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Towards Environmentally Sustainable Educational Spaces in Semi-Desert Areas: Visions from Schools in New Cairo City

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Abstract: The study examines the extent to which school building designs in Egypt, particularly in the semi-desert climate of New Cairo, align with environmental sustainability standards. In response to rapid population growth and rising demand for educational buildings, many school buildings continue to prioritize cost efficiency and basic functionality while overlooking essential sustainability considerations, such as energy performance, building orientation, and indoor environmental quality. Adopting a multi-method research approach. The initial analytical phase involved a review of both local standards, issued by the (GAEB) and the (CHPS), with a focus on core physical comfort factors: temperature, ventilation, and lighting. While other factors have been identified, but are considered less influential, outside the scope of the study, and more suitable for specialized studies. The pilot phase involved field documentation of selected school models, which, although not intended to be fully representative, serve to illustrate instances where environmental sustainability considerations were overlooked despite the availability of space. The comparative phase that utilized software tools to assess environmental performance, and then offered targeted passive design strategies to address identified gaps. Findings terms of energy efficiency, indoor comfort, and resource management. The study highlights the urgent need to embed environmental sustainability in national school design policies, emphasizing its role in reducing operational costs, enhancing occupant comfort, and improving educational outcomes. It offers original, context-specific insights and practical recommendations to support resilient, energy-efficient, and pedagogically effective educational environments in Egypt.

Keywords: Environmental sustainability, School building standards, Energy efficiency, Indoor environmental quality, Physical comfort.

1. Introduction

Education is crucial for the advancement of societies, as it facilitates innovation, critical thinking, and social cohesion. However, the physical environment of educational settings plays a significant role in the effectiveness of the learning process. A well-designed school building not only supports educational activities but also promotes the physical and mental well-being of its occupants' students, teachers, and administrative staff (UNESCO, 2017).

In Egypt, despite significant advancements in technology, economy, and social structure, the design of educational facilities has not kept pace with these developments. The existing school buildings often do not meet the evolving needs of modern education in terms of space utilization, environmental comfort, and functionality, particularly in urban areas like New Cairo City, where rapid urbanization has placed additional strain on infrastructure (Zaki, 2021).

New Cairo City, developed to accommodate future population growth and educational needs, presents an opportunity to assess the application of sustainability principles in school design. As the city is situated in a semi-desert climate, this case study is particularly relevant for evaluating the potential of environmentally sustainable design to mitigate the effects of harsh climates at minimal cost.

Environmentally sustainable school design integrates environmental and economic considerations to minimize resource consumption and environmental impact while enhancing indoor environmental quality. The United Nations Environmental Sustainable Development Goals (SDGs) emphasize the importance of resilient and inclusive educational infrastructure (UNEP, 2020). the optimization of building orientation, material selection, and energy-efficient systems, are critical for creating healthier and more productive educational environments. The World Green Building Council highlights the importance of these principles for educational buildings, where occupant's health and productivity are paramount. Furthermore, the CHPS standards in the United States promote high-performance school designs that prioritize energy efficiency, site optimization, and resource conservation (Council, 2019).

In contrast, the General Authority for Educational Buildings (GAEB) in Egypt has set standards that primarily emphasize functionality and cost-efficiency, often overlooking sustainability principles. This research aims to identify the gaps between local standards and international sustainability frameworks, like CHPS, and propose solutions for improving educational building design in Egypt, particularly in New Cairo City.

This study both educational outcomes and the well-being of its occupants. It also highlights gaps between current Egyptian school design standards and environmental sustainability frameworks, particularly in the context of rapidly urbanizing semi-desert climates. The study identifies shortcomings in current GAEB standards, which prioritize cost and functionality over sustainability, and highlights the potential for integrating passive design strategies and energy-efficient solutions. By aligning educational buildings with the principles and goals of sustainable environmental development, the study provides policy and design recommendations that contribute to the creation of resilient, healthy, and educationally effective learning environments in Egypt.

2. Research Objectives

This study aims to evaluate the extent to which educational buildings in Egypt's semi-desert regions align with environmental sustainability standards, by identifying discrepancies between national guidelines set by the General Authority for Educational Buildings (GAEB) and international frameworks such as the Collaborative for High Performance Schools (CHPS). It further proposes the integration of sustainable environmental design principles into national standards, with the objective of improving indoor environmental quality and occupant comfort, thereby fostering the development of adaptable, resilient, and pedagogically effective school environments.

3. Research Methodology

This study employs a mixed-methods research design, integrating qualitative and quantitative approaches to evaluate the alignment of educational building designs in Egypt's semi-arid regions with environmental sustainability standards. The methodology is structured into four sequential phases:

- **Analytical Phase:** A qualitative content analysis was conducted, reviewing national standards issued by the General Authority for Educational Buildings (GAEB) and international guidelines, such as those from the Collaborative for High Performance Schools (CHPS). The analysis focused on fundamental physical comfort parameters, temperature, ventilation, and lighting, to establish a baseline understanding of acceptable environmental sustainability benchmarks.
- **Experimental Phase:** Field surveys and performance assessments were carried out in selected schools within New Cairo City. These case studies, while not fully representative, provided empirical data illustrating instances where environmental sustainability considerations were overlooked, despite the availability of spatial resources.

- **Comparative Phase:** Quantitative methods were employed using specialized software tools to evaluate environmental performance indicators, including energy efficiency, building orientation, and indoor environmental quality. These metrics were compared against both GAEB and CHPS standards, with a focus on the core physical comfort factors identified earlier. Other factors, deemed less influential within the scope of this study, were acknowledged but and more suitable for specialized studies.
- **Guiding Phase:** Based on the findings from the preceding phases, this stage proposed passive design strategies aimed at enhancing indoor environmental quality and occupant comfort. The recommendations are intended to inform the integration of sustainable environmental design principles into national educational building codes.

This comprehensive methodological approach ensures a robust evaluation of current practices and provides actionable recommendations for of resilient, energy-efficient, and pedagogically effective educational environments in Egypt's semi-desert regions.

4. Literature Review

Sustainability in architecture encompasses the creation of built environments that minimize environmental impact while enhancing occupant health, comfort, and productivity. This approach includes strategies such as energy efficiency, resource conservation, and improvements in indoor air quality (Baker, 2000). In educational settings, green school designs have demonstrated significant benefits, including reductions in energy consumption by up to 50%, water usage by 40%, and notable improvements in indoor air quality, all contributing to better academic performance (UNEP, 2020).

While initial investments in environmentally sustainable school designs may be higher, the long-term savings in energy and maintenance costs offset these expenses. Moreover, the improved indoor air quality and comfort provided by such designs contribute to reduced absenteeism and better student health. For instance, (Council., 2007) notes that "a robust body of scientific evidence indicates that the health of children and adults can be affected by indoor air quality," and that "teacher productivity and student learning may also be affected by indoor air quality" (Council., 2007).

The passage in question emphasizes the benefits of passive design strategies in educational architecture, highlighting their role in reducing reliance on mechanical systems, lowering energy consumption, and enhancing indoor environmental quality. This aligns with the findings of (Gil-Ozoudeh, 2022), who state that "passive design strategies play a critical role in enhancing energy efficiency in green buildings by minimizing the need for mechanical heating, cooling, and lighting systems" (Gil-Ozoudeh, 2022).They further elaborate that "site orientation is fundamental in passive design, as it optimizes the building's exposure to the sun, wind, and other environmental factors, allowing for natural heating, cooling, and lighting" (Gil-Ozoudeh, 2022). Additionally, the authors note that "natural ventilation, another vital strategy, utilizes air movement through the building to provide cooling without relying on mechanical systems." (Gil-Ozoudeh, 2022) . These strategies collectively contribute to creating resilient and effective educational facilities that align with sustainable development

4.1 Principles of Environmentally sustainable Architecture

Key principles of environmentally sustainable architecture include but not limited to:

- Energy and Resource Efficiency: Strategies such as passive solar design, natural ventilation, and the use of renewable materials aim to reduce energy consumption and minimize resource depletion (Gibson, 2016). Additionally, (Elbakheit A. R., 2018) calls to "integrate passive and active renewable energy technologies and systems" in tall-building design. Among its "key sustainability strategies" is maximizing natural ventilation alongside natural lighting, heating and cooling.
- Indoor Environmental Quality: Ensuring good air quality, lighting, acoustics, and thermal comfort improves occupant well-being (Schneider, 2002), where (Elbakheit A. R., 2018) talks about Double-skin façades where the cavity between two layers of glass can be modulated to admit outdoor air at milder temperatures.

