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Energy retrofitting strategies for school buildings in hot arid climate

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Abstract: Sustainability has emerged as the dominant theme in the debate on architecture and building in the last decade. About 50% of the total global electric energy is consumed by buildings with their different functions. There is a close connection between energy and buildings, which, as they are designed and used today, contribute to serious environmental problems because of their excessive consumption of energy and other natural resources. Buildings' demands for heating, cooling, ventilation, and lighting cause severe depletion of invaluable environmental resources.

This research aims at revealing the potential energy savings resulting from applying energy retrofitting strategies to school buildings in hot arid climate. The study is applied on Cairo, Egypt, representing the hot arid climate. The case study building was selected to be an existing typical school building with an area of 12 000 m2

The suggested retrofitting strategies are upgrading the lighting systems to use LED lights, improving the building's air tightness and improving the R-value of the building envelope by using insulation for exterior walls and roof and substituting the existing window glazing. Those strategies were applied to the building for evaluating their potential for achieving energy savings. The conclusion of the applied study was that by combining the most effective strategies has resulted in annual energy consumption reduction by 30%.

Keywords: Schools Design, High-efficiency Schools, Environmental Performance, energy retrofitting

Research Problem and Questions:

The research is geared toward answering the following questions: (i) What are sustainable strategies for retrofitting existing buildings? (ii) How far can the thermal performance of existing buildings be improved through architectural renovation? and (iii) How far can outer shell enhancement contribute to existing buildings' thermal performance?

Methodological Approach:

The methodology is based on three different approaches: theoretical, analytical, and applied approach. First, the theoretical study leads to the identification of concepts and strategies to achieve sustainability through the retrofitting of existing buildings. This is followed by an analytical study of benchmark case studies of retrofitted existing buildings to evaluate the applied strategies in achieving sustainable educational buildings. Third, the concluded results are tested on one case study building at Public school in Cairo, Egypt. This is done through analysing the building's existing energy consumption, internal environment control system, its outer shell materials, and their thermal characteristics. Outer shell materials are manipulated as one of these factors affecting thermal performance to test their impact on reducing energy consumption. The most feasible retrofit approaches, both environmentally and economically, are defined to enhance the thermal performance of existing educational buildings. The study concludes with the recommended Building retrofit for school buildings in Egypt that would reduce the energy consumption and improve thermal performance as part of the building sustainability approach.

LITERATURE REVIEW

Multiple trials to calculate the energy savings resulting from applying retrofit strategies have been explored.

Retrofitting existing university campus buildings: This study was part of the efforts of turning the University of Applied Sciences Stuttgart (UAS) into a CO_2-neutral university and implementing key principles of sustainability. Air conditioning and lighting systems were examined and compared with other available alternatives. Following a detailed performance analysis, the best applicable options were identified, and the study concluded with the following lessons:

- Retrofitting measurements combined with continuous monitoring are essential to sustain high energy efficiency and comfort level.

- User awareness and automated systems help save energy.
- Using an effective evaporative cooling system could save up to 60% of required energy and GHG (Dilay, 2016).
- ***Improvement of the sustainability of existing school buildings, Italy:*** This project aimed to verify – in the field, and in actual buildings – the technical and economic feasibility of sustainable retrofitting of existing school buildings to improve their energy efficiency and sustainability to match the international protocols. An economic evaluation was conducted to consider the cost of the main items for retrofitting. Cost items were considered in the economic evaluation compromises; building envelope retrofit, heating systems upgrade, ventilation systems, solar PV, water efficiency cost. All costs were then apportioned according to the gross floor area and expressed in (€/m2).
- ***Study lessons:*** It is important to have a strategic vision regarding having comfortable educational buildings with high indoor air quality that will contribute to improving the learning environment. The economic aspect will always have a greater impact when operating within the public market. The real estate market can ascribe greater value to more sustainable building. The availability of a standard like LEED®, which has an international matrix, is a good thing, taking into account the consistency between the rules contained in LEED® and Local Building Codes (Giuliano et al., 2013).

Introduction

Since 1952, the real boom in the establishment of schools in Egypt has begun and the pace of their establishment has accelerated to accommodate the increase in the number of students. This has been accompanied by the emergence of many governmental institutions that were mandated to issue the design and construction standards for schools from 1952 until 1987. The General Authority for Educational Buildings was established in 1988 to be the only body entrusted with the issuance and development of the design and construction standards for schools of various kinds, as well as the development, maintenance and restoration of schools. The school design standards were issued during the period from 1990 to 1999. Issuing or developing standards of design have stopped despite the emergence of many crises and challenges in Egypt and the emergence of many approaches to the global principles for the design of modern schools in the world.

