtyards and school buildings. Many studies have also focused on landscapes and green spaces in schoolyards as important elements that help improve the building's local climate and help cool the indoor and outdoor spaces by reducing heat gain. Trees reduce the temperature by shading the ground and cooling by evaporation (El-Bardisy et al., 2016). Cultivated areas in schools reduce the heat island phenomenon, especially with the absence of the green element within the urbanization of cities (Harada et al., 2011), without focusing on the impact of courtyard architecture, its placement, and orientation on the amount of thermal performance. The microclimate of the schoolyard has a significant impact on the school's internal building also (Wong et al., 2011).

This research begins with a brief overview of the schoolyard's importance, its design parameters, and studies the effect of these parameters on thermal performance. Then, 6 schools in Tanta City were selected to determine how much the geometry, shape, and orientation of the courtyard influences its thermal performance. The environmental simulation program was used to analyze the thermal performance of the selected schoolyards, and to develop some strategies to achieve external thermal comfort for students.

2. Objective

The research aims to ascertain how the geometry, shape, and orientation of schools' outdoor courtyards affect their thermal performance and how much thermal comfort can be achieved for students throughout the academic year. This will help students' academic performance and personal skills.

3. Methodology

The research methodology is as follows:

First: The theoretical curriculum: the study of the schoolyards, its importance, and its components, in addition to its role in improving the student scientifically, socially, and physically. The research also addresses the factors that affect the thermal performance of schoolyards (finishing materials and vegetation in the courtyard, orientation, courtyard geometry) and their relationship to the courtyard's thermal performance and its impact on users.

Second: applied curriculum: the research deals with a case study of the environmental performance of a group of schools in the city of Tanta (6 schools) (Al-Salam Language School, Al-Ahmadia School, Tanta Preparatory School (Boys), Modern School, Notre Dame School, Tanta Secondary School (girls)). The study cases are described in regard of (place, location, determinants, shape of the courtyard, its area, dimensions and orientation, its various elements), analysis of the climatic characteristics of the study area. The research was carried out using the Envi met environmental simulation program to monitor the environmental performance of the courtyard in the schools under study (air temperature, radiation temperature, thermal satisfaction, surface temperature) in July and October 2022 during the solar hours of the day, and school hours.

4. Schoolyards

Throughout the history of architecture, the courtyard has been used as a common element in various places around the world (Zhu et al., 2023). A courtyard is an enclosed or semi-enclosed space surrounded by buildings and walls and open to the sky (SALAMEH, 2018; Zhu et al., 2023). Abass et al. (2016) and Forouzandeh (2018) defined it as a protected outdoor area partially or entirely surrounded by buildings open from above (Abass et al., 2016; Eid & Taleb, 2023; Forouzandeh, 2018). Nowadays, the courtyard has become a combination of engineering and nature, turning from being a functional protection both from the weather and enemies into a conductive yard for spending more time outside (Ranpise & Mhetras, 2022). Schoolyards are one of the best alternative learning environments (Al Sensoy & MİDİLLİ SARI, 2019), as they play a key role in pedagogical theory in the child's development, and act as a spatial bridge between the natural environment and school buildings (Krajnović et al., 2023). The experimental learning theory developed by John Dewey in the twentieth century advocates making the curriculum meaningful through the child's environment and experiences and emphasizing the importance of the outdoors in the learning process in the outdoor environment (Al Sensoy & MİDİLLİ SARI, 2019), where the provision of outdoor education has a great impact on the development of personal skills and educational performance of students (EL-Telwany et al., 2020). Outdoor spaces differ in their function from the rest of the built-up parts of the school, as they are considered a place of physiological health. Therefore, it is important in any school design plan to achieve health, physical fitness, and mental health among school students (Markus et al., 2017). The schoolyard is also an influential element in the development of many practical and emotional perceptions of the student, as the time spent by students in nature provides the basis for their cognitive, physical, emotional, and social development (Al Sensoy & MİDİLLİ SARI, 2019). It also works to achieve psychological balance for students and enhances various aspects of their personalities in general (Ibrahim & Muhammad, 2020). Gidlöf-Gunnarsson and Öhrström (2010) (Gidlöf-Gunnarsson & Öhrström, 2010) state that the courtyard improves the social interaction of users and gives a sense of relaxation. (Ranpise & Mhetras, 2022; Salameh et al., 2020). The schoolyard helps improve student performance, reduces discipline difficulties, encourages learning, and supports critical thinking (Bansbach et al., 2012). The happiness attained by students helps in achieving better educational achievement (SALAMEH, 2018; Salameh et al., 2020), in addition to reducing psychological stress and tension, improving students' senses, meditation, mental health, and increasing motivation (Matsuoka, 2010). The design of outdoor courtyards in schools aims to provide a stimulating and safe environment in which students can play and learn with pleasure, and enjoy sustainable and natural environments, through buildings and managing spaces sustainably to mitigate the effects of climate change (Zhang et al., 2017).

The school's outdoor spaces can be divided into three main areas:

First: the area adjacent to the buildings, which is usually the immediate boundary areas of the school buildings, often green areas, or where benches are provided as places to rest.

Second: the playgrounds, which are places where play equipment is installed outside the building. Third: the parking area; both playgrounds and parking lots are usually at a greater distance from the school buildings.(Kwon, 2022)

5. Schoolyard types

The courtyard takes many forms. It can be square, rectangular, or circular. However, square and rectangular shapes are the most common (SALAMEH, 2018; Salameh & Taleb, 2017). The variation in courtyard shape is largely due to site constraints, terrain, orientation, and many other factors. The different types of courtyards can be classified according to the relationship between buildings and external courtyards (Kwon, 2022), while the degree of closure or openness of a courtyard is determined by the number of walls surrounding it (Ibrahim et al., 2020). There are 3 common types of courtyard design in schools: closed courtyard, semi- closed courtyard, and semi-opened courtyard. Fig. 1.

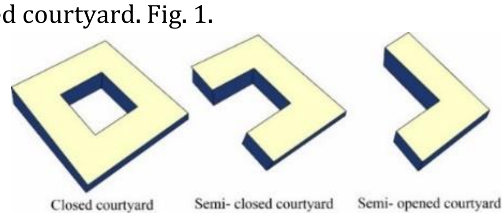


Fig. 1. Types of schoolyards

The closed courtyard is the most commonly used in deep plants because of its high level of privacy, lighting, and ventilation. The semi-closed courtyard is created between the buildings and represents a semi-private area with shaded places. As for the semi-open courtyard, it provides ventilation, direct access, and visibility to the building, but it is the least private (Salameh, 2018; Salameh & Taleb, 2017). Graduation is noticed from privacy in the closed courtyard to openness in the semi-closed courtyard, which has partially shaded and semi-private sections, to full visibility, accessibility, and ventilation in the open courtyard. Three sub-types of schoolyards are also identified, namely either single courtyards or double courtyards with open-and-closed courtyards, or multi-courtyard schools (Rigolon, 2010). Fig.2.

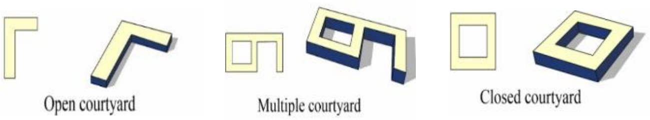


Fig. 2. Three sub-types of schoolyards

Kolozali, R., Kolozali. T. conclude that U-shaped and closed courtyards are the most prevalent types of outdoor space in schools (Kolozali & Kolozali, 2016).

6. Thermal comfort and courtyards

Thermal comfort is defined as the state of mind of satisfaction with the thermal environment (Antoniadis et al., 2020; Hassan et al., 2022; SALAMEH, 2018; Zhang et al., 2023). It is a state in which a person does not feel cold, hot, or a defect in the thermal environment (Markus & Morris, 1980). It is an essential element of a healthy and effective lifestyle (Zhang et al., 2023). Also, it is defined as the predicted mean vote (PMV) because it is associated with a stable state of heat balance of the human body (Hussain & Oosthuizen, 2012). Thermal comfort in the open air is determined by meteorology. It is influenced by a set of different factors related to the person himself, represented by the type of clothing and the level of activity, factors related to the surrounding environmental conditions such as temperature, relative humidity, air movement, and speed, and mean radiant temperature (Hassan et al., 2022). According to numerous studies, the mean radiant temperature (MRT) is the primary factor influencing a person's thermal perception (Antoniadis et al., 2018).Courtyards have been used for thousands of years as a passive design strategy in public and private buildings (Muhaisen & Gadi, 2005). Schoolyards provide a pleasant outdoor environment that improves internal thermal conditions, as they can be used as an architectural element that calms the heat inside the buildings and works to lighten and ventilate them appropriately. According to Edwards, courtyards appeared as a result of the interaction between the building and the environment to increase thermal comfort, natural ventilation and to reduce energy consumption, especially in dry areas (Salameh et al., 2020). A courtyard, as a climate-responsive design, creates a microclimate on a local scale under specific climatic conditions. (Bekci et al., 2013; Sadafi et al., 2011). Reynolds argues that the thermal behavior of a courtyard is influenced by three main factors related to building height, surrounding masses affecting heat loss and gain, and users' activities (Reynolds, 2002). Several studies have also shown that the courtyard's geometry, orientation, wall materials, and landscape elements significantly influenced the microclimate of the courtyard (Zhu et al., 2023). Hyde also noted that direction and, wind speed, are the dominant influences to be considered when designing the yard (Hyde, 2000).
The various factors and their effects are listed below.

7. Factors affecting schoolyard thermal performance.

7.1. Courtyard finishing materials and landscapes.

Landscaping can improve the microclimate of courtyards (SALAMEH, 2018), as green surfaces play an important role in achieving a balance between shaded and sunny areas (Soflaei et al., 2016). Thus, the use of natural elements, like plants and water elements creates environment-friendly conditions (Bulus, 2016). Ahmed emphasized that ventilation in courtyards can be improved by plants and water elements (Ibrahim et al., 2021).
Vegetation contributes to natural cooling through the resulting shading process, thus reducing radiation gain through the floor and facades of the courtyard in the

summer (Soflaei et al., 2016). Additionally, grass-covered land has a higher albedo and lower specific heat capacity compared to building materials such as concrete and asphalt (Zhu et al., 2023), as grass reflects about 0.2% of solar radiation and concrete about 0.4% (SALAMEH, 2018). During the winter, plants increase the absorption of radiation through the floor and walls of the courtyard, and this provides passive solar heating in the interior spaces (Soflaei et al., 2016). It was pointed out by Wei et al. that the use of vegetation in courtyards reduces the air temperature by 8°C during daylight hours (Ibrahim et al., 2021).