- Environmental Context: Environmentally sustainable design incorporates site-specific analysis and cultural sensitivity, optimizing building orientation and material selection (Harris, 2002). (Elbakheit A. R., 2012) States that by modeling prevailing wind patterns at different elevations, architects shape tower slenderness and orientation to channel breezes into habitable zones.
- Human Welfare: Environmentally sustainable design considers human behavior and comfort, fostering greater satisfaction and productivity (Schneider, 2002). Case studies cited in (Elbakheit A. R., 2018) report up to a 10% rise in worker productivity and a 15% drop in sick-leave rates in buildings that integrate passive environmental controls.

4.2 Identifying Key Elements for Assessing Physical Comfort Parameters in School Building Standards

4.2.1 Assessing Physical Comfort Parameters in Egyptian Classroom Standards

In Egypt, the General Authority for Educational Buildings (GAEB) places significant emphasis on the functional and economic aspects of school infrastructure. Its guidelines outline essential criteria such as classroom dimensions, ventilation, and safety protocols. According to GAEB standards, the maximum number of students per classroom in public schools is 40, with an area allocation of 38 to 40 square meters per classroom. This results in a spatial provision of approximately 0.95 to 1.0 square meters per student (GEAB, 2011). However, field observations reveal that these thresholds are frequently exceeded, with some classrooms accommodating as many as 80 students. This situation reduces the floor area per student to merely 0.5 square meters, leading to significant limitations in circulation, flexibility, and overall comfort within the learning environment (Nabih, 2021).

Moreover, the GAEB's standardized school design models have been critiqued for their inability to respond to Egypt's diverse climatic zones. Many of these models replicate generic structural forms primarily to minimize costs, often at the expense of contextual responsiveness. This approach fails to integrate environmental sustainability principles or passive design techniques that are crucial for optimizing indoor thermal comfort and energy efficiency. Notably, GAEB guidelines lack specific metrics for thermal comfort, such as optimal temperature ranges, adequate ventilation rates, or target levels for natural lighting. Although a preferred building orientation (north-facing with a 25-degree deviation east or west) is acknowledged, window openings are restricted to 18% of the classroom area, and there are no explicit requirements for window types to optimize ventilation or lighting (GEAB, 2011); (Nabih, 2021).

4.2.2 Assessing Physical Comfort Parameters CHPS Classroom Standards

In contrast to the Egyptian context, the Collaborative for High-Performance Schools (CHPS) framework in the United States is rooted in the principles of sustainability and high indoor environmental quality. CHPS guidelines advocate for the use of energy-efficient building systems, conservation of natural resources, and the promotion of indoor comfort through both active and passive strategies. Empirical studies of CHPS-certified schools indicate that such facilities consistently benefit from reduced energy consumption, enhanced air quality, and improved occupant comfort and productivity (CHPS, 2020).

CHPS standards place considerable emphasis on passive design features such as optimized building orientation, natural ventilation, and daylighting to achieve thermal and visual comfort without excessive reliance on mechanical systems. These strategies are aligned with broader sustainable development goals and support long-term operational efficiency. Furthermore, the CHPS framework incorporates measurable environmental performance indicators, including ventilation rates, target temperature ranges, and illumination levels, with the intent of fostering healthier and more effective learning environments (CHPS, 2020).

4.2.3 Comparative Analysis and Synthesis of Findings

A comparative review of the GAEB and CHPS standards reveals fundamental differences in how physical comfort within educational facilities is conceptualized and implemented. GAEB guidelines are predominantly utilitarian, with a primary focus on cost-efficiency and functional capacity, while CHPS provides a holistic and performance-based approach that prioritizes indoor environmental quality and energy conservation. For instance, CHPS-certified schools have demonstrated up to 50% reductions in energy consumption and 40% savings in water use, alongside marked improvements in indoor air quality and student academic outcomes (CHPS, 2020).

Additionally, literature supports the assertion that the integration of passive design techniques such as natural ventilation and strategic orientation can substantially enhance thermal comfort in school buildings. In the Egyptian context, the absence of such measures has been particularly problematic in southern regions like Aswan, where high temperatures and insufficient ventilation exacerbate thermal discomfort. These findings highlight the pressing need for GAEB to revise its school design standards to incorporate sustainable and context-responsive design strategies that enhance physical comfort and educational performance nationwide (Nabih, 2021).

5. Data Collection: Documenting the Study Sample

5.1 New Cairo City as a Model for Urban Areas in Semi-Desert Climates

New Cairo City is a strategic urban expansion of Cairo, Fig. 1. initiated in the late 1990s to alleviate the high levels of urban congestion in Greater Cairo (El-Batran, 1998). It ranges in elevation between 250 and 307 meters (820 and 1,007 ft.) above sea level, on a site of approximately 70,000 hectares designed to be modern and accommodate over one million people. The city was designed to contain well-planned residential, commercial, and institutional areas, integrated within a grid layout, interconnected green spaces, open areas, and a comprehensive road network reflecting an initial commitment to sustainability. Despite this framework, strategies for employing environmental considerations were not fully integrated, particularly in utilizing passive design principles to reduce energy consumption and ensure thermal comfort.

New Cairo City is strategically located 25 kilometers east of Cairo Fig. 2) and was intended to balance urban growth with the demands of a semi-desert environment. This type of climate, with its high variations throughout the day and night and predominantly high temperatures, requires specific planning measures to achieve environmentally sustainable development (Fahmy, 2009).

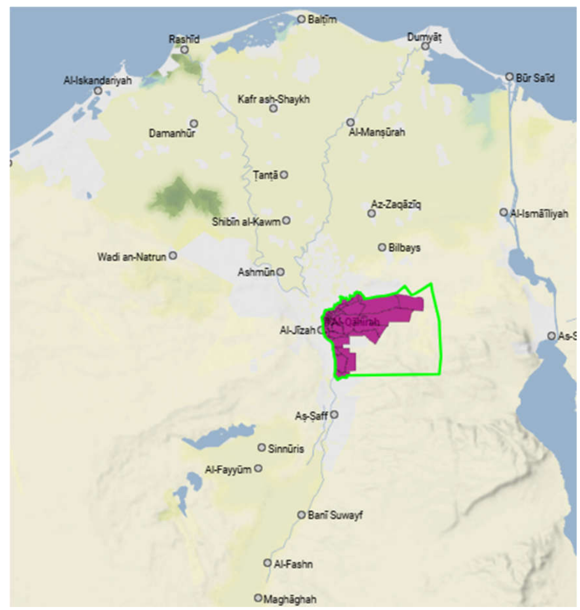


Figure (1). Location of Cairo city in relation to Egypt. (Population, 2023).