During the current academic year, there are 45279 public education schools operating, with 419961 classrooms, and 18,608,730 male and female students, 738385 private schools operating with 62755 classrooms, 2032679 students, and 2397 experimental schools operating with 19135 classrooms and 749275 students. [Statistical Overview – Egypt,2018].

In the last decade, Egypt has shown interest in designing school buildings according to the concepts of sustainability and high efficiency of energy consumption, but these were individual attempts by the private sector. These concepts were not generalized to governmental schools, which represent the largest percentage of the schools in Egypt. There is a shortage, however, in applying environmental design standards for these governmental schools. Thus, such schools could not provide thermal, acoustic and visual comfort in their interior spaces. Therefore, the paper aims to develop a proposal for the principles and standards of design and evaluation of high- efficient schools in Cairo and to raise the efficiency of environmental performance of one of the typical governmental schools as a model.

The paper aims to develop a proposal for the design criteria of high-efficiency basic education school buildings in Cairo. In addition to redesigning the external envelope of a public-school building to study the energy consumption in the current situation and after modification and comparing them to measure the amount of rationalization in consumption and to improve the efficiency of the environmental performance of the building through using simulation programs.

High-efficiency schools

Definition of High-efficiency school buildings

High-efficiency school buildings are buildings that improve the educational and health environment for students and teachers at the same time in the study spaces, while reducing the consumption of energy and resources in all their forms and reduce the expenses spent on the school building (i.e., Maintenance & operation) [Colker, R.,2001].

Design objectives for high-efficiency schools

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Table (1) shows the most important design goals for high-efficiency schools. For example, constructing high-efficiency buildings, in terms of design, providing economic efficiency in aspects of operation and maintenance of the school building and applying the principles of sustainability [Council, S.B.I,2001].

Table 1. shows the main objectives of the design of the high-efficiency school building.

Constructing high-efficiency buildings in terms of design	•Providing high levels of acoustic, thermal, and visual comfort in study spaces. • Maximizing the natural lighting factor in school spaces. • Increasing air efficiency in study spaces in the school building and saving the environment in general.
Providing economic efficiency in the aspects of operation and maintenance of the school building	• Analysis of energy consumption in order to increase the efficiency of consumption to the highest levels. • Analysis of the cost of the building life cycle in order to reduce the total costs paid by the owner, while maintaining the design objectives set by the decision makers.
Applying the principles of sustainability to the school building	• Activating policies for energy conservation and application of renewable energy policies to the school building • Increasing the efficiency of mechanical systems and artificial lighting systems within the school building. • Using environmentally friendly materials and products. • Managing and reducing the consumption of water resources in the school building. • Management of Energy and operational systems to ensure the highest levels of operational efficiency of the building.

Standards of planning and design of high-efficiency basic education schools in Cairo

The standards of design of high-efficiency basic education schools are divided into the following 16 standards: Designing and planning the masterplan, efficiency of acoustic comfort, thermal comfort, Visual comfort, natural and artificial lighting efficiency, efficiency of the indoor air quality of the spaces, efficiency of the external envelope design, efficiency of ventilation of the building (natural ventilation - HVAC systems), sustainability for Materials and Operational Systems, energy consumption efficiency analysis, efficient use of materials and products in the building, efficiency of the plan of (implementation - testing - maintenance) of the school building, building life cycle cost analysis, water Use Efficiency (WBDG, 2013; Myrsalieva, N., 2012; Amann, J.et al, 2003; NIST ,2001; Seep, B. et al, 2000; Kincaid, J.et al ,1995; Egan, M. D. ,1983; Evants, M., 1980; Markus, T. et al., 1980)

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Energy Sustainability within the School Building

Studying and determination of the requirements for applying renewable energy technologies in the school building, whether solar or wind energy, in schools in Cairo Region - Monitoring the impact of this application on the rates of reducing energy consumption and the building life cycle cost, as well as the educational and cultural aspects for students and society in general [Lackney, J. A.,1999].

An analytical study of the research case to redesign the external envelope of the building of a typical governmental school in Cairo

This model has been chosen because it is a typical regular model applied to all regions and geographic boundaries of the Cairo region without taking into consideration the conditions and determinants of the site. To evaluate the school design and operational efficiency in the post-occupancy phase, a method of analysis and evaluation was applied, which is divided into two parts: Part I: Documentation and monitoring of data stage, Part II: modification of the building external envelope to reduce energy consumption and improve the efficiency of thermal performance inside the building through the use of design builder program stage [Shaghayegh,2013].