7.2. Orientation

Forouzandeh (2018) pointed out the obvious influence of courtyard direction on thermal behavior (Forouzandeh, 2018). According to Meir et al. (1995), accurate orientation of the courtyard improves thermal conditions, but orientation that is independent of sun angle or wind direction can lead to thermal stress (Bulus, 2016). The courtyard orientation has a significant impact on its thermal performance as it can help reduce the courtyard air temperature by about 0.5: 5°C from the outside temperature (Almhafdy et al., 2013).The optimal orientation of the courtyard varies according to different climatic conditions, the need for varying degrees of radiation absorption, the required shading, or the ability to receive optimal wind levels (Zhu et al., 2023). Both N-S and NE-SW orientations are advised in hot, dry climates. For optimal shading index performance in a hot, humid climate, the courtyard's long axis should be oriented NE-SW. In temperate and cold climates, orienting around the N-S axis is recommended, steering the long axis of the yard away from the E-W lowers the MRT (Berkovic et al., 2012; Rodríguez-Algeciras et al., 2018; Taleghani et al., 2014; Zhu et al., 2023). Bagneid (2010) confirmed that both shading according to the position of the sun and the direction of the wind affect the courtyard thermal performance (SALAMEH, 2018). Many studies have found that the thermal performance of semi-closed courtyards varies depending on the direction of the open side (SALAMEH, 2018). Considering the direction of the courtyards, it is possible to design courtyards more effectively, considering the movement of the sun and the direction of the wind.

7.3. Courtyard geometry

Courtyard geometry is one of the most crucial factors affecting the effectiveness of shade that directly determines the level of exposure to solar radiation (Zhu et al., 2023). Many studies have demonstrated that natural ventilation and shading are primarily influenced by the geometric characteristics of the courtyard (Al-Hafith et al., 2019). Shading lowers the air temperature, especially in hot, dry areas, improving the thermal performance of the surrounding areas (Soflaei et al., 2016). Fig.3.

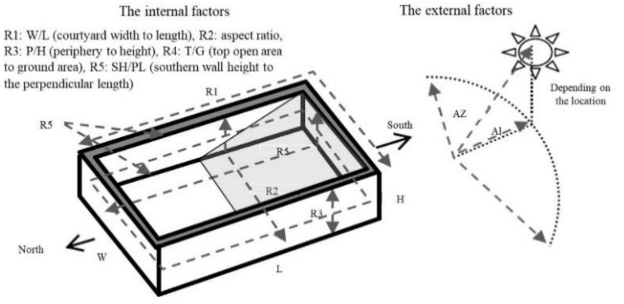


Fig. 3. Courtyard geometric characteristics that affecting its thermal performance

These geometric characteristics include both the shape and dimensions of the courtyard, the aspect ratio along the length of the courtyard, the aspect ratio (height/ width), and the perimeter: height, area, and direction (Al-Hafith et al., 2019).

7.3.1. The ratio of the courtyard area to the built area

Tablada (2013) recommended that the appropriate courtyard area for the built-up area be > 25%, which enhances thermal performance. As Soflaei, Shokouhian, and Mofidi Shemirani (2016) pointed out, for better thermal performance, the ratio between the courtyard area and the built area must be between 18:44% (SALAMEH, 2018; Soflaei et al., 2016).

7.3.2. Courtyard shape and plan dimensions

The dimensions of the courtyard represented by length and width influence its thermal performance (Manioğlu & Oral, 2015), as illustrated by Soflaei, Shokouhian, and Mofidi (2016) and Almhafdy et al. (2015) that the thermal behavior of the courtyard is decided by its dimensions and proportions in hot regions (Salameh & Taleb, 2017; Soflaei et al., 2016). The ratio of width to length is imperative within the handle of shading courtyards, which is additionally reflected within the courtyard's shape(Zhu et al., 2023). A study by Soflaei et al. showed that square-shaped courtyards performed superior to rectangular (Soflaei et al., 2017).Yasa explained that the plan aspect ratio that received less summertime sunlight was 1 in hot, dry, and humid areas while it was 3 in cold areas (Yaşa & Ok, 2014). By controlling the proportions of the courtyard, it is possible to develop a solution for its thermal performance throughout the year.

7.3.3. Courtyard aspect ratio

Various studies have proven that the height of the walls surrounding the courtyard is the most influential factor in the thermal environment of the courtyard (Rodríguez-Algeciras et al., 2018). The aspect ratio (AR) has a stronger effect on the thermal conditions in courtyards than the orientation because of the greater spatial-temporal variation of MRT, as increasing the aspect ratio (AR) in courtyards clearly reduces the level of MRT during the day (Rodríguez-Algeciras et al., 2018).

Aspect ratio is the height-to-width ratio AR= H/W (Alvarez et al., 1998). It can also be measured according to Reynolds (2002) and Sthapak and Bandyopadhyay (2014) by dividing the floor area of the courtyard by the square of the average wall height around the courtyard, this value represents the range of openness to the sky. Therefore, the higher the percentage, the greater the courtyard’s view of the sky (SALAMEH, 2018).

The aspect ratio of the courtyard affects the airflow and the temperature inside the courtyard. Additionally, they noted that shallow courtyards with low ARs up to 0.1 have little inverted air flow and no satisfaction compared to medium courtyards with ARs of 0.3, 0.5, and 1; deep courtyards with ARs above 1.5, however, have high satisfaction because of miner air velocity through the courtyard (Alvarez et al., 1998; SALAMEH, 2018).

Koch Nielsen recommended that the optimal ratio is when the height of a building x and its width are between x:3x (Salameh & Taleb, 2017). Several studies have concluded that in terms of seasonality, if a high aspect ratio guarantees protection from sunlight in summer, a low one increases the use of solar energy in winter. High levels of shading in the summer also increase thermal comfort during the daytime but increase thermal stress at night in terms of daily thermal performance (Zhu et al., 2023).

Below, the research discusses the case study in which environmental performance was analyzed.

8. Case study

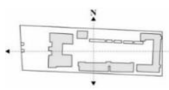
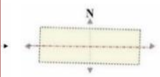
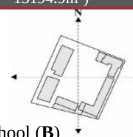
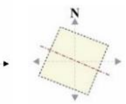
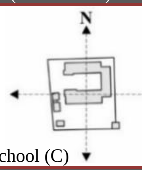
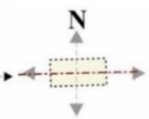
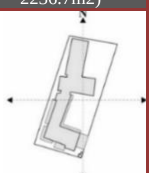
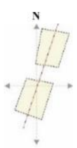
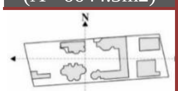
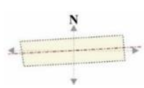
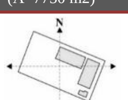
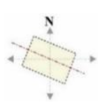
The city of Tanta is in the heart of the central Delta region between the Rachid and Damietta Nile branches at Lat./Long: 30˚47'N / 31˚00'E. According to the Köppen climate classification and Geiger modifications, Egypt falls within the hot dry desert climate range (BWh). The average annual rainfall in the Delta region is estimated at 100-200 mm, mostly in winter. In summer, the temperature usually ranges from 32 to 38 ℃, rarely 45 ℃, in July and August. In winter, the temperature usually ranges from 9℃ at night to 19℃ during the daytime, with very high relative humidity (Kassem et al., 2019).

8.1. Selected study samples

From the previous theoretical study, it becomes clear that there are many characteristics of schoolyards. Six different schools in Tanta City were chosen to examine the effects of these characteristics on students' thermal comfort in schoolyards. Some of the schools are similar to one another, while others have different longitudinal axes, the proportions and the shape of the courtyard vary from square to highly elongated courtyard, and the proportions of the courtyards range from 1: 1 to more than 1: 3. Schools with semi-closed and semi-open courtyards were also chosen with a change in the orientation of the direction of opening in the courtyard.

The following table shows the characterization of the various schools selected. Table (1)

Table 1. The characterization of the various schools selected.

	Schoolyard shape + orientation	W/L	AR (H/W)	Ratio of built-up area	vegetation
 School (A) Al-Salam Language School (A= 13194.9m²)	 Semi closed (E-W)	1: 2.8	0.41	27%	20%
 School (B) Al-Ahmadia School (A= 6202.7m2)	 Semi closed (NW-SE)	1: 1.1	0.31	36%	8.5%
 School (C) Tanta Preparatory School (Boys) (A= 2236.7m2)	 Semi closed (E-W)	1: 2.1	1.3	30%	22%
 School (D) Modern School (A= 6644.3m2)	 Semi closed-Semi opened. (NE-SW)	1: 1.6--1: 1.7	0.5	39%	12%
 School (E) Notre Dame School (A=7750 m2)	 Semi closed. (E-W)	More than 1: 3	0.5	33%	9%
 School (F) Tanta Secondary School (girls) (A=4500 m2)	 Semi opened (NW-SE)	1: 1.5	0.57	22%	23.5%

8.2. Description of the program

In this paper, the Envi-Met environmental simulation program is used. Envi-Met is developed by Michael Bruse. The latest version is (Envi-Met 5.1) that is updated by adding more improvements as compared to older versions.

The program uses a comprehensive approach that connects all aspects of the local climate in one model, considering the multiplicity of mathematical operations that occur between the elements (Altunkasa & Uslu, 2020). It features several facades, each of which is important to simulate reliable or read output data. The program offers three main components that provide the required inputs, while the simulation interface is examining the data globally by applying the account forms. It has different possibilities in local climate modeling, calculating and simulating climate in urban areas accurately ranges from 0.5 to 10 meters and with time separators of up to 10 seconds. It merges the laws of thermal dynamics and fluid mechanics. Envi-Met uses the orthogonal Arakawa C network to represent its environment and surroundings (Bruse & Fleer, 1998). The numerical simulation program allows researchers to evaluate reliable and comprehensive local climatic outputs, through the simulation of local climate in urban areas, to improve human thermal comfort (Basaly et al., 2021). It can calculate the temperature of the air, humidity, wind speed and direction, the average radioactive temperature, instability, flow of gas and various particles, and dispersion of pollutants. It is able to examine even thermal exchanges and surface-related mass. Understanding the local climate of the landscape elements and the built environment is an important step before creating and evaluating the environmental modeling system (Altunkasa & Uslu, 2020; Ouyang et al., 2022).

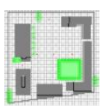
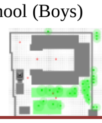
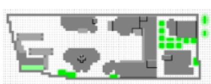
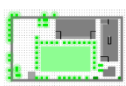
As it is famous software for its environmental capabilities and accuracy, it is employed in many studies. In Pantavou, K., Koletsis, I., Tseliou, A., Lykoudis, S., & Tsiros, I.X. (2019) study (Pantavou et al., 2019), shows that with proper settings and using proper climatic data for initialization, the results of Envi-Met can reach higher levels of accuracy and closer to reality. In Bande L, Afshari A, Al Masri D, Jha M, Norford L, Tsoupos A, Marpu P, Pasha Y, Armstrong P. (2019) study (Bande et al., 2019), shows a good correspondence between measurements and simulations when using Envi-Met. Overall Envi-Met can capture the environmental performance with highly acceptable estimations.