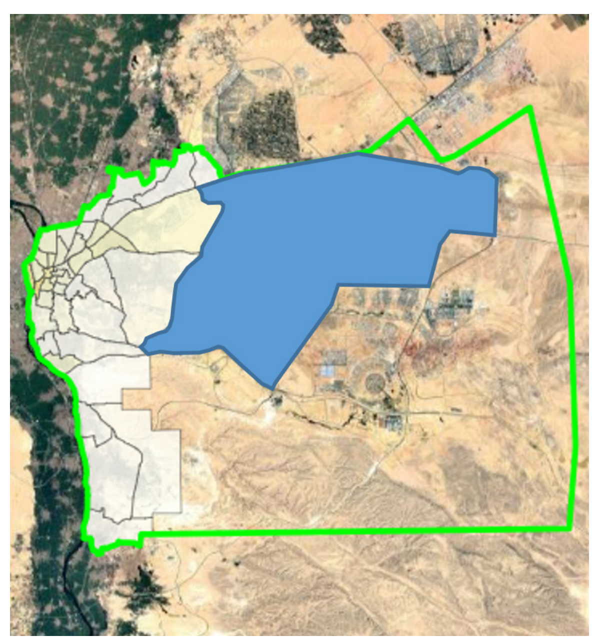


Figure (2). Location of New Cairo city in relation to Cairo. (Population, 2023).

However, most projects in the city, such as educational buildings, have not successfully implemented appropriate passive cooling strategies and do not optimize building orientations. This leads to an over-reliance on energy-intensive systems that undermine sustainability goals. The study specifically highlights the large gap between stated intentions for environmentally sustainable design and actual implementation of educational buildings in New Cairo. Despite the availability of space, school designs rarely incorporate strategies to reduce solar heat gain or improve natural ventilation. Extensions to existing schools also tend to perpetuate these imbalances, continuing to increase energy use and reducing occupant comfort. This trend highlights the growing need for more robust sustainability regulations and mechanisms to mitigate these negative impacts.

The proposed methodology follows the assessment of sustainability principles and passive cooling strategies in New Cairo schools, with special attention to the challenges presented by the city being a semi-desert area. The study examines how different school designs incorporate or neglect passive cooling measures, aiming for energy-efficient and comfortable indoor environments.

5.2 Sampling Framework

The pilot phase involved field documentation of selected school models, which, although not intended to be fully representative, serve to illustrate instances where environmental sustainability considerations were overlooked despite the availability of space.

The study employs a systematic sampling framework to examine critical school design cases in New Cairo, with a focus on architectural diversity and adaptability to sustainability principles, as detailed in subsequent sections. The selected schools are categorized based on four key criteria: (1) Building Configuration, distinguishing between single-structure schools and multi-building layouts; (2) Expansion Status, assessing whether schools have undergone structural modifications and their impact on performance; (3) Design Authority Subordination, differentiating between standardized models developed by the Educational Buildings Authority (EBA) and regionally adapted designs by the New Urban Communities Authority (NUCA); and (4) Classroom Space Assembly along Corridors, examining the influence of corridor configurations on ventilation and thermal comfort. Schools with single-loaded corridors (Model No.1) may facilitate cross-ventilation but are prone to excessive solar heat gain, whereas double-loaded corridors (Model No. 2) typically restrict natural ventilation, increasing reliance on mechanical cooling. Additionally, schools constructed in multiple buildings using a uniform design without consideration of site-specific sustainability needs often exhibit inefficiencies in energy consumption and thermal comfort.

5.2.1 Building Configuration

- Single Building Designs: Schools in which all the design requirements are combined into one structure; this would provide potential for centralized passive cooling strategies. (Fatima Annan Girls Preparatory School).
- Multiple Buildings on the Same Site: This divides educational services between multiple buildings and increases travel distances between educational spaces. (Martyr Ahmed Ibrahim Al-Jamal Language School), (Salah El-Din Experimental Languages School)

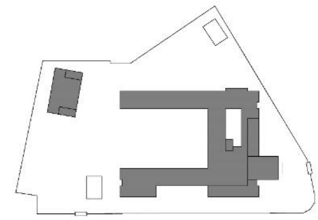
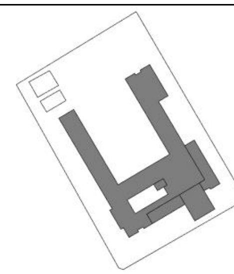
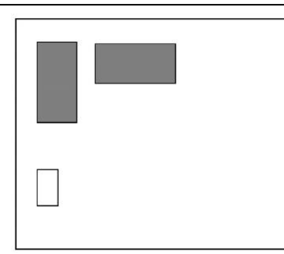
5.2.2 Status of Expansion in School

- Schools without Expansions: It is an original design without modification and thus reflects the performance of the initial design to the present situation. (Fatima Annan Girls Preparatory School). TABLEI
- Schools with Unplanned Expansions: It depicts the impact of uncoordinated additions on energy performance and indoor comfort. (Martyr Ahmed Ibrahim Al-Jamal Language School), (Salah El-Din Experimental Languages School). TABLE I

5.2.3 Design Authority Subordination

- Educational Buildings Authority Models: These are standardized designs implemented across all governorates in the Republic. (Salah El-Din Experimental Languages School). TABLE I
- New Urban Communities Authority Designs: These designs vary according to the specific needs and characteristics of each urban region, reflecting localized adaptations. (Martyr Ahmed Ibrahim Al-Jamal Language School), (Fatima Annan Girls Preparatory School). TABLE I

Table (1). Sampling cases according to Building Configuration, Status of Expansion, Design Authority

	School Map Site	School Layout
Martyr Ahmed Ibrahim Al-Jamal Language School	 St 15 Cairo 1-Cairo Governorate 4722231. **(GoogleEarth, 2023)** • Site Area = 11378.2 m2 • Perimeter = 454.5 m	 Layout **(Author., 2023)** - Building Configuration: Multiple Buildings on the Same Site - Status of Expansion: School with Unplanned Expansion - Design Authority Subordination: New Urban Communities Authority Design. And another Educational Buildings Authority Model
Fatima Annan Girls Preparatory School	 St 23-New Cairo 1 Cairo Governorate 4722606, **(GoogleEarth, 2023)** • Site Area = 9495.3 m2 • Perimeter = 397.8 m	 Layout **(Author., 2023)** - Building Configuration: Single Building on the Same Site - Status of Expansion: School Not Expanded - Design Authority Subordination: New Urban Communities Authority Design.
Salah El-Din Experimental Languages School	 St 2-New Cairo 1 Cairo Governorate 4722661, **(GoogleEarth, 2023)** • Site Area = 9213.5 m2 • Perimeter = 385.8 m	 Layout **(Author., 2023)** - Building Configuration: Multiple Building on the Same Site - Status of Expansion: School with Unplanned Expansion - Design Authority Subordination: Educational Buildings Authority Model.

5.2.4 Classroom Space Assembly along Corridors

- Single Loading (Model No. 1) Fig. 2: Classrooms arranged on one side of the corridor could permit cross-ventilation but are often subjected to undesirable solar heat gain.
- Double Loading (Model No. 2) Fig. 2: Classrooms on both sides of the corridor, which generally restricts ventilation and promotes mechanical cooling.