Criteria for selecting a case study

The Tabari Al Hijaz School- Heliopolis – Cairo has been chosen as it is one of the typical governmental schools established in more than location within the boundaries of Cairo. The field study and personal interview with students and teachers indicated that the architect did not achieve thermal, visual and acoustic comforts within the internal spaces. Due to the economic conditions of Egypt, all governmental schools do not use mechanical means for air conditioning to achieve comfort within the internal spaces of the classrooms.

Figure 1. The general location of Tabari Al Hegaz School - Heliopolis – Cairo.

Locating a case study site

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Cairo was chosen to conduct the field study in the Arab Republic of Egypt because it is the capital of Egypt, with a population of 9.1 million, 10.6% of the population of Egypt, which is growing very rapidly. It also contains the largest number of educational buildings in Egypt.
The building is located at the following coordinates, 30° East 30° North. The building lies in a vital location in Al Hijaz Square – Heliopolis. Al Hijaz Square is one of the most important areas in Heliopolis district and also the most important in Cairo. Moreover, the school is located on the junction of three streets from the north, west and south.

Climatic analysis of Cairo

Cairo is the capital of Egypt; it lies at a longitude of 31° East and latitude of 30° North. It is classified as a hot arid region. According to the Egyptian Organization for Energy Conservation and Planning (EOECP), Cairo is classified as a Semi Desert zone within the seven climate classification zones of Egypt. The Semi desert zone has an average annual temperature of 22.2C°, with a maximum monthly average temperature of 34.2 C° in August and minimum monthly average temperature of 10.2 C° in January. Extreme temperature in Cairo may reach a maximum of 44 C° and an extreme minimum of 3 C°. As for diurnal ranges, it has a monthly mean difference of 12- 17 C° with a mean of 14 C° in summer and 13 C° in winter.

The monthly average relative humidity is 57.75%, with a maximum monthly average of 68% in January and a minimum monthly average of 44% in May.

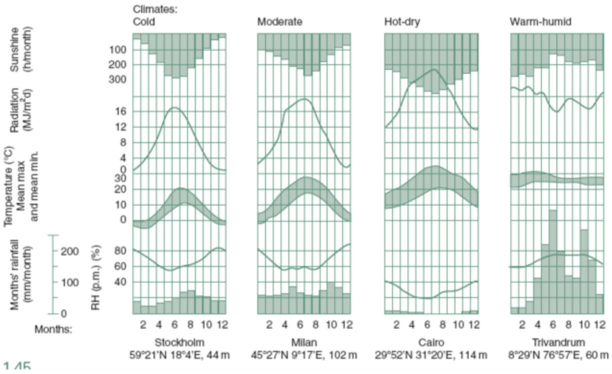

Figure 2. Composite (simplified) climate graphs for the four basic climate types.

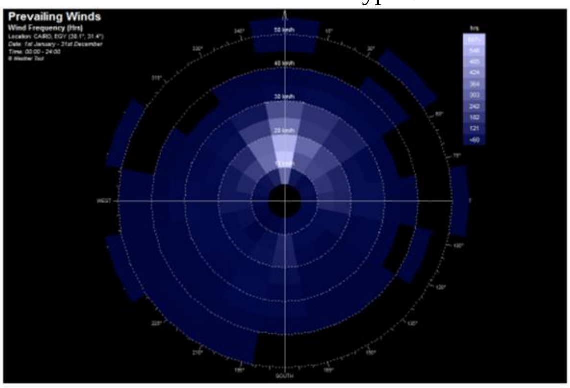

Figure 3. Cairo wind rose.
Source: Researcher using weather tool

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The Khamsin winds hit Cairo in spring time, which are southern hot winds accompanied with sand and dust. Whereas, the preferable wind blows from North West.