8.3. Experiment Description

In this research, the simulation program was used to measure air temperature, MRT radiation temperature, surface temperature, as well as thermals convenience by measuring thermal satisfaction for PMV.

The average expected vote (PMV) is one of the most recognized indicators to assess the thermal sensation of users, which has been developed to deal with external conditions by Jendritzky and Nübler (Fahmy, 2016). The scale usually ranges from (+4) hot to (-4) cold (El-Bardisy et al., 2016), where (0) is a neutral value that represents the level of thermal comfort, and the values can exceed (4) or less than (-4) according to local climatic conditions (El-Bardisy et al., 2016). The measurement included six of the selected schools indicated in Table (2).

Table 2. The case studies in Envi- Met environmental simulation program

Al-Salam Language School 	Al-Ahmadia School 	Tanta Preparatory School (Boys) 
Modern School 	Notre Dame School 	Tanta Secondary School (girls) 

It was also entered into the Envi Met program, where the measurement took place from 10 o'clock until 16 pm. The registration took place at a head of every hour during the hours of solar presence, during the summer, when the measurement took place in the month of July, which is the highest month of the year in the solar presence. Also, the measurement was carried out during the month of October, which represents the period of student's presence at schools.

In the selected study samples, the impact of the buildings surrounding schools from abroad was neutralized, to focus on the impact of the guidance of the annihilation and the percentage of its developer, as well as the percentage of its sector on thermal performance, during the measurement process. Wall finishing materials were installed in school buildings under study to install their effect on thermal performance in external spaces. The following table shows the characteristics and specifications of the study samples that were entered into the Envi-Met program. Table (3)

Table 3. The specifications entered into the Envi-Met program.

Data, time of simulation		21 July 2022 & 21October 2022
		Started simulation at time = 10 o'clock
		Total simulation time in hours = 8 hours
		Save model state each 120 minutes
Boundary conditions	July	Air temperature C = 28-39° c
		Relative humidity =45%-61%
		Wind speed at inflow border (m/s) = 3
		Wind direction (constant wind direction at inflow) = 320°
	October	Air temperature C = 18-27° c
		Relative humidity =40%-80%
		Wind speed at inflow border (m/s) = 3
		Wind direction (constant wind direction at inflow) = 320°

BIOMET Wizard was used to calculate thermal convenience with different schools. BIOMET Wizard includes a set of data-related such as air temperature, direction and wind speed, and relative humidity, as well as a set of Personal Hyman Parameters data that was identified in the search as follows: Table (4)

Table 4. Personal Hyman Parameters data for study samples

Body parameters	Age = 16
	Weight = 55 kg
	Height = 165 cm

The results were dealt with on Leonardo 5.1.1 with the determination of Position View Plane K = 3 which equal 1.4m height, where this is the closest height of the average student in schools.

9. Results and discussion

9.1. Thermal Performance Analysis of Study Samples July 2022

The following tables show the result of simulations for study samples in July 2022. Table (5, 6, 7, 8)

Table 5. T air analysis in the study samples schoolyards (July)

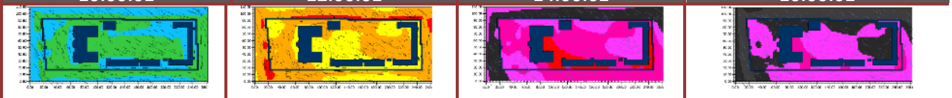
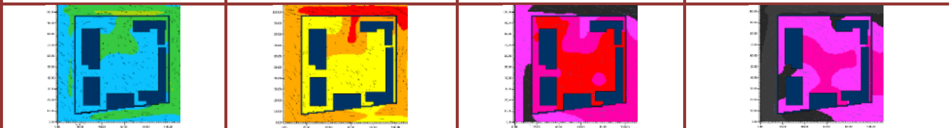
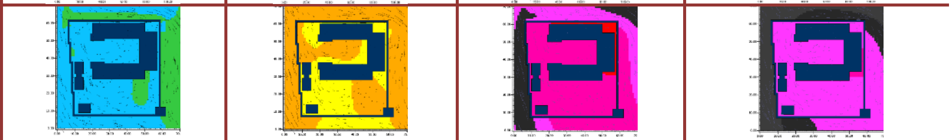
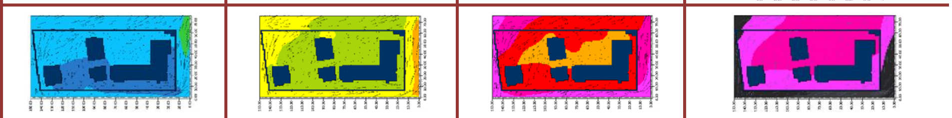
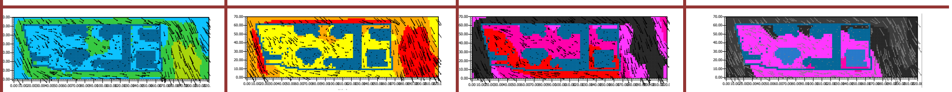
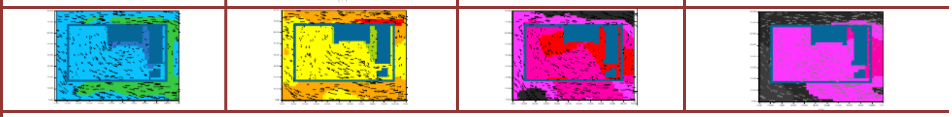
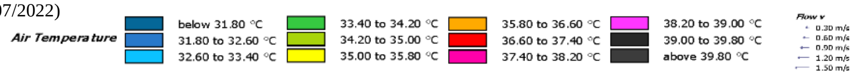
<table>
<tr><th></th><th>10.00.01</th><th>12.00.01</th><th>14.00.01</th><th>16.00.01</th></tr>
<tr><td>Al-Salam Language School (A)</td><td colspan="4"></td></tr>
<tr><td>Al-Ahmadia School (B)</td><td colspan="4"></td></tr>
<tr><td>Tanta Preparatory School (Boys) (C)</td><td colspan="4"></td></tr>
<tr><td>Modern School (D)</td><td colspan="4"></td></tr>
<tr><td>Notre Dame School (E)</td><td colspan="4"></td></tr>
<tr><td>Tanta Secondary School (girls) (F)</td><td colspan="4"></td></tr>
<tr><td>Tair Key</td><td colspan="4">(21/07/2022)
</td></tr>
</table>

Table 6. MRT analysis in the study samples schoolyards (July)

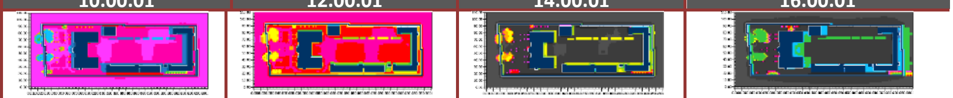
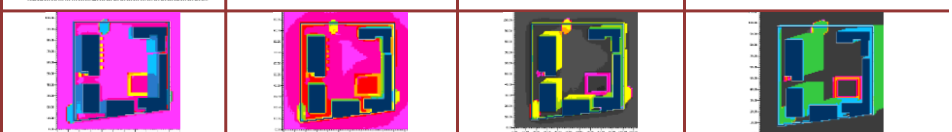
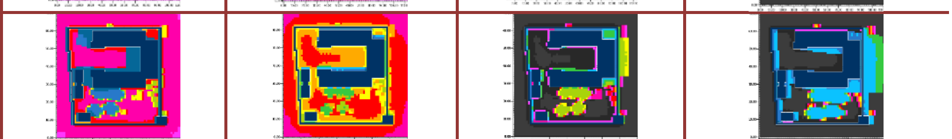
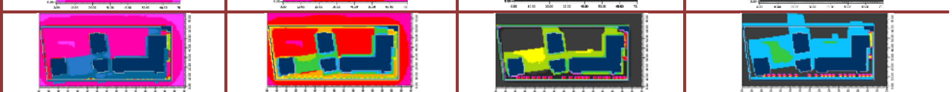
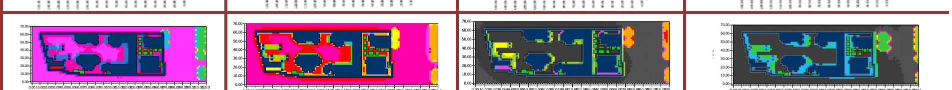
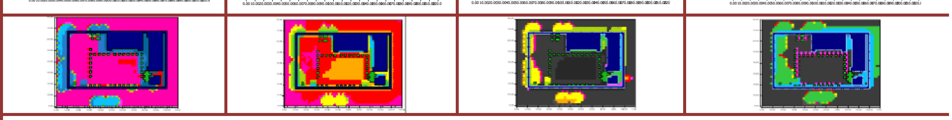
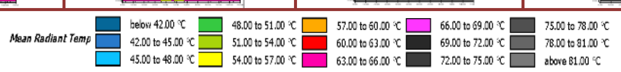
<table>
<tr><th></th><th>10.00.01</th><th>12.00.01</th><th>14.00.01</th><th>16.00.01</th></tr>
<tr><td>Al-Salam Language School (A)</td><td colspan="4"></td></tr>
<tr><td>Al-Ahmadia School (B)</td><td colspan="4"></td></tr>
<tr><td>Tanta Preparatory School (Boys) (C)</td><td colspan="4"></td></tr>
<tr><td>Modern School (D)</td><td colspan="4"></td></tr>
<tr><td>Notre Dame School (E)</td><td colspan="4"></td></tr>
<tr><td>Tanta Secondary School (girls) (F)</td><td colspan="4"></td></tr>
<tr><td>MRT Key</td><td colspan="4">(21/07/2022)
</td></tr>
</table>

Table 7. PMV analysis in the study samples schoolyards (July)