Schools that are designed with several buildings constructed in one phase, using the same design and without regard to the site-specific sustainability needs, are inherently less efficient in

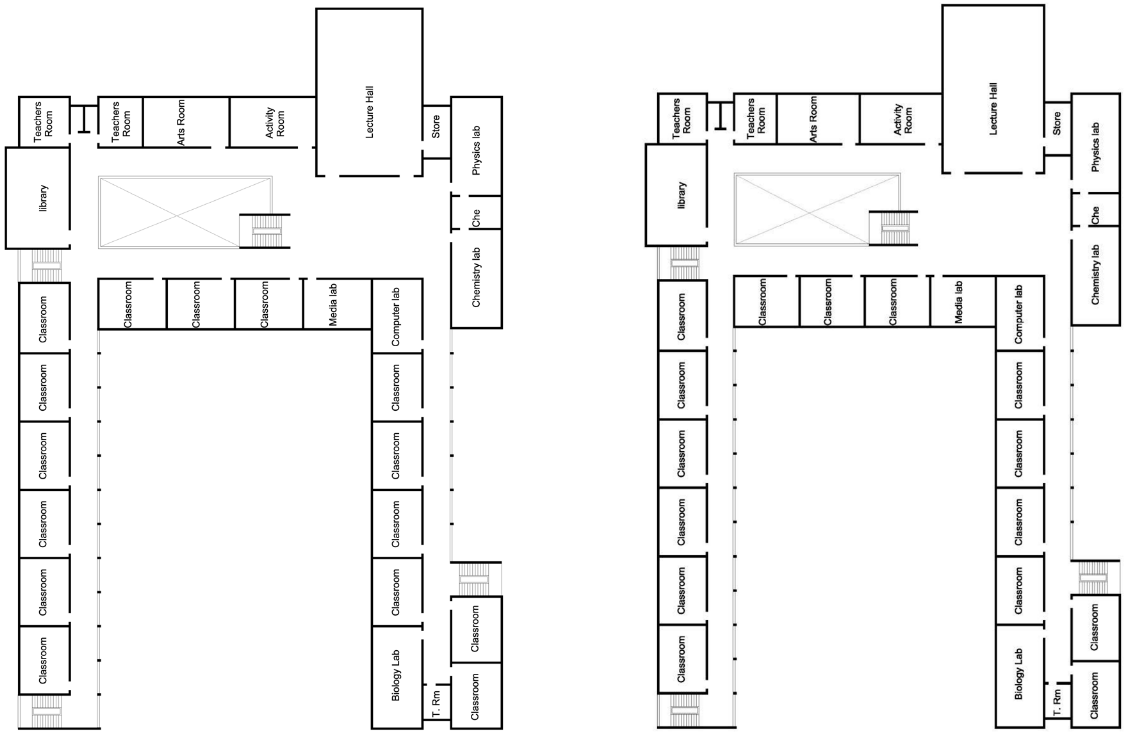


Figure (3). Classroom Space Assembly along Corridors. Single Loading (Model No. 1) & Double Loading (Model No. 2) (Author., 2023)

terms of energy consumption and comfort.

This methodology gives a structured way of understanding the integration of sustainability principles in school designs in New Cairo. By studying diverse cases across different levels, this research brings into focus important gaps and opportunities for improvement in passive cooling strategies, thereby assuring energy-efficient and comfortable educational settings. (Department A. D., 2021)

6. Comparative Analysis Framework for Enhancing School Building Performance

The study presents a structured framework for analyzing the performance of school buildings, especially classrooms, with a focus on energy efficiency, indoor environmental quality (IEQ), and alignment with sustainability objectives. The framework compares the criteria established by the General Authority for Educational Buildings (GAEB) in Egypt with internationally recognized standards such as those by ASHRAE, CHPS, and ANSI Table 2. The analysis highlights key factors of physical comfort, including ventilation, lighting, and thermal comfort, aiming to provide actionable insights for improving classroom spaces. Additionally, it examines the compliance of school buildings with sustainability goals, specifically in semi-desert climates, underscoring the importance of strategic building orientation, climate-responsive design, and measurable performance standards.

Table (2). Key International Standards Referenced in School Building Performance Evaluation

Abbreviation	Full Name	Scope in Context
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers	Provides quantitative standards for ventilation and thermal comfort
CHPS	Collaborative for High Performance Schools	Offers measurable criteria for daylight and glare control in schools
ANSI	American National Standards Institute	Accredits the development of recognized and consensus-based standards

6.1 Analysis Framework for School Building Performance

The analysis framework offers a comprehensive approach to evaluating school building performance, focusing on energy efficiency, IEQ, and sustainability objectives. The comparison between GAEB criteria and internationally recognized standards identifies areas of alignment and divergence. Key indoor environmental quality factors such as ventilation, lighting quality, acoustic performance, and thermal comfort are evaluated to ensure an optimal learning environment.

6.1.1 Air Quality

- GAEB Criteria: Ventilation requirements are tailored to local climate conditions, with an emphasis on natural ventilation as a cost-effective strategy, considering resource constraints. (GAEB, 2020).
- International Standards: According to ASHRAE Standard 62.1:
  - A range of 6-12 Air changes per hour (ACH) is required per occupant (ASHRAE, 2019).
  - A minimum of 0.36 m/s indoor air velocity (Kwok, 1998).
- Comparison: GAEB prioritizes natural ventilation, which is economically feasible but lacks the quantifiable metrics provided by ASHRAE for more precise air quality assessment. This gap presents opportunities for incorporating measurable ventilation standards into GAEB guidelines.

6.1.2 Lighting Quality

GAEB Criteria: Emphasis is placed on site planning that ensures natural daylight access while minimizing glare through optimal building orientation and shading devices (GAEB, 2020).

International Standards: The Collaborative for High Performance Schools (CHPS, 2020) uses the Daylight Glare Index (DGI) as a standard for visual comfort:

Acceptable Range: DGI ≤ 22, indicating glare levels that are imperceptible or acceptable for classroom environments.

Comparison: While GAEB relies on passive design strategies to enhance daylight access, CHPS provides measurable benchmarks for glare and lighting efficiency, offering a structured approach to evaluating daylight quality.

6.1.3 Thermal Comfort

- GAEB Criteria: The guidelines advocate for climate-responsive design, recommending building orientation toward the north, with minimal deviation to the east or west, and solar breakers on facades facing other directions to reduce heat gain (GAEB, 2020).
- International Standards: ASHRAE Standard 55 outlines:
  - Temperature Control: Indoor temperatures should be maintained between 68–77°F (20–25°C). (ASHRAE, 2019)
  - Humidity Control: Relative humidity should be kept between 30–60% to prevent condensation and mold growth. (ASHRAE, 2019)
- Comparison: GAEB's focus on building orientation and shading aligns with ASHRAE's recommendations for thermal comfort. However, incorporating precise parameters such as temperature and humidity ranges could enhance the robustness of thermal performance standards.

6.2 Building Orientation

Building orientation is a fundamental determinant of a structure's energy performance and indoor environmental quality, particularly in semi-arid and desert climates such as that of New Cairo. Proper orientation can significantly reduce energy consumption by optimizing natural lighting, enhancing cross-ventilation, and mitigating excessive heat gain. (Olgyay, 1963) emphasizes that strategic building orientation is crucial in passive design strategies, allowing structures to respond effectively to climatic conditions. In warm climates, optimal orientation minimizes solar heat gain while maximizing daylighting benefits. (Katz, 2006) argues that orienting buildings to control solar exposure can lead to substantial energy savings by reducing reliance on artificial cooling and lighting systems. Furthermore, (Katz, 2006) highlights that well-planned orientations enhance passive cooling strategies, such as cross-ventilation, which is particularly beneficial in educational environments where indoor air quality and thermal comfort directly influence student performance and well-being (Givoni, 1998).

The study examines school building orientations in New Cairo through architectural analysis and field assessments. The research evaluates key parameters, including solar exposure, shading efficiency, and ventilation potential, to determine their impact on energy efficiency and indoor comfort. By incorporating climate-responsive orientation strategies, educational buildings can improve sustainability and provide a more conducive learning environment.

6.3 Indoor Environmental Quality (IEQ) Components

Indoor Environmental Quality (IEQ) plays a vital role in shaping the comfort, health, and productivity of building occupants, particularly in educational environments. Key aspects of IEQ, including lighting, air quality, and thermal comfort, directly influence learning conditions. Studies indicate that well-regulated IEQ enhances cognitive performance, reduces absenteeism, and fosters a more conducive educational atmosphere (Chatzidiakou, 2012).