Being classified as hot and arid, Cairo has a recorded maximum direct solar radiation in

Figure 4. School facades

Figure 5. Ground floor plan

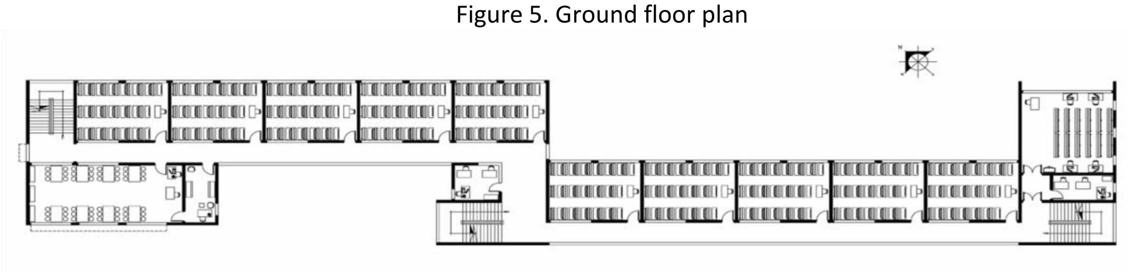

Figure 6. Typical floor plan

the month of July of 597w/m^2 and a minimum of 304w/m^2 in January.

Tabri School – Cairo

Type of building: Educational building

Owner: Ministry of Education

Location: Al Hijaz Square - Heliopolis - Cairo - Egypt

The ground floor area of the school building is 1012 m^2 and the total area of the floors is 4048 m^2, where the building consists of a ground floor and three typical floors.

The building was oriented towards the North-east due to the conditions and location determinants. The school classrooms were oriented North-east and the corridor between the classrooms was oriented South-west at a 45° angle. The school was built according to a structural system based on reinforced concrete, the use of red bricks for the construction of external and internal walls, the use of glass and wood for windows, the use of terrazzo tiles for the floors of the spaces inside the building and the use of cement tiles for the roof of the school building.

The school consists of the followings:

- An administrative building consists of a ground floor only.
- The old educational building consists of a ground floor and three typical floors (case study).
- The modern educational building consists of a ground floor and three typical floors.

Building Simulation

The design builder program was applied to the secondary school building to calculate the energy consumption, then several different alternatives were put in place to modify the design of the external envelope of the building and to modify the types of lighting used in order to reduce energy consumption to increase the efficiency of environmental performance of the building.

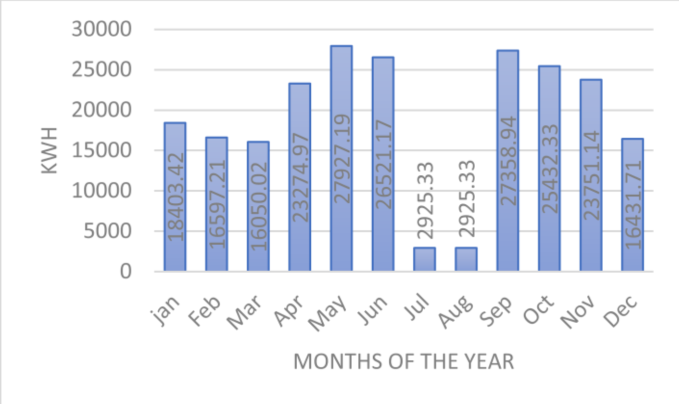

Figure 7. Energy consumption throughout the year in the current situation. Total quantity of electricity consumed in the current situation of the building during one year = 227598kWh

Table 2. physical Characteristics of wall components

Component	Layer L cm	Conductivity k watt/m. c°	Density ρ kg/m³	Specific C (jol/kg.c°)	Resistance R (m². c°/watt)
1-Cement mortar	2	0.93	2000	750	0.021
2-Solid Cement brick	25	1.4	2000	840	0.178
3-cement mortar	2	0.93	2000	750	0.021
U-value	2.51 (W/m². K)				
R	0.398 (m². K/ W)				

Table 3. physical Characteristics of roof components

Component	layer L cm	Conductivity k watt/m. c°	Density ρ kg/m³	Specific C (jol/kg.c°)	Resistance R (m². c°/watt)
1- Gypsum Plastering	2	0.4	1000	1000	0.05
2-renforeced concrete	26	2.3	2300	1000	0.11
3- expanded polystyrene	5	0.035	35	1400	1.42
4- Preference Concrete	7	0.72	1850	840	0.096
5- sand	5	0.3	1500	800	0.167
6-cement tile & mortar	5	1	1900	840	0.05
U-value	0.47(W/m². K)				
R	2.083(m². K/ W)				

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Table 4. optical properties of the glass used in the case study.

Type of glass	SHGC	U-value	VT
Single glass 6mm	0.81	6.12	0.88

Base case simulation results

All data and information for the site, such as the occupancy periods of the building during the day and the year, the construction systems, the specifications of the external envelope and the internal spaces, the nature of furniture and the activities being carried out within these spaces. The used electrical devices have been entered to the design program to study the current state of energy consumption throughout the year.