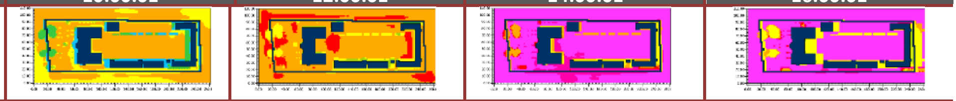
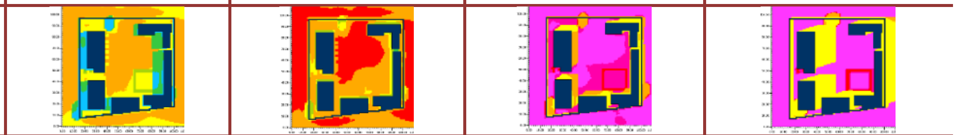
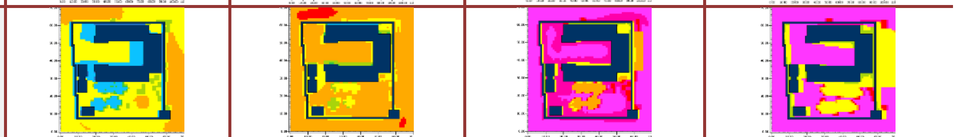
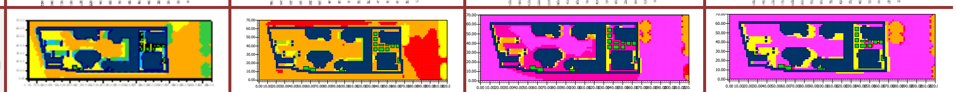
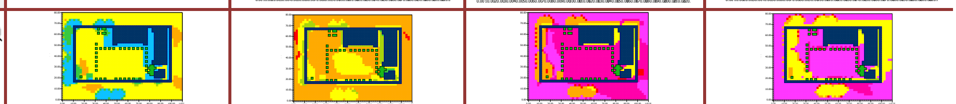
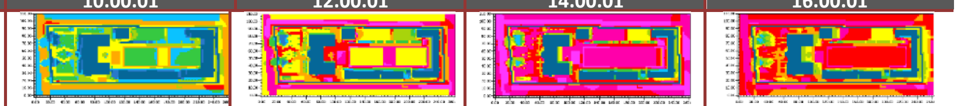
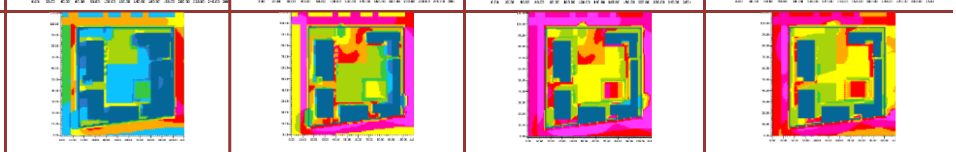
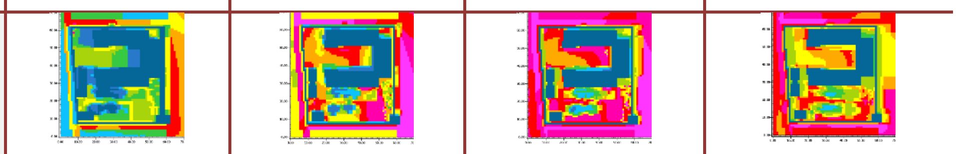
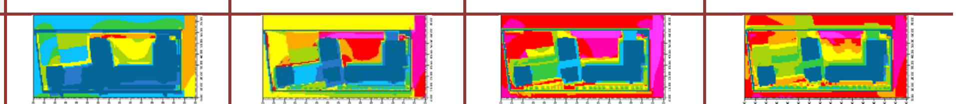
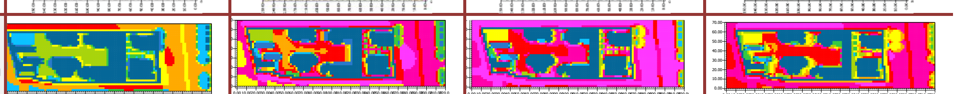
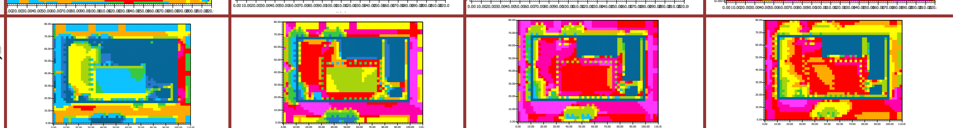
	10.00.01	12.00.01	14.00.01	16.00.01
Al-Salam Language School (A)				
Al-Ahmadia School (B)				
Tanta Preparatory School (Boys) (C)				
Modern School (D)				
Notre Dame School (E)				
Tanta Secondary School (girls) (F)				
PMV Key	(21/07/2022) PMV: below 2.40; 2.40 to 2.80; 2.80 to 3.20; 3.20 to 3.60; 3.60 to 4.00; 4.00 to 4.40; 4.40 to 4.80; 4.80 to 5.20; 5.20 to 5.60; above 5.60			

Table 8. T surface analysis in the study samples schoolyards

	10.00.01	12.00.01	14.00.01	16.00.01
Al-Salam Language School (A)				
Al-Ahmadia School (B)				
Tanta Preparatory School (Boys) (C)				
Modern School (D)				
Notre Dame School (E)				
Tanta Secondary School (girls) (F)				
Tsureace Key	(21/07/2022) T Surface: below 27.00 °C; 27.00 to 30.00 °C; 30.00 to 33.00 °C; 33.00 to 36.00 °C; 36.00 to 39.00 °C; 39.00 to 42.00 °C; 42.00 to 45.00 °C; 45.00 to 48.00 °C; 48.00 to 51.00 °C; above 51.00 °C			

9.1.1. T air analysis in the schoolyards under study (July):

- At 10 o'clock, T-air ranges between 32.2° and 33° in School (D) and School (F), with the highest degree of the courtyard of School (D) to the west having 32.2°. As for School (C), it reached about 33°. They are followed by School (B), School (E), and School (A), respectively, where the air temperature ranges between 33° and 33.8°. However, in School (B), most of the courtyard area is 33°. As for School (A), most of the surface is 33.8°, except for parts of the northeastern courtyard 33°.

- At 12 o'clock, School (D) has the lowest average T-air, about 34.7˚, followed by School (F), about 35.2. While in School (B) and School (E) it ranges between 35.4˚C and 36.2˚, followed by School (A) with an average of 35.8˚. As for School (C), the average was 35.88˚.

- At 14 o'clock, the average T-air at School (D) ranges between 36.2° and 37°. However, about 65% of the courtyard's surface has about 36.2°, followed by School (B), where 60% of the courtyard's surface area was 37°, and the northeastern part ranged between 37.8° and 38.6°. As for School (F), the average temperature in the courtyard was 37.4°, while in School (E), School (C), and School (A), it was about 37.6°, 37.8°, and 37.9°, respectively.

- At 16 o'clock, School (D) recorded the lowest T-air, reaching 37.9°. It is followed by School (B) with an average of about 38.2˚, while School (C) and School (F) recorded an average of about 38.5˚. School (E) and School (A) had the highest average air temperature.

From the above, School (D) has the best T-air in the summer. This is due to the longitudinal axis of the courtyard being directed north south, while the buildings are in the western and southern. As for School (B) and School (F), (with the longitudinal axis of the courtyard southeast-northwest), with different courtyard ratios, respectively, 1:1, 1:1.5, School (F) is better in thermal performance by a difference of 0.08°, because of afforestation around the courtyard. The difference in the thermal performance of School (C), School (A) , and School (E), where the longitudinal axis of their courtyards takes an approximately east-west direction, is also due to the difference in the courtyard ratio, which is respectively 1:2.1, 1:2.8, and more than 1:3. In addition to the difference in the orientation of the open side of the courtyard, in School (A), the courtyard opens from the north. While in both School (C) and School (E) it opens from the western direction.

9.1.2. MRT analysis in the schoolyards under study (July):

- At 10 o'clock, it becomes clear that the radiant temperature in the courtyard of School (D) ranges from 63-66˚, which represents the same value in School (F), and in the courtyard of School (C). However, about 30% of the area of School (C)'s courtyard has a MRT drop of less than 45˚, because of shading by buildings and trees. As for the courtyard of School (A), School (B), and School (E), their MRT ranges from 66-69˚.

- At 12 o'clock, School (C) and School (F) are the lowest in MRT, as (30-40% of the courtyard area) in each of them reaches 60°. While the MRT in the School (D) courtyard was 60-63°. As for School (A), about 30-40% of its courtyard area reaches about 63-65°, while the MRT in most of the courtyards in both School (B) and School (E) reaches more than 66°.

- At 14 o'clock, MRT rises significantly in most of the courtyards as the number of hours of exposure to direct solar radiation increases. MRT in the courtyards of School (D), School (F) and School (C) reaches about 70˚, except for some shaded areas in the buildings at School (D) and in the landscaping at school (C). School (A) and School (E) rise to about 72˚, and about 60% of the courtyard of School (B) reaches about 72-75˚.

- At 16 o'clock, the shading effect begins to appear in the courtyards of some schools on the MRT. About 70% of the courtyard area at School (D) reaches about 45-48˚. MRT also decreases by about 50% of the courtyard of school (C) because of shading to 45-48˚. As for School (F) and School (B), the MRT in 30%-40% of the courtyard reaches 48-51˚, while the rise in School (A) and School (E) is still clear, as the MRT reaches 70˚.

From the above, the courtyard of School (C) has the lowest MRT, due to the height of the buildings, as the H/W reaches 1.3, besides the presence of tree areas that provide shading in the backyard and protection from direct sunlight. As for the School (D), with its longitudinal axis north-south, it is considered one of the lowest MRT as well, due to the shaded areas. While School (F), with a courtyard ratio of 1:1.5, with trees in the western and southwestern parts, has better thermal performance, than School (B), which agrees with it in the same orientation of the longitudinal axis of the courtyard (south-east-northwest). This is due to the aspect ratio. As for School (A) and School (E), which are oriented east-west along the longitudinal axis of the courtyard, they have the highest radiant temperature because of exposure to direct solar radiation during the day.

9.1.3. PMV analysis in the schoolyards under study (July):

- At 10 o'clock, the PMV reaches 2.8 in about 50% of the courtyard of School (D), and in about 30-40% in the courtyard of both School (C) and School (F), and the PMV value in the rest of the courtyard does not exceed 4. As for School (B), School (A), and School (E), the PMV ranges from 4-4.4.

- At 12 o'clock, the PMV reaches 4-4.4 in about 40% of the courtyard of School (F), followed by the courtyard at School (D) and School (C), where the PMV reaches 4-4.8. While School (A) and School (E) reach 4.4-4.8, School (B) is the highest in PMV, reaching 4.8-5.2.

- At 14 o'clock, the PMV in the courtyard of both School (F) and School (D) is the best, as the PMV reaches about 5.2, while the shaded parts of School (D) are less than 4, and the wooded parts of School (F) reach 4.4. As for School (C), 50% of the school's courtyard area ranges in PMV value from 5.2-5.6. As for School (B), School (A), and School (E), the PMV in their courtyards is higher than 5.6.

- At 16 o'clock, shade areas affect the amount of thermal comfort in each of the courtyards of School (D) and School (C), as well as School (B), as the amount of PMV decreases to 4, by about 50%, 30%, and 25%, respectively, in each of them. Planting trees in the courtyard of School (F) reduces PMV to 4 in the wooded area. while it reaches more than 5.6 in the courtyards of School (A) and School (E), causing thermal stress in the courtyard.