To support evidence-based design, it is essential to institutionalize the use of environmental simulation tools within the architectural design process. Emphasis should be placed on simple, widely accessible platforms that early-stage designers and non-specialist practitioners can effectively utilize. The goal is not to achieve highly precise climate predictions, but rather to establish acceptable performance margins and understand their implications for building behavior across varied climatic conditions. In this context, advanced computational tools such as Autodesk Ecotect Analysis offer valuable analytical capabilities. While primarily used for daylighting evaluation, Ecotect also facilitates shadow range analyses, which inform the strategic placement of design elements such as shading devices, fenestrations, and outdoor spaces. These insights contribute to regulating solar exposure, minimizing heat gain and glare, and enhancing thermal comfort, all of which support greater energy efficiency in building performance (Tzempelikos, 2007).

6.3.1 Air Quality Analysis

Improving air circulation and reducing indoor pollutant concentrations enhances indoor air quality, which is particularly crucial in educational environments where air freshness directly impacts occupant health, cognitive function, and overall learning outcomes (Yin, 2014). The combined application of daylighting, shading, and airflow analyses supports data-driven design decisions, promoting healthier, more comfortable, and environmentally sustainable spaces.

Air Ventilation Efficiency Analysis:

The analysis of the three architectural models according to the results of Table 3 revealed notable variations in natural ventilation performance, assessed through air velocity and Air Changes per Hour (ACH). According to (ASHRAE, 2019) effective ventilation in classroom environments should range between 6 and 12 ACH per occupant, while (Kwok, 1998) suggests a minimum indoor air velocity of 0.36 m/s to support thermal comfort through passive means.

ACH can be calculated using the following formulas:

Air velocity inside the classroom analysis:

$$\frac{\text{Air velocity outside (m/s) X total window area (m}^2\text{)}}{\text{cross−section perpendicular to the airflow path (m}^2\text{)}} \text{ (FishXing, 2023) (Stax, 2023)}$$

ACH analysis:

$$\frac{\text{Air velocity inside the classroom (m/s) X 3600}}{\text{Volume of classroom(m}^3\text{)}} \text{ (ASHRAE., 2021)}$$

Model B demonstrated the most favorable results, achieving an air velocity of 0.38 m/s and an ACH of 11.4, both of which meet or exceed international benchmarks. This model, characterized by an inner courtyard orientation toward the north and northwest, aligns well with prevailing wind patterns in New Cairo, thereby enhancing passive airflow and cross-ventilation efficiency.

$$\text{Air velocity inside the classroom} = \frac{1.6\ X\ 3.6}{15} = 0.38 m/s$$

$$\text{ACH} = \frac{0.38\ X\ 3600}{120} = 11.4$$

In contrast, Model A recorded an air velocity of 0.28 m/s and an ACH of 8.4. While the air change rate meets ASHRAE’s minimum threshold, the substandard air velocity suggests a lower capacity for effective thermal comfort through natural ventilation alone. The westward orientation of the courtyard likely contributed to the formation of turbulent vortices and heat accumulation, thereby compromising performance.

$$\text{Air velocity inside the classroom} = \frac{1.17\ X\ 3.6}{15} = 0.28 m/s$$

$$\text{ACH} = \frac{0.28\ X\ 3600}{120} = 8.4$$

Model C performed least effectively, with an air velocity of 0.17 m/s and an ACH of 5.1. Both metrics fall below the recommended standards, indicating inadequate ventilation and thermal comfort. Despite the presence of strong wind currents between the buildings, the design resulted in uneven airflow distribution, particularly affecting classrooms on the eastern side.

$$\text{Air velocity inside the classroom} = \frac{0.7\ X\ 3.6}{15} = 0.17 m/s$$

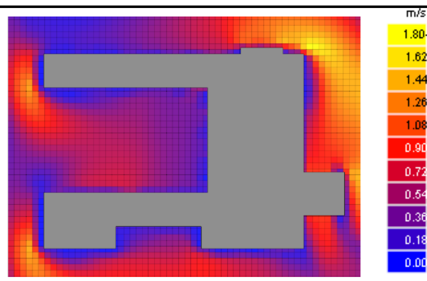
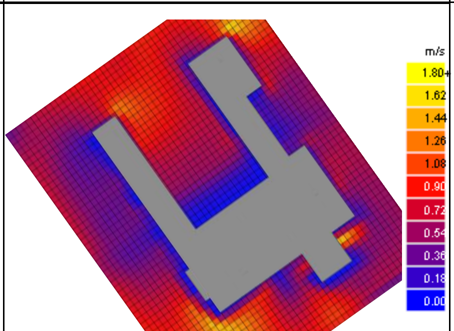
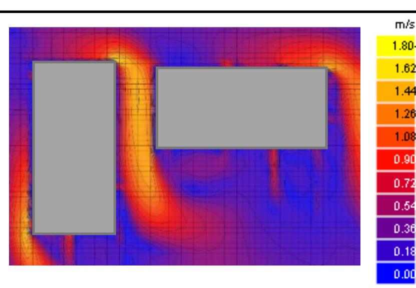
$$\text{ACH} = \frac{0.17\ X\ 3600}{120} = 5.1$$

These findings underscore the importance of building orientation and spatial configuration in achieving compliance with international ventilation standards. Model B, through strategic alignment with climatic conditions, demonstrates that passive design can effectively meet both air quality and comfort requirements.

6.3.2 Solar Radiation Exposure

Solar radiation exposure plays a crucial role in thermal comfort and energy efficiency. In semi-desert climates, excessive solar radiation can lead to higher cooling demands, thermal discomfort, and glare-related disruptions (Alwetaishi, 2019). Solar radiation exposure analysis revealed that north-facing classrooms in Model A experienced the lowest exposure, minimizing heat gain and glare. In contrast, classrooms facing west, east, and south in Models B and C experienced higher radiation, emphasizing the need for shading devices to optimize daylight while reducing heat gain.

Table (3). Air Ventilation Analysis

	Air Flow Rate	Data Analysis
(A) Martyr Ahmed Ibrahim Al-Jamal Language School		The yellow-colored regions signify an increase in wind speed around the northeastern and southwestern corners of the building, where wind velocity exceeds 2.5 m/s. This acceleration results in the formation of irregular air vortices, which extend into the courtyard airspace and adversely impact portions of the windows on the northern façade. The increased wind speed contributes to elevated heat loss from these facades, thereby affecting the building's thermal performance.
(B) Fatima Annan Girls Preparatory School		Air vortices develop at a wind speed of 3 m/s along the north and south facades, leading to rapid heat loss in classrooms oriented towards the northeastern facade. Conversely, classrooms situated along the southwestern wings of the building do not receive the favorable north and northwest winds but are instead exposed predominantly to hot southern winds. The interior courtyard benefits from effective ventilation without the formation of disruptive air vortices. Meanwhile, classrooms facing the northwestern side of the building experience optimal natural ventilation rates. Moreover, the occurrence of air vortices around the building is significantly reduced compared to the results observed in the corresponding experiment for Model A.
(C) Salah El-Din Experimental Languages		High wind speeds are observed between the first and second buildings, with velocities exceeding 5 m/s. The classrooms oriented towards the north and west benefit from enhanced natural ventilation, primarily due to the prevailing northerly and northwesterly winds. However, the close proximity and height of the buildings contribute to the formation of strong air vortices in the intermediate spaces. In contrast, the southern classrooms experience significantly reduced ventilation rates, with wind speeds falling below 0.5 m/s.