After studying the current situation and determining the amount of electrical energy consumed inside the building, we proposed some alternatives to improve the efficiency of the building and reduce the use of electric energy. Some of the inputs to the Design Builder program are changed . The effect of changing these inputs on the efficiency of the building and the reduction in electrical energy consumption is studied.

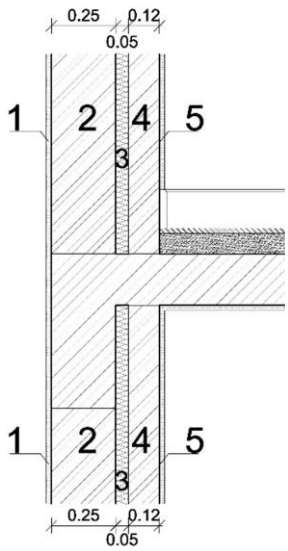

Figure 8. cross section of the double wall

Suggested solutions to reduce energy consumption in the building

The first alternative (using a double wall with a gap)

The first alternative is to change the wall type to a double wall with a 5cm vacuum thermal insulation.

1- Cement mortar, layer 2 cm, R=0.024 m^2.c/watt
2- Light sand brick, layer 25 cm, R=1. 92m^2.c/watt
3- Expended polystyrene, layer 5 cm, R=1.82 m^2.c/watt
4- Light sand brick, layer 12 cm, R=1. 92m^2.c/watt
5- Cement mortar, layer 2 cm, R=0.024 m^2.c/watt

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Quantity of electricity consumed by the building according to the first alternative during one year = 190525kWh after saving electricity consumption of 37073Kwh compared to the current situation by reducing the consumption by 16%.

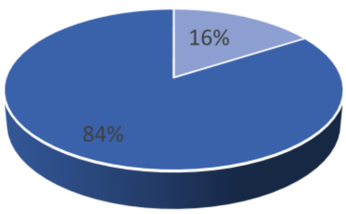
The second alternative: Using double blue glass in the transparent part of the building

The effect of using double blue glass (production of SAINT-GOBIN) in the transparent part of the building on the energy consumption.

Table 5. physical Characteristics of glass.

Characteristics	**Blue (#2) 12mm Air Space 6mm Clear**
VISIBLE LIGHT	
Transmission (%)	49
Reflection out (%)	8
Reflection in (%)	11
SOLAR ENERGY	
Transmission (%)	30
Reflection out (%)	8
U-VALUE (W/M2. K)	1.80
G Value	0.36
Shading Coefficient	0.42
1st Lite Price (L.E/sqm)	165
2nd Lite Price (L.E/sqm)	35
Both Lite Price(L.E/sqm)	200

- Amount of electricity consumed by the building according to the second alternative during one year = 195325kWh.
- The amount of electricity consumption according to the second alternative = 195325Kwh after saving electricity consumption 32273Kwh compared to the current situation by rationalizing the consumption by 14%.



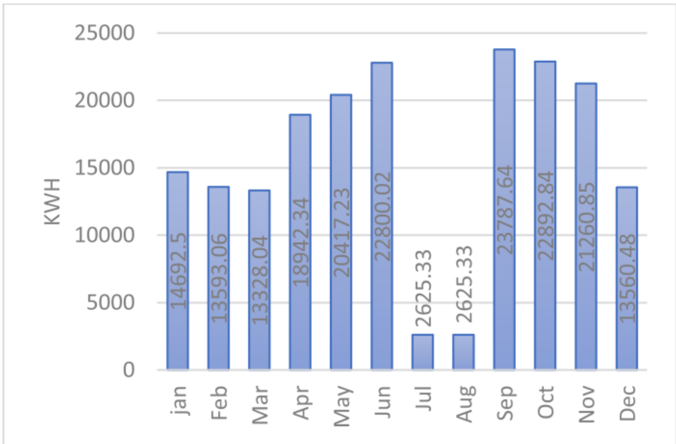


Figure 9. (left) the percentage of energy saved according to the first alternative
Figure 10. (Right) the amount of electricity consumed in the building during the months of the year according to the first alternative

The third alternative: Return-air ducted

This alternative replaces the current situation light units with return-air ducted light units, which reduce the heat emission from the light units, so that the heat is drawn out of the space.

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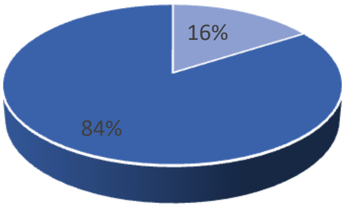
This helps to reduce the amount of electrical energy consumed. Figure 14 shows how to draw that hot air.

