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Research Article

Towards Attaining Net Zero-Energy Buildings through Retrofitting School Buildings

Aya Helmy Zakaria†* and Morad Abdelkader‡

†MSc Researcher, Faculty of Engineering, Architecture Department, Ain Shams University, Egypt
‡Professor of Architecture and Environmental Control, Faculty of Engineering, Ain Shams University, Egypt

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Abstract

Educational sector in Egypt needs a great interest; in order to update educational buildings especially school buildings. The existing school buildings represent both the problem and the solution, because working on existing school buildings would reflect immediately on the current energy consumption situation, unlike solutions of designing new schools that would take a lot of time to show results. Private schools depend heavily on air conditioners to achieve thermal comfort to students without paying attention to passive design strategies, and this leads to high energy consumption and increased carbon dioxide emission. The objective of this paper is to propose a methodology that can be used to convert private school buildings in Egypt from high energy demand into net-zero energy buildings. The paper concludes with analysis, deduction and evidence that with energy efficient retrofitting, school buildings will be able to reduce energy consumption by 33%, and produce energy with solar panels equal to energy consumed.

Keywords: *Retrofitting School Buildings, Net Zero Energy Building (NZEB), Energy Efficiency, Renewable Energy.*

1. Introduction

Existing buildings represent a large proportion of our buildings compared to new construction. Therefore, more attention should be paid for the development of existing buildings to improve their performance. The development of existing buildings is a significant trend for saving energy consumed in operating systems in lighting and ventilating. Energy consumption in Egyptian public buildings, including administrative, educational and health buildings is the second largest type after residential buildings.

Retrofitting of existing buildings in the third world countries focuses on structural or aesthetic aspects and mainly on historical buildings. However, reducing energy consumption levels is of equal importance because of its environmental impacts. It can be more cost effective than building a new one, saving energy, reducing energy consumption.

The Government of Egypt should take some steps to achieve this goal; where the preparation of suitable school buildings presents itself as one of the first missions to be accomplished. This step is accomplished by up-grading the existing stock of school buildings rather than constructing totally new facilities.

*Corresponding author's ORCID ID: 0000-0000-0000-0000
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This strategy was adopted internationally, and it requires strong non-stopped effort from decision makers to improve the educational framework.

Among the relatively new strategies that have been practiced all over the world in the last few years is Net-Zero Energy Building concept. This concept aims at designing greener buildings in terms of energy usage. The whole concept is based on two major aspects: the first is energy saving, and the second is renewable energy generation. Saving energy usually equals saving money, and this is the motivator for people to pursue advanced energy solutions, and recently it also secures the plenty of energy itself. A possible solution is retrofitting existing buildings to net zero energy buildings through enhancing the envelope's efficiency that will reflect on the reduction of energy usage of buildings, while also integrating renewable energy with the existing structure to generate clean energy.

2. Retrofitting School Buildings

The thermal performance of the building envelope is one of the most important determinates of the building's energy consumption. Predictions published by the Intergovernmental Panel on Climate Change (IPCC) indicate an increase in global average surface temperature in different scenario ranges of 1.1–2.9°C to 2.4–6.4°C from a 1990s baseline towards the end of the 21st century.

Across Egypt, which is the focus of this study, air temperature has already increased between 1˚C and 2˚C since 1970 and is expected to increase another 4˚C by 2100 as the special Report of Emission Scenario states (Nakicenovic & Swart, 2000).

2.1. Energy efficiency

Energy-efficient buildings are considered to consume as little energy as possible; energy efficiency is the amount of output compared to the amount of input under the same conditions so that energy efficiency in buildings can be obtained by using as little energy as possible in any building to be fully functional.

Energy efficiency is one of the methods that controls and manages the energy consumption (El-Darwish & Gomaa, 2017), and it is related to the thermal performance concept, which depends on; prevent temperature leakage in all the seasons through building structure.