Source: (Author, 2024)

Solar Radiation Exposure Analysis:

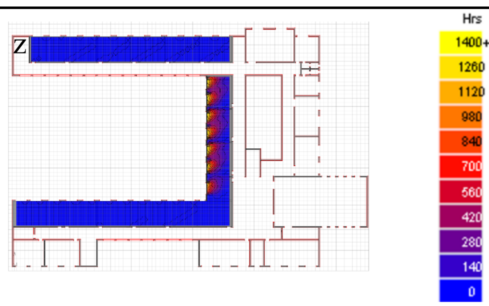
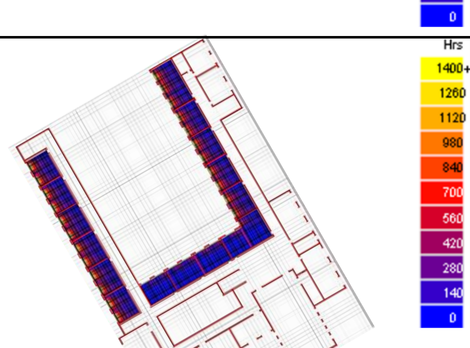
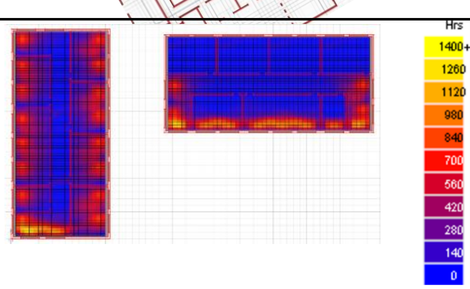
In a comparative analysis of three experimental models, Model A exhibited the lowest duration of direct solar exposure in north-facing classrooms, effectively minimizing heat gain and glare. Conversely, west-, east-, and south-facing classrooms in Models B and C recorded significantly higher solar radiation exposure, with values ranging from 35% to 55% of the total floor area during peak sunlight hours between 12:00 PM and 4:00 PM throughout the academic year. Such prolonged exposure necessitates the implementation of sun breakers, shading devices around

window openings to optimize daylight penetration while mitigating excessive heat gain and visual discomfort. Proper shading strategies contribute to improving indoor environmental quality (IEQ), enhancing the overall thermal performance of classrooms in semi-desert climates. Table 4

6.3.3 Thermal Comfort Analysis

Thermal comfort is a primary concern in classroom design, particularly in semi-desert climates where extreme temperature fluctuations significantly impact indoor conditions. This study employs Ecotect software to analyze classroom orientations across all four cardinal directions, assessing their thermal loads and contributions to indoor comfort. Such analyses offer valuable insights for optimizing building design and enhancing thermal performance. To promote broader application, priority should be given to simple, widely accessible simulation tools

Table (4). Solar Radiation Exposure Analysis

	Total Sunlight Hours	Data Analysis
(A) Martyr Ahmed Ibrahim Al-Jamal Language School		North-facing classrooms exhibited the lowest levels of direct solar radiation exposure, with annual exposure rates falling below 140 hours. In contrast, west-facing classrooms recorded significantly higher exposure levels, exceeding 1,400 hours of direct solar radiation annually. This increased exposure is attributed to the extended afternoon sun exposure, which results in greater thermal loads. Additionally, the percentage of the classroom floor area directly exposed to solar radiation in west-facing classrooms reached 35%, further exacerbating heat gain.
(B) Fatima Annan Girls Preparatory School		. Southwest-facing classrooms recorded the highest levels of direct solar radiation exposure, reaching approximately 1,400 hours annually. This prolonged exposure contributes to increased thermal loads and potential overheating concerns. Conversely, northwest-facing classrooms experienced the lowest levels of solar radiation exposure, with recorded values approaching 140 hours throughout the academic year. Additionally, the proportion of the floor area directly exposed to solar radiation in southwest-facing classrooms was found to be 55% of the total classroom area, further exacerbating indoor temperature variations.
(C) Salah El-Din Languages School		The classrooms facing east and west achieved the highest rates of direct solar radiation exposure, with exposure rates exceeding 1400 hours. In contrast, the south-facing classrooms recorded rates of approximately 600 hours. The proportion of the floor area exposed to direct solar radiation in the east and west-facing classrooms reaches 55% of the classroom's total area.

Source: (Author, 2024)

Table (5). average ambient temperatures in Cairo during school hours

zWeather by Month // Cairo Weather Averages												
`		School Study Days				Vacation			School Study Days			
	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	13.4 °C (56.1) °F	14.8 °C (58.7) °F	17.9 °C (64.2) °F	21.4 °C (70.5) °F	25.3 °C (77.6) °F	27.9 °C (82.3) °F	29.1 °C (84.4) °F	29.2 °C (84.6) °F	27.4 °C (81.2) °F	24 °C (75.2) °F	19.4 °C (66.9) °F	15.1 °C (59.2) °F
Min. Temperature °C (°F)	7.8 °C (46.1) °F	8.7 °C (47.6) °F	10.8 °C (51.5) °F	13.6 °C (56.4) °F	17.1 °C (62.7) °F	19.7 °C (67.5) °F	21.3 °C (70.3) °F	21.8 °C (71.3) °F	20.3 °C (68.6) °F	17.7 °C (63.9) °F	13.7 °C (56.7) °F	9.8 °C (49.7) °F
Max. Temperature °C (°F)	19.2 °C (66.5) °F	21.1 °C (70) °F	24.9 °C (76.8) °F	29 °C (84.2) °F	33.1 °C (91.6) °F	35.8 °C (96.4) °F	36.8 °C (98.2) °F	36.6 °C (97.8) °F	34.5 °C (94) °F	30.4 °C (86.7) °F	25.5 °C (77.9) °F	20.8 °C (69.5) °F

Source: (Author, 2024)

that can be used effectively by non-specialist practitioners and early-stage designers. The aim is not to produce highly detailed predictions, but rather to identify acceptable performance margins and evaluate their impact on building behavior in diverse climatic settings supporting informed, climate-responsive design decisions from the early stages of the architectural process. The academic calendar in Cairo is typically structured into two main semesters: the first semester spans from mid-September to mid-January, while the second semester extends from the beginning of February to the end of May. The standard school day runs from 7:00 AM until 4:00 PM, aligning educational activities with the prevailing climatic conditions of the region.

During these periods, average ambient temperatures in Cairo during school hours generally range between 16°C and 30°C, depending on the season (Data, 2024).This range frequently coincides with the thermal comfort zone for educational settings, which is widely recognized to lie between 20°C and 26°C (ASHRAE, 2019). These conditions, particularly prevalent during the autumn and spring months, create a naturally comfortable environment for students and staff, often negating the need for mechanical air conditioning systems. Table 5

This climatic moderation contrasts sharply with colder regions, such as the United States, where average winter temperatures (December to February) frequently fall below freezing in many states, with national averages ranging from -1°C to 4°C for daily highs and -10°C to -3°C for daily lows, particularly in the northern and central regions (NOAA, 2024).

In these colder climates, mechanical heating systems are essential to maintain safe and comfortable indoor temperatures, significantly increasing energy consumption and operational costs in educational institutions. In contrast, Cairo's mild winter and temperate transitional seasons support a more sustainable building performance model by reducing dependency on mechanical heating, ventilation, and air conditioning (HVAC) systems, thereby contributing to energy efficiency and economic savings. Table. 5

In the study, the orientation considered is on the coldest day of the year, shown in Fig. 4. And on the hottest day of the year, as depicted in Fig. 5. The consideration of both of these two extreme conditions may be used comprehensively for assessing thermal performance because the variation of temperature on those days might seriously influence indoor conditions.

According to the simulated results, there was a marginal difference in the internal temperature within classrooms oriented in different directions. This could indicate that insulation, ventilation, and other material properties play a huge role in indoor temperature regulation. Though there is little variation of temperatures between orientations, some orientations performed better under certain conditions.

These results indicate that the north-facing classrooms had the least heat absorbed, which agrees with earlier research in the field of solar exposure for semi-arid regions (Bekkouche, 2013) .This can be explained by the fact that the north facades receive minimal direct solar radiation during peak afternoon hours. The classrooms facing south experienced higher thermal loads, particularly on the hottest day of the year, necessitating the application of strategies to balance the heat gain.