• Quantity of electricity consumed according to the third alternative of the building during the year = 202014kWh



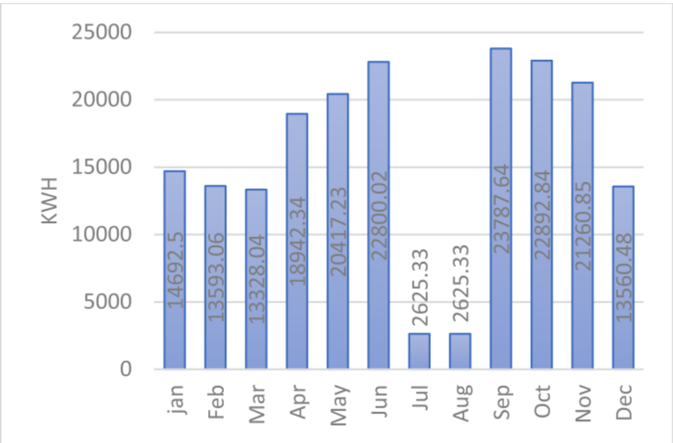


Figure 11. (left) The energy saving percentage according to the second alternative 14%
Figure 12. (Right) The quantity of electricity consumed in the building in the second alternative

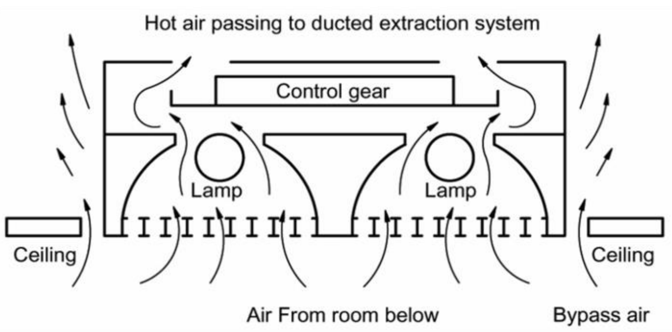


Figure 13. (Left) How the return-air ducted system appears in the ceiling
Figure 14. (Right) Shows how to draw hot air into the Return air ducted system

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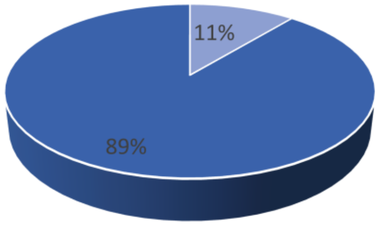

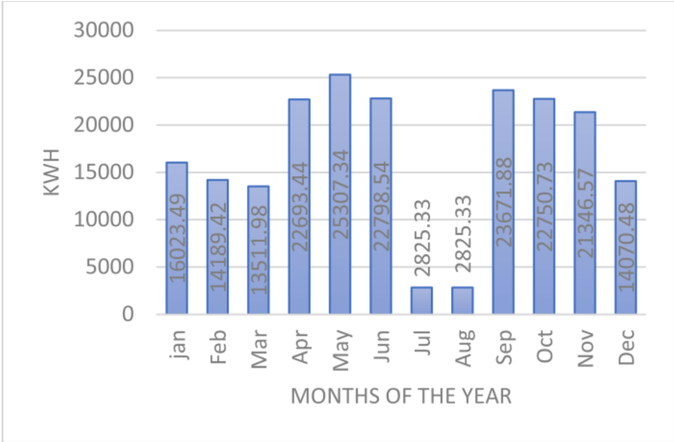

Figure 15. (left) The energy saving percentage according to the third alternative 11%
Figure 16. (Right) The amount of electricity consumed in the building in the third alternative

• The amount of electricity consumption according to alternative three = 202014Kwh after saving electricity consumption of 25584Kwh compared to the current situation by reducing the consumption by 11%

The fourth alternative (Change the type of light source and use T5 (Ø16mm)

This alternative depends on changing the type of light source from the current situation and replacing it with a light source T5 (Ø16mm) Fluorescent lamp, triphoshor, high-frequency control gear. It helps to reduce energy consumption, which reduces the effect of the school building on the surrounding environment and makes it more environment – friendly.

• Quantity of electricity consumed according to the fourth alternative of the building during the year = 169551kWh

• The amount of electricity consumption according to alternative four = 169551Kwh after saving electricity consumption of 58047Kwh compared to the current situation by reducing the consumption by 25%.