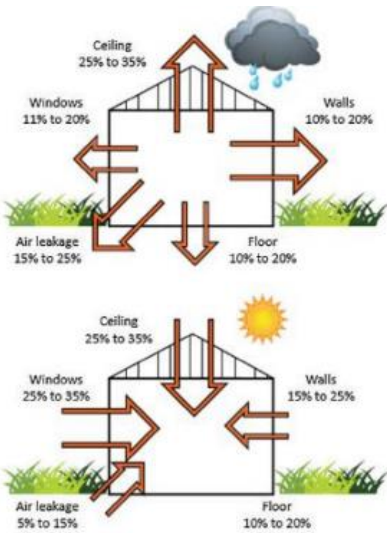


Fig.1 Heat Flow in an Un-insulated building

2.2. Overview of Egyptian private school buildings

A minority of families send their children to private schools. Private schools are divided into regular private schools and (foreign) language private schools, where the language of instruction is not Arabic. All of the above school mentioned types are supervised by the Ministry of Education.

2.2.1. Common structure systems of private schools in Egypt

After doing a survey of private schools in Fifth Settlement, New Cairo; the common structure systems that cover the majority of private school building types in Fifth Settlement, are as follows:

- Reinforced concrete skeleton with masonry.
- The fenestration is simple sliding aluminum section frames around the glass; the glazing type is single 6mm clear.

2.2.2. Common types of private schools design plan

As regards the type of the design, no single type can be recommended. However, the school building can be of several types.

1. The L shape type – L type with an extension on one side.
2. The T shape type – T type with an extension on one side both ways.
3. The U shape type – Two I type joined on one side.
4. The H shape type.
5. Finger shape type.

3. Retrofitting Strategies

Retrofit is defined as to install, fit, or adapt for use with something older. Recently, retrofitting refers to the addition of new technology or features to older systems for some reason or another. Some of reasons for retrofit could be for the improvement of power plant efficiency; for strengthening older buildings in order to make them earthquake resistant; or for the improvement of existing buildings with energy efficiency equipment (El-Darwish & Gomaa, 2017)

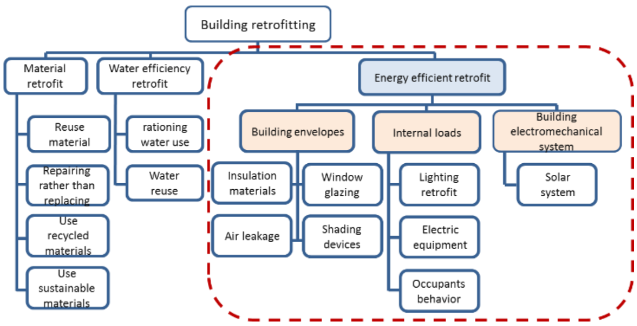


Fig.2 Building retrofitting strategies

(The highlighted parts are retrofitting techniques that are applied in the simulation section in this research.)

3.1. Energy efficiency retrofit techniques

Retrofitting energy efficiency can be divided to three main aspects

a. Retrofitting building envelopes.
b. Retrofitting internal loads.
c. Retrofitting building electromechanical systems

3.1.1. Retrofitting building envelopes

Building envelopes include the resistance to air, water, heat, light, and noise transfer. As for thermal envelopes, they include outer walls, roof, foundation, windows and doors. The purpose of the thermal envelope is to prevent heat transfer form interior of a house to its exterior in winter and vice versa in summer (El-Darwish & Gomaa, 2017).

3.1.1.1. *Insulation and thermal bridge*

Thermal insulation depends on decreasing the U-Value (heat transmission coefficient) and increasing the thermal Resistance (R-value) of the building envelope material. High thermal mass structure such (stone, masonry, or concrete) with framing structure cavities act as thermal bridges with low thermal resistance and high conductivity. For that reason insulation is a need. Extruded polystyrene has been suggested for thermal insulation on the outside of the building in hot regions (Attia& Herde, 2009).