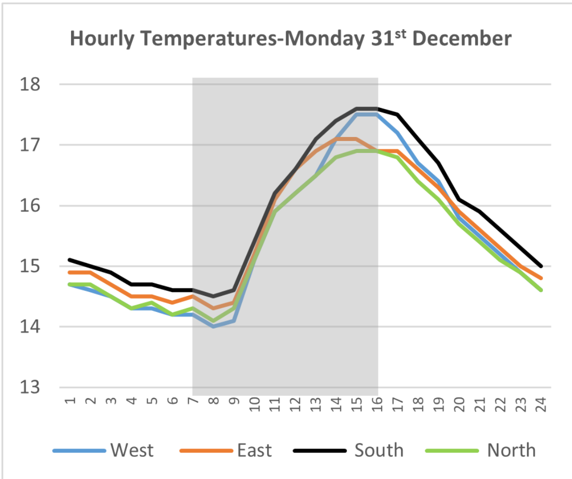


Figure (4). Hourly Temperatures Of the coldest day of the year. (Author, 2024)

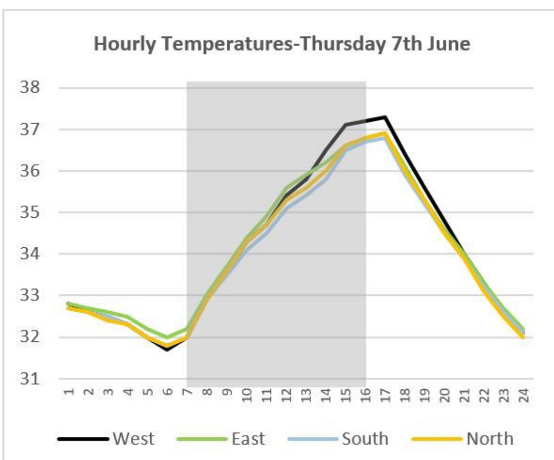


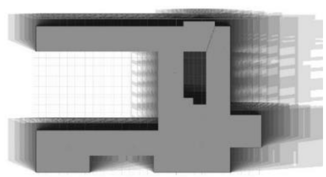
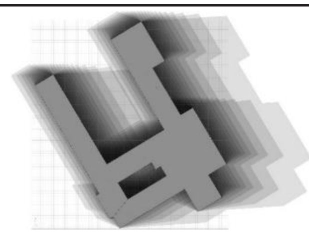
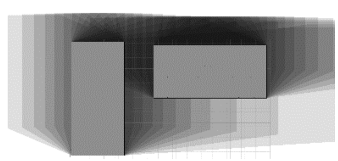
Figure (5). Hourly Temperatures Of the hottest day of the year. (Author, 2024)

Thermal Comfort Analysis:

- Model A Table 6
  - Orientation Adjustment: The orientation of Model A was not as effective in improving the shading of the exposed areas inside the courtyard as that of Model B.
  - Shading Efficiency: The percentage of shading was around 20% lower compared to Model B.
  - Thermal Performance: Lessened shading then again generated a greater increase in thermal loads from the freer areas inside the courtyard. These have consequently brought about a higher ambient temperature and greater dependence on cooling and shading interventions.
- Model B Table 6
  - Optimization of Orientation: In Model B, orientation change has been used to result in more and extended shade within the inner court area.
  - Shading Efficiency: From all the Models, Model B yielded the best shading performance, which ranges up to 55% of the daylight period.
  - Thermal Performance: The effective increase in shading reduced much of the thermal load transmission in the courtyard and therefore cools the students and staff. This reduction in heat gain reduces the dependency on mechanical cooling systems; hence, energy is conserved for better sustainability.
- Separated Buildings in Model C Table 6
  - Building Configuration: The arrangement of buildings in this Model failed to allow adequate shading of open areas.
  - Shading Efficiency: The potential for shading around these buildings was the least among all arrangements, with their shaded areas failing to be integrated functionally in the built-up environment.
  - Thermal Performance and Use: In the case of exposed areas, whose surrounding courtyards did not exist, they are hotter than others and thus highly dependent on cooling. Although the authors identified a few shaded open spaces, they were not utilized for student activities or congregation, thereby underutilizing the potential benefits these spaces could offer for thermal comfort.

The study explores the impact of strategic orientation and spatial planning on shading performance, emphasizing their role in enhancing thermal comfort and functional usability in educational environments. Effective shading solutions are particularly crucial in regions with high solar exposure, as they contribute to energy efficiency by reducing cooling demands and

Table (6). Thermal Comfort Analysis

	Study of Outer Shadow Range	Data Analysis
(A) Martyr Ahmed Ibrahim Al-Jamal Language School		The shading percentage of the inner courtyard floor in the school, as determined by the building's orientation and height, reaches approximately 30% between 9:00 AM and 4:00 PM throughout the academic year. This results in an average shading duration of two to three hours per day within the courtyard. Consequently, the exposed surfaces of the school courtyard experience prolonged periods of direct solar radiation, leading to increased heat accumulation and higher thermal loads.
(B) Fatima Annan Girls Preparatory School		Throughout the academic year, from 9:00 AM to 4:00 PM, the shading percentage of the school's inner courtyard increases to 55% as a result of adjustments in the building's orientation. This modification extends the shaded duration within the courtyard to approximately five to six hours per day, representing a significant improvement over the conditions observed in Building "A.".
(C) Salah El-Din Experimental Languages School		The highest shading is observed in the spaces between the two buildings and the ground area between the northern facades and the school fence. However, these shaded areas are not effectively exploited as functional spaces for students to gather within the unshaded courtyard. Thus, while these areas provide significant shade throughout the day, their potential benefits remain underutilized between the buildings and the fences.

Source: (Author, 2024)

improving indoor conditions. An evaluation of sun breaker applications in Model "C" revealed significant inefficiencies due to improper alignment with solar movement. Vertical sun breakers installed on the southern façade were ineffective because they failed to account for the sun's high-angle trajectory. Similarly, horizontal sun breakers on the western façade failed to provide adequate shading, as the lower sun altitude in the afternoon required an alternative shading approach. Fig. 6

Figure (6). Sun breakers on the western and southern facade. (Author., 2023)

A more rigorous environmental assessment is necessary to optimize shading configurations for both façades. Properly designed shading elements should align with seasonal solar variations, mitigating heat gain while ensuring sufficient daylight access. This approach minimizes reliance on artificial lighting and prevents visual glare, ultimately fostering a thermally comfortable and energy-efficient educational setting (Zomorodian, 2016).

7. Enhancing Building Performance through Passive Design Strategies in Semi-Desert Climates

In semi-desert climates like New Cairo City, extreme temperature fluctuations and high solar radiation necessitate passive design strategies to enhance thermal comfort, reduce energy consumption, and improve indoor environmental quality. However, many school buildings in the region lack climate-responsive architectural solutions, highlighting the need for environmentally sustainable design integration. The study focuses on thermal performance and the role of building orientation in temperature regulation. Additionally, it analyzes shading techniques such as overhangs and vertical fins for heat reduction. The study further explores the impact of thermal mass in stabilizing indoor climates and emphasizes the importance of daylight optimization and natural ventilation in enhancing air quality and minimizing overheating.