The fifth alternative (accumulation of all changes made in the previous alternatives in one alternative)

This alternative is a combination of all the previous alternatives in one alternative, where all of these changes are put together: Wall thickness - Type of glass - Type of lighting unit - Type of light source.

• By analysing the data, it was found that the quantity of electricity consumed in the fifth alternative of the building during the year = 160343 kWh

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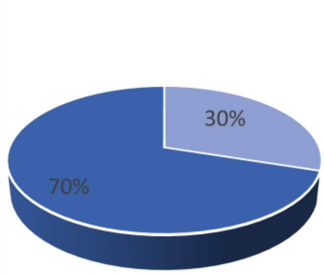
• The amount of electricity consumption in Alternative five = 160343Kwh after saving electricity consumption of 67255Kwh compared to the current situation by reducing the consumption by 30%.

Comparison between the current Situation with the five alternatives and the chart shows the following

• The quantity of electricity consumed in the first alternative during the year =



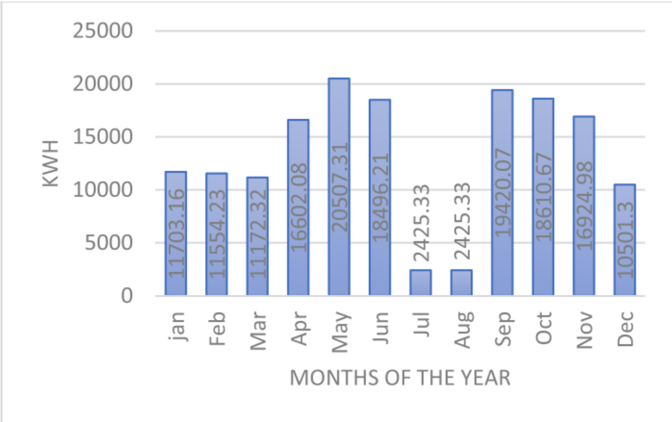
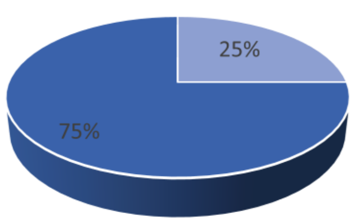


Figure 19. (left) The energy saving percentage according to the fifth alternative 30%
Figure 20. (Right) The quantity of electricity consumed in the building in the fifth alternative

190525kWh with electricity consumption saving of 37073Kwh compared to the current situation, with a reduction percentage of 16%.



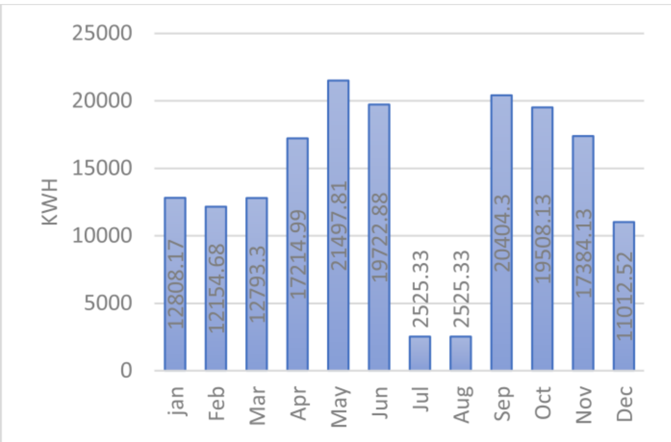


Figure 17. (left) The energy saving percentage according to the fourth alternative 25%
Figure 18. (Right) The quantity of electricity consumed in the building in the fourth alternative