From the above it is clear that the amount of PMV in the School (D) with the longitudinal axis of the courtyard north-south is the lowest. School (C) came second, where the aspect ratio is 1.3, which helps provide shading in the courtyard. School (F), which has its courtyard is oriented south-east-northwest, came third. Then School (B), which agrees with it in the orientation of the courtyard, but its courtyard area is larger. As for School (A) and School (E), which are oriented east-west along the longitudinal axis of the courtyard, they are the highest in the amount of PMV and therefore the lowest in the amount of thermal comfort.

9.1.4. T-surface analysis in the schoolyards under study (July):

The following is evident from the analysis during the measuring hours: The grass T-surface at School (F) reaches 30° at 10 o'clock, while its maximum reaches about 45° at 14 o'clock and begins to fall after that. The temperature of the adjacent gray concrete floors reaches about 39° at 10 a.m., and reaches more than 51° at 14 o'clock, and begins to fall after that. As for the same gray concrete floors shaded by trees, the temperature reaches 30° at 10 o'clock and the maximum reaches 36° at 14 o'clock. This is also evident in School (D) with concrete surface, where the T-surface ranges from 36° to more than 51° during the daylight hours in which it was measured, while the temperature of the shaded surfaces in the buildings reaches from 27° to 36°. This is consistent with the performance of the floors in School (C).

As for School (B), which has light-colored floors, the T-surface differs from schools with gray surface, as it reaches 30° at 10 o'clock, while at 14 o'clock it reaches about 42°. This explains the extent of the effect of color on the decrease in surface temperature by more than 10° at 14 o'clock. As for the courtyards of School (A) and School (E), which are completely exposed to direct solar radiation and with dark colors on the floors, the temperature of the courtyard at 10 o'clock reaches about 33°, while it reaches more than 51° at 14 o'clock and begins to decrease after that.

9.2. Thermal Performance Analysis of Study Samples October 2022

The following tables show the result in October 2022. Tables (9, 10, 11, 12)

Table 9. T air analysis in the study samples schoolyards (October)

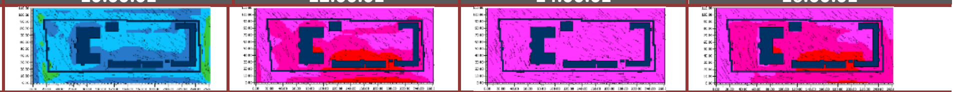
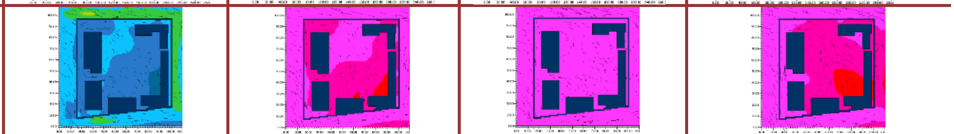
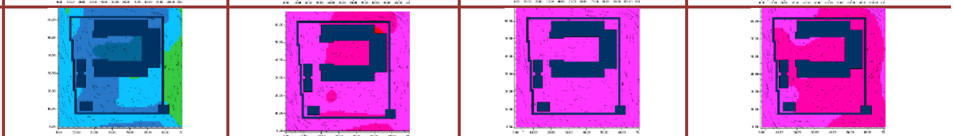
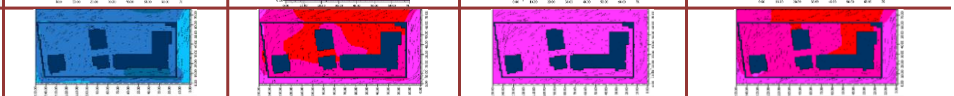
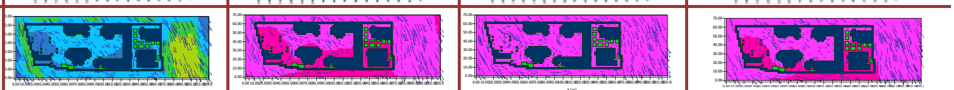
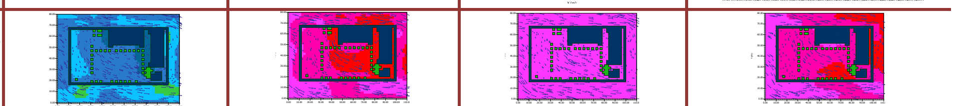
	10.00.01	12.00.01	14.00.01	16.00.01
Al-Salam Language School (A)				
Al-Ahmadia School (B)				
Tanta Preparatory School (Boys) (C)				
Modern School (D)				
Notre Dame School (E)				
Tanta Secondary School (girls) (F)				
T air Key	(21/10/2022) 			

Table 10. MRT analysis in the study samples schoolyards (October)

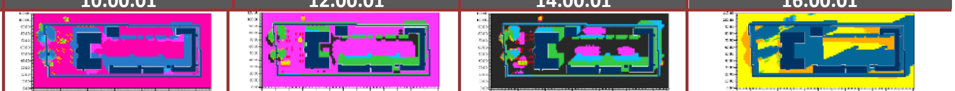
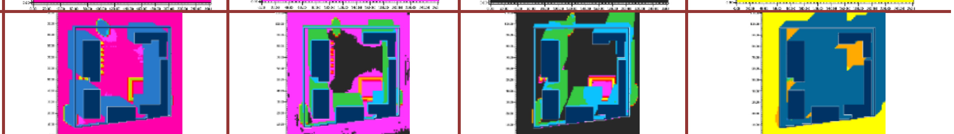
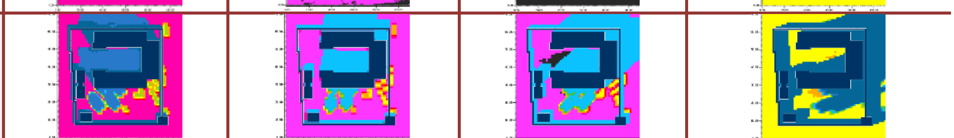
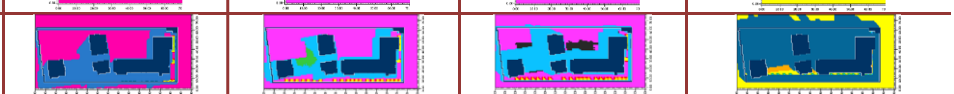
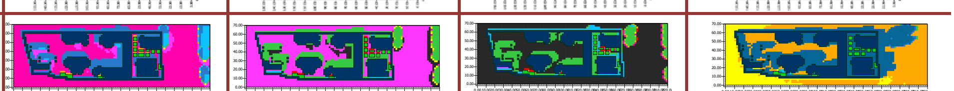
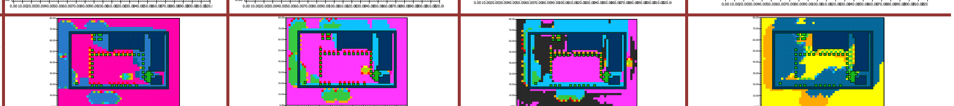
	10.00.01	12.00.01	14.00.01	16.00.01
Al-Salam Language School (A)				
Al-Ahmadia School (B)				
Tanta Preparatory School (Boys) (C)				
Modern School (D)				
Notre Dame School (E)				
Tanta Secondary School (girls) (F)				
MRT (21/10/2022)				

Table 11. PMV analysis in the study samples schoolyards (October)

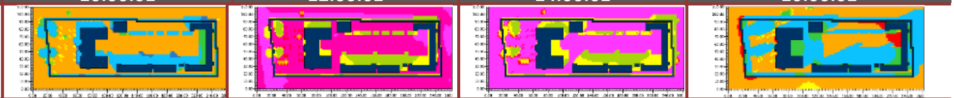
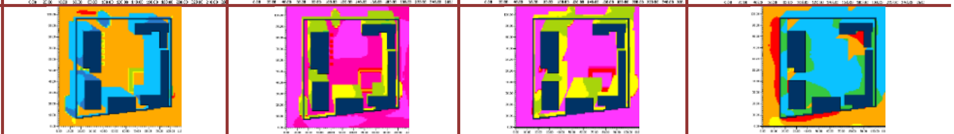
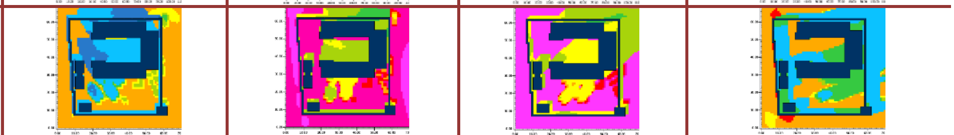
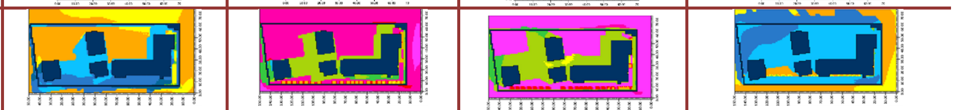
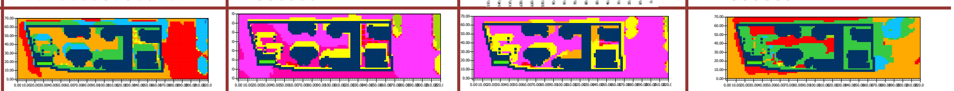
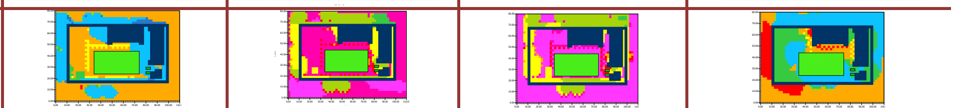
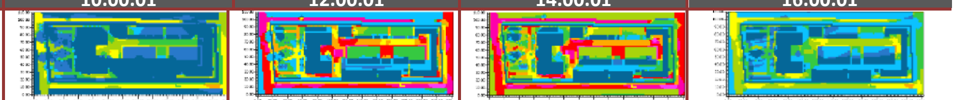
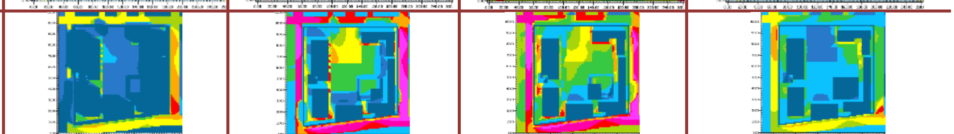
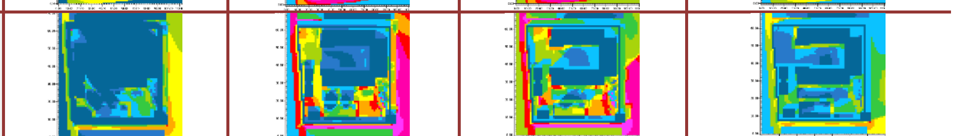
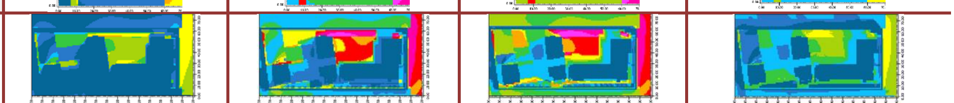
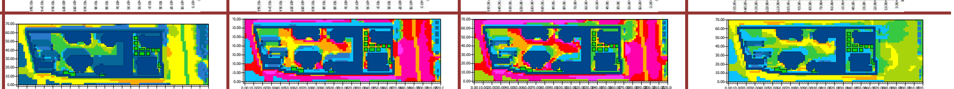
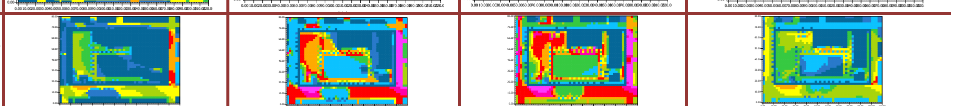
	10.00.01	12.00.01	14.00.01	16.00.01
Al-Salam Language School (A)				
Al-Ahmadia School (B)				
Tanta Preparatory School (Boys) (C)				
Modern School (D)				
Notre Dame School (E)				
Tanta Secondary School (girls) (F)				
PMV Key	(21/10/2022) PMV: below 0.50; 0.50 to 0.80; 0.80 to 1.10; 1.10 to 1.40; 1.40 to 1.70; 1.70 to 2.00; 2.00 to 2.30; 2.30 to 2.60; 2.60 to 2.90; above 2.90			