- Shading Strategies for Heat Reduction: Effective shading solutions reduce heat gain. Horizontal slats, awnings, and overhangs are ideal for south-facing facades, while vertical fins and adjustable blinds are more effective for east- and west-facing facades. Additionally, green shading, such as tree planting and vegetative facades, can create microclimates that naturally cool the environment (Alwetaishi, 2019).
- Thermal Performance: Building orientation plays a crucial role in regulating indoor temperatures. North-facing buildings minimize direct sunlight, reducing heat gain and glare (Santamouris M. , 2016).
- Thermal Insulation and Energy Efficiency: Proper insulation is essential for stabilizing indoor temperatures in semi-desert environments. Materials like fiberglass, foam, and reflective barriers minimize heat transfer. Double-glazed windows further enhance thermal efficiency by regulating solar penetration and maintaining daylight levels, ultimately lowering energy consumption (Taleghani, 2014).
- Thermal Mass and Indoor Temperature Regulation: Thermal mass, provided by materials such as concrete and brick, helps stabilize indoor temperatures by absorbing heat during the day and releasing it at night. This strategy is particularly effective in climates with high diurnal temperature variation, ensuring balanced indoor conditions without excessive reliance on mechanical heating or cooling (Santamouris M. , 2016).
- Enhancing Natural Lighting: Daylight Optimization: Proper building orientation maximizes daylight penetration while mitigating overheating risks. North-facing windows provide consistent daylight with minimal glare, whereas south-facing windows require shading solutions to control excessive heat gain while optimizing winter solar exposure.
- Ventilation Strategies: Cross-ventilation is critical for maintaining indoor air quality and thermal comfort. Strategically positioning windows along prevailing wind directions facilitates natural airflow, reducing the need for mechanical cooling. Additionally, night ventilation techniques help expel accumulated heat, ensuring a cooler indoor environment during daytime hours (Santamouris M. G., 2006).

8. Conclusion

This study examined to what extent Egyptian school building designs particularly in the semi-desert climate of New Cairo are meeting environmental sustainability criteria. The findings revealed significant discrepancies between prevailing design practice and internationally accepted standards, namely those of the Collaborative for High Performance Schools (CHPS). Most prominent shortfalls were in passive design application, energy efficiency, building orientation, and indoor environmental quality. Though CHPS prescribes precise thresholds for parameters such as thermal regulation, ventilation rates, and lighting levels, adherence to such standards using mechanical systems remains economically and practically unviable in Egypt. However, the relatively mild climate of the area presents a compelling incentive to explore passive design solutions that optimize orientation and natural ventilation to improve thermal comfort and reduce mechanical dependence.

Despite these advantages, current national standards developed by the General Authority for Educational Buildings continue to emphasize minimum capital cost and functionality with limited attention to long-term environmental performance and occupant comfort. The research highlights the potential of environmentally responsive school design to reduce operational costs and environmental impact while simultaneously enhancing learning outcomes and user comfort.

The sample was chosen purposively to provide examples of non-compliance with sustainability parameters, namely, where spatial capacity existed but was not being used. While not wholly representative of Egypt's overall educational infrastructure, the study foregrounded temperature, ventilation, and lighting as the most significant parameters of indoor environmental quality in semi-arid climates. Other determinants, including psychosocial and behavioral factors, were acknowledged but were considered beyond the scope of the research. Moreover, the geographical uniqueness of New Cairo limits the generalizability of the findings. Future research should expand the sample size, broaden the scope of sustainability and well-being indicators, and examine occupant behavior and long-term performance to inform more sustainable and resilient school design strategies in various contexts.

The study proposes a comprehensive revision of national school building standards to integrate environmental sustainability as a foundational design criterion. Key recommendations include:

- Use of Environmental Simulation Tools in Design Decision-Making: To support evidence-based design, it is essential to institutionalize the use of environmental simulation tools within the architectural design process. Priority should be given to simple and widely accessible software platforms that non-specialist practitioners and early-stage designers can effectively use. The objective is not to generate highly precise climate predictions, but rather to establish acceptable performance margins and assess their implications for building behavior across diverse climatic contexts. This approach enables performance-based design strategies and promotes the integration of principles for responding to diverse climates.
- Policy Integration: Embed passive design strategies and sustainability principles within GAEB guidelines, drawing on international models like CHPS and ASHRAE.
- Design Optimization: Prioritize site-responsive design, including orientation optimization, cross-ventilation, and thermal mass utilization to minimize energy use.
- Shading and Daylighting: Implement fixed and movable shading devices to reduce solar heat gain and enhance natural lighting, thereby improving indoor thermal and visual comfort.
- Improving the learning environment: Designing flexible, thermally comfortable spaces with good ventilation and natural lighting suitable for supporting diverse teaching methods and student needs.
- Together, these strategies aim to create environmentally sustainable, resilient, and educationally appropriate learning environments. By developing environmentally sustainable school designs, Egypt can align educational buildings with physical comfort goals while simultaneously promoting health, well-being, and academic achievement.

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نحـو فراغـات تعليميـة مسـتدامة بيئيـاً في المناطـق شـبه الصحراويـة: رؤى مـن مـدارس مدينـة القاهـرة الجديـدة

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قدم للنشر في ٢٠/ ٨/ ١٤٤٦ هـ؛ وقبل للنشر في ١٧/ ١١/ ١٤٤٦ هـ.

ملخص البحث. تتناول الدراسة مدى توافق تصميمات المباني المدرسية في مصر، ولا سيما في المناخ شبه الصحراوي لمنطقة القاهرة الجديدة، مع معايير الاستدامة البيئية. فمع التسارع الكبير في النمو السكاني وازدياد الطلب على المباني التعليمية، لا تزال العديد من المدارس تُشيَّد مع التركيز على الكفاءة الاقتصادية والوظائف الأساسية، مع إغفال اعتبارات جوهرية تتعلق بالاستدامة، مثل: كفاءة استهلاك الطاقة، وتوجيه المبنى، وجودة البيئة الداخلية. اعتمدت الدراسة منهجية بحثية متعددة الأدوات؛ إذ شملت المرحلة التحليلية الأولى مراجعة للمعايير المحلية الصادرة عن الهيئة العامة للأبنية التعليمية، إلى جانب معايير «المدارس عالية الأداء» (CHPS)، مع التركيز على عوامل الراحة الفيزيائية الأساسية: درجة الحرارة، والتهوية، والإضاءة. وقد تم الأخذ ببعض العوامل الإضافية الأخرى، إلا أنه تم اعتبارها أقل تأثيراً، وأكثر ملاءمة للدراسات المتخصصة. أما المرحلة التجريبية، فقد اشتملت على توثيق ميداني لنماذج مختارة من المدارس، والتي وإن لم تكن تمثيلية بشكل كامل، إلا أنها تُظهر حالات تم فيها إغفال اعتبارات الاستدامة البيئية، رغم توافر المساحات اللازمة لذلك. وفي المرحلة المقارنة، تم استخدام أدوات برمجية لتقييم الأداء البيئي، تلتها مرحلة توصيفية قدمت استراتيجيات تصميم سلبي موجهة لمعالجة أوجه القصور المحددة. أظهرت النتائج وجود فجوات كبيرة بين الممارسات الحالية ومعايير الاستدامة البيئية، ولا سيما في مجالات كفاءة الطاقة، وراحة المستخدمين، وإدارة الموارد. وتؤكد الدراسة على الحاجة الملحة لإدماج الاستدامة البيئية في السياسات الوطنية لتصميم المدارس، من خلال استخدام برمجيات محاكاة مناخية بسيطة يسهل التعامل معها؛ لما لها من دور في خفض تكاليف التشغيل، وتحسين راحة المستخدمين، وتعزيز جودة العملية التعليمية. وتقدم الدراسة رؤى أصيلة وموائمة للسياق المحلي، بالإضافة إلى توصيات عملية تدعم إنشاء بيئات تعليمية مرنة وفعالة في استخدام الطاقة وتتماشى مع متطلبات التعليم المعاصر في مصر.

الكلمات المفتاحية: الاستدامة البيئية، معايير بناء المدرسة، كفاءة الطاقة، جودة البيئة الداخلية، عوامل الراحة المادية.