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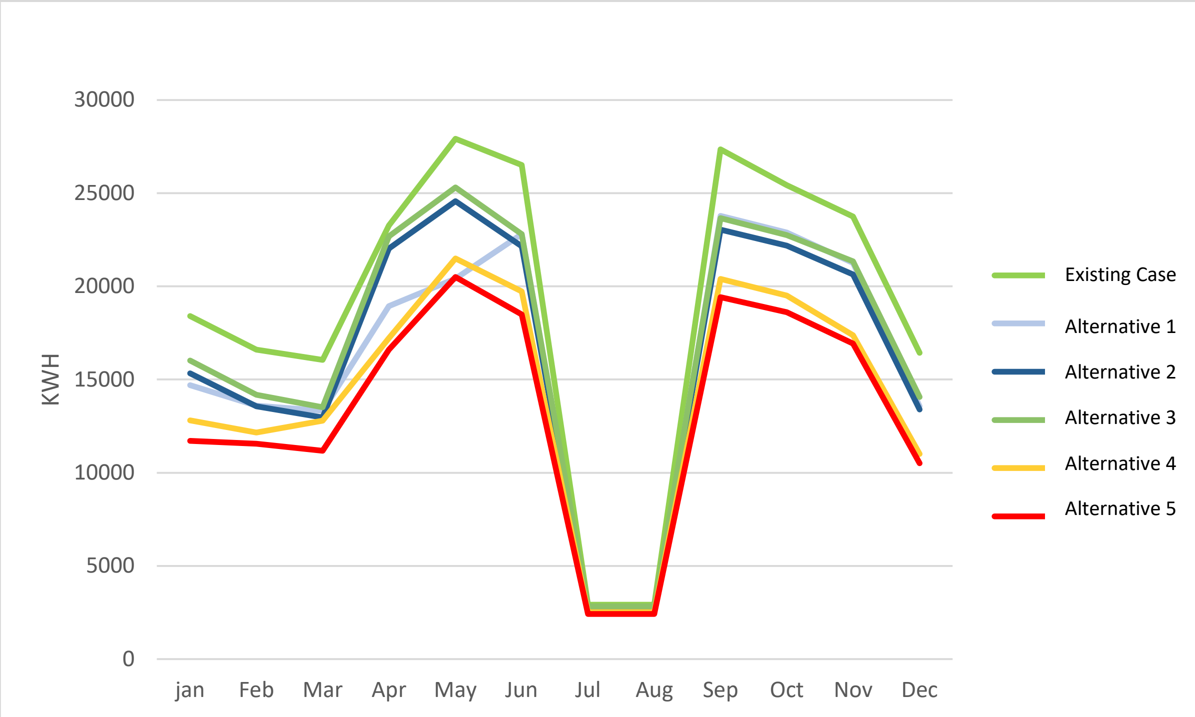

- The quantity of electricity consumed in the second alternative during the year = 195325kWh with electricity consumption saving of 32273Kwh compared to the current situation, with a reduction percentage of 14%
- The quantity of electricity consumed in the third alternative during the year = 202014kWh with electricity consumption saving of 25584Kwh compared to the current situation, with a reduction percentage of 11%
- The quantity of electricity consumed in the fourth alternative during the year = 169551kWh with electricity consumption saving of 58047Kwh compared to the current situation, with a reduction percentage of 25%

When a comparison was made between the current situation and alternative five, it was found that the electricity consumption in the current situation is 227598Kwh, the amount of electricity consumption in alternative number five is 160343Kwh, which means electricity consumption saving of 67255Kwh, with a reduction percentage of 30%.

Figure 21. Comparison between the existing case and all alternatives

Results

High-efficiency schools are buildings provide a healthy educational environment (for students and teachers). It helps to reduce energy consumption, as well as operating and maintenance expenses of the building, while applying the principles of sustainability regarding “energy -

water - the use of materials". The school building itself can be used as an educational tool to remove environmental illiteracy for students, teachers and the society.

The design and assessment approach for high efficiency schools is a successful framework for upgrading the design standards of schools in Egypt and an appropriate system for evaluating the design and operational efficiency of schools in Egypt in general.

The proposed design and evaluation criteria for high efficiency basic education schools in the Cairo Region are in line with the green assessment systems for schools, which increases the design and operational efficiency of schools in the Cairo Region in particular and in the rest of the climatic regions in Egypt in the near future when it is applied on the rest of the republic regions according to the circumstances associated with each climatic or planning region.

The design of a high efficiency basic education school buildings is neither expensive nor complex, but requires an understanding, awareness and study of all the direct and indirect effects of high efficiency school design standards and their impact on the design and operational efficiency of the school building in general.

The designer has a significant impact in the process of providing thermal and visual comfort within the interior spaces.

There is not yet a typical school assessment method in Egypt to evaluate schools in terms of efficiency (design efficiency, operational efficiency, adaptation to the environment, application of sustainability principles, conservation of energy consumption, operating and maintenance costs).

Basic education school building design Standards in Cairo and the rest of the Republic are acceptable as far as producing a traditional school building is concerned. However, as the frequency of crises and contemporary and future challenges in the fields of (energy, water, economy) has increased this traditional building will become a hotbed of problems and a burden for the state and the competent ministries. If these entities try to solve some of these problems, it will be a temporary solution, which does not tackle the root of the problem in the long term.

The applied study has shown that it is possible to redesign the external envelope of the school building in order to achieve the thermal comfort and energy consumption reduction to reach a high efficiency school building.

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