Table 12. T surface analysis in the study samples schoolyards (October)

	10.00.01	12.00.01	14.00.01	16.00.01
Al-Salam Language School (A)				
Al-Ahmadia School (B)				
Tanta Preparatory School (Boys) (C)				
Modern School (D)				
Notre Dame School (E)				
Tanta Secondary School (girls) (F)				
Tsurface Key	(21/10/2022) T Surface: below 24.00 °C; 24.00 to 26.00 °C; 26.00 to 28.00 °C; 28.00 to 30.00 °C; 30.00 to 32.00 °C; 32.00 to 34.00 °C; 34.00 to 36.00 °C; 36.00 to 38.00 °C; 38.00 to 40.00 °C; above 40.00 °C			

9.2.1. T air analysis in the schoolyards under study (October):

- **At 10 o'clock,** it is clear that T-air in the courtyards is within the thermal comfort rates, as it records its lowest degrees in the courtyard of the School (C), where it reached about 23.5°, followed by School (D) and School (F), where the average air temperature reached about 23.6°. The averages in School (B), School (A), and School (E) were 23.7°, 23.88° and 23.9°, respectively.

- **At 12 o'clock,** School (D) yard has the lowest average T-air at 26.18°. It was followed by School (F) about 26.22°, then School (A) with an average of 26.35°. The average air temperature in the courtyards of both School (B) and School (C) was about 26.4°. The courtyard of School (E) recorded the highest average T-air at about 26.5°.

- **At 14 o'clock,** the average T-air in the courtyards is higher than 26.6°.

- **At 16 o'clock,** the courtyard of School (D) and School (F) recorded the lowest average T-air 26.3°, followed by both School (A) and School (B) with an average of about 26.34°, while School (C) recorded 26.4°. School (E) had the highest average T-air 26.6°, with an H/W of 0.5.

From the above, School (D), School (F), and School (C) are the best in T-air throughout school hours during the month of October, where the average T-air over the measurement hours is about 25.7°. School (D) tops other schools in terms of T-air because of the orientation of the longitudinal axis of the courtyard North–South while the buildings are in the western and southern part of the courtyard. But in School (F), quality of T-air is attributed to the ratio of the courtyard 1: 1.5, along with the height in the mass, where H/W was 0.57, also the use of plants for shading through the trees surrounding the courtyard. In School (C), both W/L and H/W are respectively 1: 2.1, 1.3, which helped to increase the shadows inside the courtyard and thus improve the T-air inside it.

School (E) recorded the highest average T-air in the courtyard over the measurement hours because of the elongation ratio in the courtyard with its longitudinal axis directed in an East-West direction. The H/W also reached 0.5, thus exposing the courtyard to heat significantly. Although the courtyard of School (A) takes the same orientation and reaches H/W of 0.41, the elongation ratio of the courtyard of 1:2.8 had the effect of lowering the average air temperature from School (E) by about 0.1°, along with the presence of specific blocks of the courtyard in the east, south and west direction, which provides shading inside the courtyard.

9.2.2. MRT analysis in the schoolyards under study (October):

- **At 10 o'clock,** the radiation temperature in most of the courtyard of the School (C) is about 30°, where the buildings are completely shaded. In School (A) (46.11°) 50% of the courtyard reaches 32°, while the other part reaches 62°. They are followed by School (B) with an average of 49.5, then School (E), where it reaches 52.75°, while at School (D), it was about 55.5°, since most of the shadows are behind the block outside the courtyard. The highest in the morning was in the courtyard of School (F), where it scored an average of 55.8°.

- **At 12 o'clock**, the courtyard of the School (C) recorded the lowest MRT of 37°, as 96% of the surface of the courtyard had MRT of 36°, because of the shadows from the high mass surrounding the courtyard from the north, east, and south. It was followed by School (E) with an average of 52.5°, while in School (A) it was about 56.1°, and 70% of the courtyard area recorded an average of 64°. As for School (D), the average was 58.07°, followed by School (F) with an average of 59.98°. The highest value was in School (B), where was 61.31°.

- **At 14 o'clock,** the courtyard of School (C) recorded the lowest average MRT about 41.43° and about 82% of the yard was 36°. It is followed by School (D) with an average of 51.29°, while School (B), School (F), School (A), and School (E) scored respectively 57.14°, 57.15°, 58.15° and 60.1°.

- At 16 o'clock, the shading effect appears in some schoolyards on the MRT. School (D) yard recorded the lowest average MRT, reaching 30°, followed by School (B), with an average of 32.9°, and 87% of the courtyard surface recorded less than 30°. At School (A), the average reached 37.3°, and 60% of the courtyard recorded less than 30°. The average score for School (C) was 38.36°, and 54% of the courtyard area had an average of less than 30°. They are followed, respectively, by School (F), 42.1°, and School (E), 45.75°.

According to the above, the courtyard of School (C) has the lowest MRT during the measurement period, as the H/W was 1.3 and the W/L was 1:2.1, which provides shade inside the courtyard and protection from direct sun radiation. Likewise, School (D) courtyard has one of the lowest MRT, given that the longitudinal direction of the courtyard is North-South, which provides the shortest period of exposure to solar radiation, with the height of the blocks in the south and west direction, which works to provide an amount of shadows within the courtyard. Next is School (A), where the tall buildings face east, south, and west. The highest ones are School (F) and School (E).

9.2.3. . PMV analysis in the schoolyards under study (October)

- At 10 o'clock, the PMV of School (C)'s courtyard reaches 0.95, while in School (D), it is about 1.9. School (A), School (B), and School (E) follow with an average of 1.7. In 25% of the area of School (F) courtyard, it recorded about 0.95, and 2-2.3 for the remaining areas.

- At 12 o'clock, the PMV in the courtyard of School (C) was approximately 1.7, while in School (A), it was about 2.48. At School (D), School (E), and School (B), it was 2.5, 2.54, and 2.58, respectively. School (F) scored 2.75.

- At 14 o'clock, the courtyard of School (C) had a PMV value of about 2.06, followed by School (D) 2.3. School (E) also scored 2.4 followed by School (B) 2.5 and then School (A) 2.6. The highest value was School (F) with an average score of about 2.9.

- At 16 o'clock, School (D) recorded the lowest value, reaching 0.7, then School (B) 1.2. School (A) follows with value 1.3. 40% of the courtyard area of School (F) was 0.95 and the rest of the area was between 1.7:2.3. The value in School (C) and School (E) was 1.59, 1.63.

From the above, the PMV of School (C), where aspect ratio is 1.3, is the lowest because of providing adequate shading in the courtyard during daylight hours, which contributes to a sense of thermal satisfaction in the school courtyard. This followed by School (D) with a North-South orientation, where there is still an obvious feeling of thermal satisfaction within the courtyard. Then School (B), which is oriented Southeast-Northwest to the main axis of the courtyard, while the PMV in School (F) is higher than its amount in School (B), which has the same orientation, because of the placement of the buildings and their relationship to the courtyard and the openness of the courtyard in the southwest direction. They are followed by School (A), then School (E), with an east-west orientation for the longitudinal axis of the courtyard.

9.2.4. T-surface analysis in the schoolyards under study (October)

Analysis during the measurement hours of the study samples shows the following:

T-surface of the grass at School (F) ranges between 24° and 26° at 10 o'clock, while it reaches a maximum at 14 o'clock at about 29°, and decreases after that, while the temperature of the adjacent gray concrete floors reaches approximately 29° at 10 o'clock. It reaches about 37° at 14 o'clock and decreases after that. As for the same gray concrete floors shaded by trees, the T-surface reaches 27° at 10 o'clock and reaches a maximum of 35° at 14 o'clock. This is also clear in School (D) with concrete floors, where the T-surface ranges from 25° to over 30° during the daylight hours in which it was measured, while the T-surface of the shaded floors in the building ranges from less than 24° to 27°. This is consistent with performing the floors in School (C), where it ranges from less than 24° to 27°. As for School (B), which has light-colored floors, the temperature of the floors differs from schools with gray floors, as it reaches 25° at 10 o'clock, while at 14 o'clock it reaches approximately 29°: 31°, which confirms the extent of the effect of color on the decrease in T-surface for over 5 degrees at 14 o'clock, which represents the highest temperature for the surface. As for the courtyards of School (A) and School (E), which are completely exposed to direct solar radiation and with dark colors on the floors, the T-surface of the courtyard at 10 o'clock reaches about 28°, while it reaches about 38° at o'clock pm and decreases after that.

Based on sample analysis, the research reached the following conclusions:

Using the Envi-met program to measure central schoolyard points in a selected sample in July and October 2022, the study concluded:

- As for T-air in the schoolyard in July

The extent of the effect of the orientation of the longitudinal axis of the courtyard on T-air becomes clear, as T-air drops in summer by about 0.2° - 0.4° at 10 o'clock in Modern School(D), with the North-South orientation of the longitudinal axis of the courtyard, compared to both Al-Salam Language School (A) and Notre Dame school(E), which have the longitudinal axis of the courtyard to the East-West, while the drop reaches over 0.7° at 14 o'clock. Fig.4 The position of the buildings and their relationship to the courtyard also affects the T-air in it. So, T-air temperature drops in the early hours of the day in the courtyard of Tanta Secondary School for girls(F), which is oriented Southeast-Northwest of the longitudinal axis of the courtyard, compared to the Al-Ahmadia School(B), which agrees with it in the courtyard's orientation. Because of the height of buildings, which occupy the eastern and southern sides, the courtyard of Al-Ahmadia School(B) is surrounded by buildings in the southern and western direction, which affects the lower temperature of the courtyard at 14 o'clock than its counterpart in the orientation.

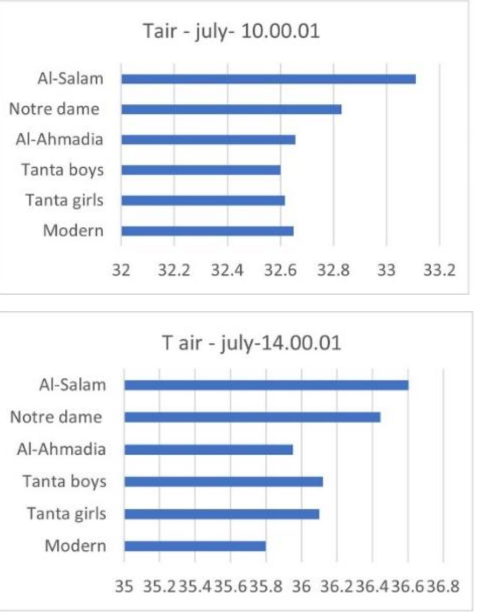


Fig. 4. T air analysis in July 2022

- As for T-air in the schoolyard in October

Analysis of the extent to which the orientation of the courtyard axis affects the air temperature in it, as it decreases at 10 o'clock in Modern School(D) with North-South orientation from the other schools by approximately 0.02°: 0.25°. The decrease in the schoolyards-oriented Southeast-Northwest (Tanta Secondary School for girls(F), Al-Ahmadia School(B) ranges from 0.01°: 0.1°, and between it and the schoolyards of schools-oriented East-West, it ranges between 0.2°: 0.25°. This confirms that the closer the courtyard's orientation is to the North-South direction, the lower the air temperature in it. At 14 o'clock, the effect of both W/L and H/W appeared stronger, as the air temperature in the courtyard of the Preparatory School for boys (C) decreased by about 0.06° compared to Modern School(D) (however, Modern School, with the courtyard oriented North-South(E), is still one of the lowest courtyards in air temperature over the course of hours of the day), and Tanta Preparatory School for boys(C) courtyard is also lower than the courtyards with the same orientation (Al-Salam Language School (A), Notre Dame(E)) from 0.3°: 0.31°. Fig.5

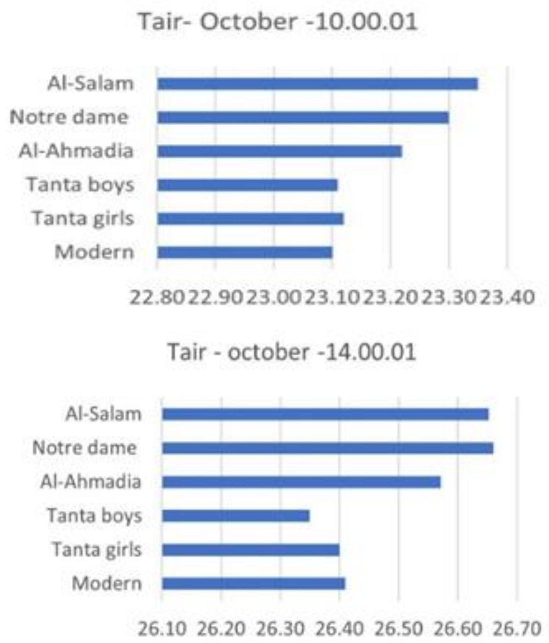


Fig. 5. T air analysis in October 2022

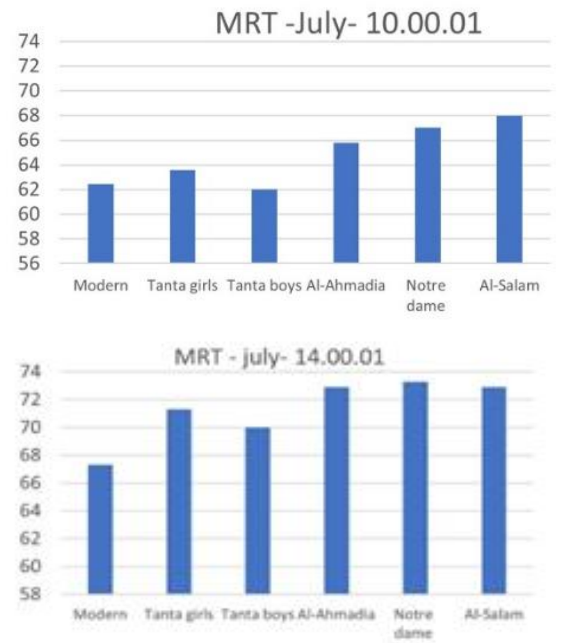


Fig. 6 MRT analysis in July 2022

- As for MRT in the schoolyard in July

MRT is even 6-13% lower in the courtyard of the Modern School, whose longitudinal axis is North-South, compared to Al-Salam Language School (A) and Notre Dame school(E), which have a longitudinal axis of the courtyard, East-West, with an elongation ratio exceeding 1:2.5.

The reduction in MRT in the courtyard of Tanta Preparatory School for boys(C), where the aspect ratio reaches 1.3, increases the shaded area of the building and reduces the radiant temperature by up to 5-10% during the day. As for Tanta Secondary School for girls (F) and Al-Ahmadia School(B), which is oriented Southeast-Northwest along the longitudinal axis of the courtyard, the radiant temperature decreases by about 10% in Secondary School for girls(F), which has an aspect ratio of 0.57, compared to Al-Ahmadia School(B), which has an aspect ratio of 0.31, during the hours of student presence. Fig.6

As for MRT in the schoolyard in October

MRT is low in the courtyard of Tanta Preparatory School for boys(C), with an aspect ratio of 1.3 has a significantly lower radiant temperature of about 30%, as the buildings in the east and south provide shading for the semi-square courtyard during October.

As for Modern School(D), with the longitudinal axis of the courtyard North-South, its exposure to solar radiation during the first hours of the day is greater than Al-Salam Language School (A) and Notre Dame school(E), which have the longitudinal axis of the courtyard East-West during October because of its exposure to low sun, by a rate of up to over 10% at 10 o'clock. While the two schools with an East-West longitudinal axis increase exposure to solar radiation for the rest of the day by about 12%.

For Tanta Secondary School for girls(F), which has a courtyard Southeast-Northwest, its courtyard is exposed to direct sunlight, especially during the first hours of the day, because there are no shaded spaces in the southeast direction. Fig.7.

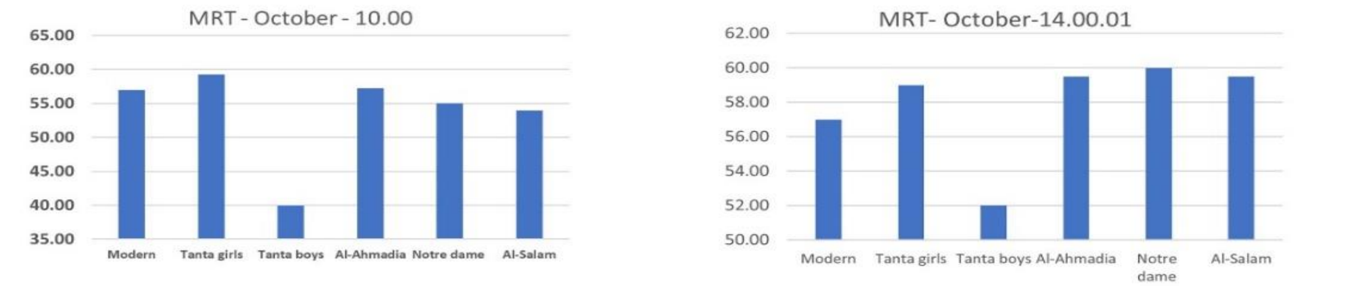


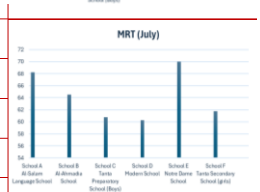
Fig. 7 MRT analysis in October 2022

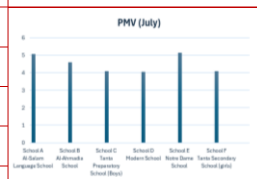
From the above, the research concluded with the following matrix of results, Table (13) and Table (14)

Table 13. The matrix of schoolyards results (July)

July	School A Al-Salam Language School	School B Al-Ahmadia School	School C Tanta Preparatory School (Boys)	School D Modern School	School E Notre Dame School	School F Tanta Secondary School (girls)
shape + orientation	Semi closed (E-W)	Semi closed (NW-SE)	Semi closed (E-W)	Semi closed- Semi opened (NE-SW)	Semi closed (E-W)	Semi opened (NW-SE)
W/L	1: 2.8	1: 1.1	1: 2.1	1:1.6-1: 1.7	1:3	1:1.5
AR (H/W)	0.41	0.31	1.3	0.5	0.5	0.57
vegetation	20.00%	8.50%	22.00%	12.00%	9.00%	23.50%
surface materials	grass - dark colors floors	grass - light-colored floors	grass - concrete	grass -concrete	grass - dark colors floors	grass - gray concrete

		School A	School B	School C	School D	School E	School F
T-air	10.00.01	33.5	33.18	33	32.8	33.2	32.9
	12.00.01	35.8	35.65	35.88	34.7	35.5	35.2
	14.00.01	37.9	37.3	37.8	36.5	37.6	37.4
	16.00.01	38.6	38.24	38.5	37.9	38.7	38.5
	Average	36.45	36.08	36.29	35.45	36.25	36.03
MRT	10.00.01	66	67	66	66	69	66
	12.00.01	65	68	60	60	69	60
	14.00.01	72	72	70	70	72	70
	16.00.01	70	51	47	45	70	51
	Average	68.25	64.5	60.75	60.25	70	61.75
PMV	10.00.01	4.4	4	2.8	2.8	4.4	2.8
	12.00.01	4.6	4.8	4.2	4.2	4.8	4.4
	14.00.01	5.6	5.6	5.4	5.2	5.6	5.2
	16.00.01	5.7	4	4	4	5.8	4
	Average	5.075	4.6	4.1	4.05	5.15	4.1



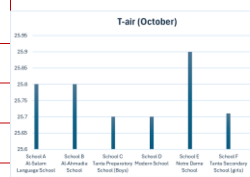


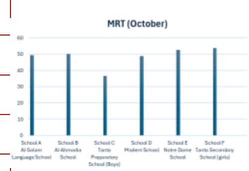
From table (13), we find that the school courtyard with the north-south orientation of its longitudinal axis represents the best thermal satisfaction for users (PMV), which reaches 4.05.

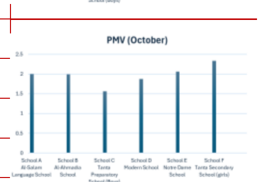
It also represents the lowest air temperature and radiant temperature in the hot month of July, which enhances the effect of the orientation of the longitudinal axis of the courtyard in achieving thermal comfort.

Table 14. The matrix of schoolyards results (October)

<table>
<tr><td rowspan="3" colspan="2">October</td><td colspan="5">School A
Al-Salam Language School</td><td colspan="5">School B
Al-Ahmadia School</td><td colspan="5">School C
Tanta Preparatory School (Boys)</td><td colspan="5">School D
Modern School</td><td colspan="5">School E
Notre Dame School</td><td colspan="5">School F
Tanta Secondary School (girls)</td></tr>
<tr><td>shape + orientation</td><td>W/L</td><td>AR (H/W)</td><td>vegetation</td><td>surface materials</td><td>shape + orientation</td><td>W/L</td><td>AR (H/W)</td><td>vegetation</td><td>surface materials</td><td>shape + orientation</td><td>W/L</td><td>AR (H/W)</td><td>vegetation</td><td>surface materials</td><td>shape + orientation</td><td>W/L</td><td>AR (H/W)</td><td>vegetation</td><td>surface materials</td><td>shape + orientation</td><td>W/L</td><td>AR (H/W)</td><td>vegetation</td><td>surface materials</td><td>shape + orientation</td><td>W/L</td><td>AR (H/W)</td><td>vegetation</td><td>surface materials</td></tr>
<tr><td>Semi closed (E-W)</td><td>1: 2.8</td><td>0.41</td><td>20.00%</td><td>grass - dark colors floors</td><td>Semi closed (NW-SE)</td><td>1: 1.1</td><td>0.31</td><td>8.50%</td><td>grass - light-colored floors</td><td>Semi closed (E-W)</td><td>1: 2.1</td><td>1.3</td><td>22.00%</td><td>grass - concrete</td><td>Semi closed- Semi opened (NE-SW)</td><td>1:1.6
1: 1.7</td><td>0.5</td><td>12.00%</td><td>grass -concrete</td><td>Semi closed (E-W)</td><td>1:3</td><td>0.5</td><td>9.00%</td><td>grass - dark colors floors</td><td>Semi opened (NW-SE)</td><td>1:1.5</td><td>0.57</td><td>23.50%</td><td>grass - gray concrete</td></tr>
<tr><td rowspan="5">T-air</td><td>10.00.01</td><td colspan="5">23.81</td><td colspan="5">23.67</td><td colspan="5">23.46</td><td colspan="5">23.6</td><td colspan="5">23.8</td><td colspan="5">23.58</td></tr>
<tr><td>12.00.01</td><td colspan="5">26.35</td><td colspan="5">26.44</td><td colspan="5">26.43</td><td colspan="5">26.1</td><td colspan="5">26.51</td><td colspan="5">26.21</td></tr>
<tr><td>14.00.01</td><td colspan="5">> 26.6</td><td colspan="5">> 26.6</td><td colspan="5">> 26.6</td><td colspan="5">> 26.6</td><td colspan="5">> 26.6</td><td colspan="5">> 26.6</td></tr>
<tr><td>16.00.01</td><td colspan="5">26.34</td><td colspan="5">26.34</td><td colspan="5">26.42</td><td colspan="5">26.33</td><td colspan="5">26.55</td><td colspan="5">26.31</td></tr>
<tr><td>Average</td><td colspan="5">25.8</td><td colspan="5">25.8</td><td colspan="5">25.7</td><td colspan="5">25.7</td><td colspan="5">25.9</td><td colspan="5">25.71</td></tr>
<tr><td rowspan="5">MRT</td><td>10.00.01</td><td colspan="5">46.1</td><td colspan="5">49.53</td><td colspan="5"><30</td><td colspan="5">55.75</td><td colspan="5">52.75</td><td colspan="5">55.8</td></tr>
<tr><td>12.00.01</td><td colspan="5">56.1</td><td colspan="5">61.31</td><td colspan="5">37</td><td colspan="5">58.07</td><td colspan="5">52.5</td><td colspan="5">59.9</td></tr>
<tr><td>14.00.01</td><td colspan="5">58.15</td><td colspan="5">57.14</td><td colspan="5">41.43</td><td colspan="5">51.29</td><td colspan="5">60.13</td><td colspan="5">57.15</td></tr>
<tr><td>16.00.01</td><td colspan="5">37.33</td><td colspan="5">32.9</td><td colspan="5">38.36</td><td colspan="5">< 30</td><td colspan="5">45.75</td><td colspan="5">42.1</td></tr>
<tr><td>Average</td><td colspan="5">49.42</td><td colspan="5">50.22</td><td colspan="5">36.7</td><td colspan="5">48.8</td><td colspan="5">52.66</td><td colspan="5">53.76</td></tr>
<tr><td rowspan="5">PMV</td><td>10.00.01</td><td colspan="5">1.67</td><td colspan="5">1.75</td><td colspan="5">0.92</td><td colspan="5">1.95</td><td colspan="5">1.68</td><td colspan="5">1.85</td></tr>
<tr><td>12.00.01</td><td colspan="5">2.48</td><td colspan="5">2.58</td><td colspan="5">1.66</td><td colspan="5">2.5</td><td colspan="5">2.54</td><td colspan="5">2.57</td></tr>
<tr><td>14.00.01</td><td colspan="5">2.59</td><td colspan="5">2.51</td><td colspan="5">2.06</td><td colspan="5">2.34</td><td colspan="5">2.14</td><td colspan="5">3.3</td></tr>
<tr><td>16.00.01</td><td colspan="5">1.27</td><td colspan="5">1.15</td><td colspan="5">1.59</td><td colspan="5">0.68</td><td colspan="5">1.65</td><td colspan="5">1.58</td></tr>
<tr><td>Average</td><td colspan="5">2</td><td colspan="5">1.99</td><td colspan="5">1.56</td><td colspan="5">1.87</td><td colspan="5">2.06</td><td colspan="5">2.33</td></tr>
</table>







Through Table (14), it was found that the school courtyard with a sector ratio (H/W) of 1.3 has the best level of thermal satisfaction for users, 1.56. This is due to the effect of the sector's ratio in the courtyard on protection from exposure to direct sunlight and achieving adequate shading in the month of October, which led to the courtyard in that school being the lowest in air temperature and radiant temperature.

It also highlights the effect of the orientation of the longitudinal axis of the school courtyard, as the school courtyard has a north-south longitudinal axis. It is one of the best courtyards in terms of thermal satisfaction for users in the month of October also because the amount of thermal satisfaction is 10% better due to the significantly lower PMV than the courtyards with perpendicular directions.

10. Conclusions

- The longitudinal axis of the schoolyard has a significant impact on its thermal performance, as the air temperature in the courtyard with the longitudinal axis North-South decreased by over 0.7° during the solar presence hours in summer compared to the courtyard with the longitudinal axis East-West. In contrast, during the month of October, it reaches about 0.2°. The radiant temperature was significantly lower in schools with a North-South orientation than in those with an

East-West longitudinal axis.

- The level of thermal satisfaction in schoolyards with the longitudinal axis North-South is higher by 20% than the thermal satisfaction of children in the schoolyards with the longitudinal axis East-West, due to the impact of the directive on the number of hours the courtyard is exposed to direct solar radiation during the school day.

- The schoolyard ratio (width: length) impacts thermal performance, as the research found that schools that agree in orientation (East-West) and differ in the courtyard ratio differ in their thermal performance and radiant temperature. The comparison between schoolyards with ratios of 1:2, 1:2.8, and 1:3 found that the mean radiant temperature decreased by 7% and 13%, respectively, during July, as well as 52%, and 27%, during October. This confirms that thermal satisfaction decreases as the length of the yard > its width.

- The schoolyard aspect ratio affects the thermal performance, as the study samples revealed that the schools with the highest aspect ratio, which reaches 1.3, have a decrease in the mean radiant temperature during July by a rate of up to 5–10% during the daytime hours. While the percentage of decrease reaches about 30%, as the buildings in the east and south provide shading for the semi-square courtyard during October.

- Both the orientation of the buildings surrounding a courtyard and the orientation of the courtyard openings influence its thermal performance. The study concluded that buildings oriented to the north and northeast shade the courtyard in the early morning hours, while buildings oriented to the south and west protect the courtyard from exposure to direct solar radiation during peak thermal hours. The openness of the courtyard from the southern direction allows direct solar radiation to enter the courtyard without adequate shading to protect from direct sunlight, so shading of the courtyard in this direction is important.

- Afforestation affects the radiation temperature and air temperature, as it provides shaded areas that achieve thermal satisfaction, but it is clear in most of the study samples that they lack afforestation, except small areas in some schoolyards, where the low radiation temperature under the wooded areas reaches about 20 in summers.

- The schoolyard finishing materials are one of the primary factors affecting the thermal comfort of students in the courtyard. The floors treated with gray concrete in the study samples showed the highest ground surface temperatures of about 45° in July and 33° in October, which are higher than floors covered with grass by about 9° and 6°, respectively. The surface temperature of vegetation and light floors is similar. This confirms the possibility of regulating thermal comfort through different T-surface treatments, as the choice of coating materials affects the ambient T-air. Surrounding the courtyard with buildings also affects the surface temperature of different materials because of the resulting shading effect. Floors in the shadow effect of buildings recorded a greater decrease in the temperature of finishing materials than surfaces exposed to solar radiation.

11. Recommendations

The research recommends a number of strategies to achieve thermal comfort in schoolyards in Egypt as follows:

- Orient the courtyard's long axis north-south for improved thermal performance and user satisfaction during the study months.
- Enclosing the schoolyard by building in the southwestern direction, providing shading and protection from direct sunlight and undesirable winds.
- Schoolyards should have a width-to-length ratio that falls between square and rectangular, with a length ratio of no more than 1:1.5.
- Design the courtyard spaces to accommodate different student activities, while incorporating shaded areas and tree-filled spaces, in a suitable shape and size to ensure thermal comfort for the users.

- Using eco-friendly materials with low absorption and emissivity coefficients for schoolyard flooring to prevent adverse effects on air temperature and provide users with thermal comfort.

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