3.1.1.2. *Air tightness and infiltration*

Normal air movement in and out of buildings is known as air leakage. Air leakage is measured by air change per hour (AC/H).. Reducing air leakage can save 5–40% of heating and cooling energy. (El-Darwish & Gomaa, 2017)

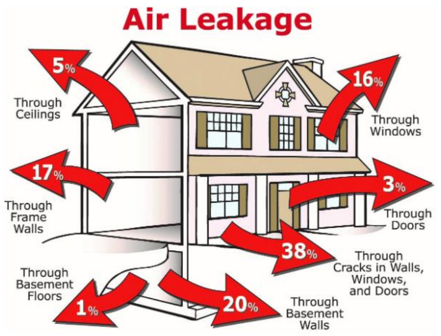


Fig.3 Air leakage spots at building

There are many techniques to achieve this reduction like applying two simple and effective air-sealing techniques:

- Caulk (is a flexible material used to seal air leaks through cracks, gaps, or joints)

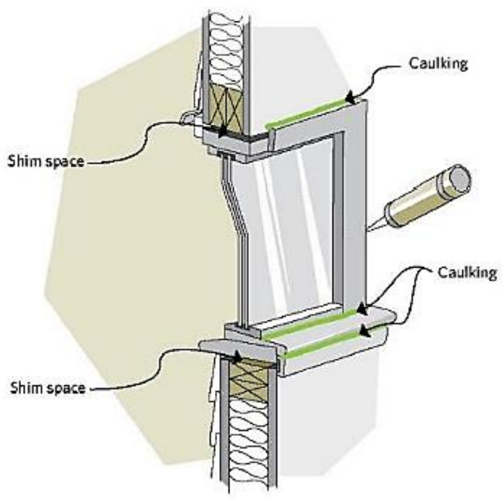


Fig.4 Applying caulk to a window frame to prevent air leakage

- Weather-stripping (is used to seal air leaks around movable building components, such as doors or windows)

Fig.5 Weather stripping doors, operable windows

3.1.1.3. *Window glazing*

Windows have several functions it allows direct and indirect sunlight, heat flow, and a view for outside. Currently single-glazed, with clear glass and poorly insulated frames are mostly used in many regions of the world. These have U-values of approximately 4.5 watts per square meter Kelvin (W/m2 K) to 5.6 W/m2 K. (El-Darwish & Gomaa, 2017).

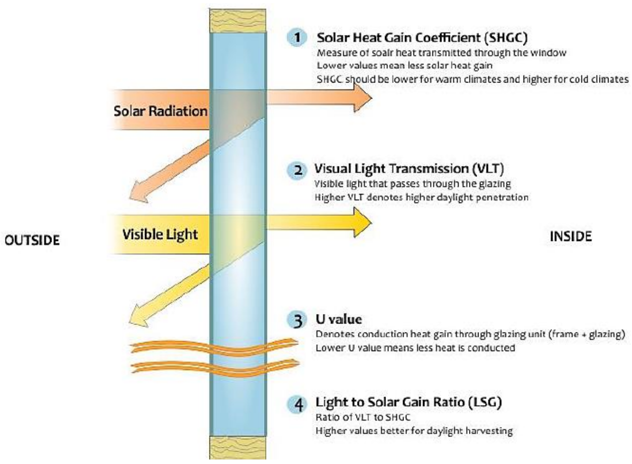


Fig.6 window thermal characteristics

There are three basic approaches which are applied to the window glass production to ensure high energy performance. (Basarir,Sahin&Diri)

1. Changing the physical properties or the chemical structure of glass material. An example of this is colored glass.
2. Coating the surface of the glass material with a reflective film to reduce glare and solar heat gains.
3. Creating spaces between the glass layers whose properties can be controlled. These windows consist of two or more layers and the space between them is filled with low-conductivity gas. (Basarir,Sahin & Diri)

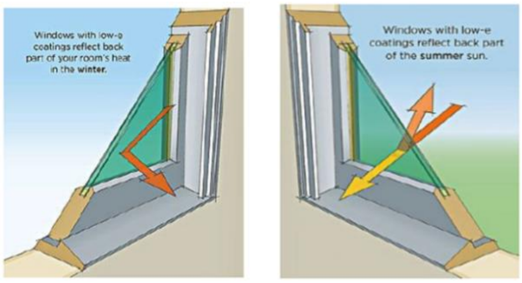


Fig.7 window's improvement and energy efficiency

3.1.1.4. Solar Shading

Well-designed shading devices can reduce heat gain, improve natural day lighting quality, and improve user vision by controlling glare and contrast level in the building.

It is common to use horizontal shading devices in the south elevation and the vertical shading devices in the east and west elevations. Design of the shading devices depends on the sun angels during the year (Kim, Lim, Lim, Schaefer, & Kimd, 2011).

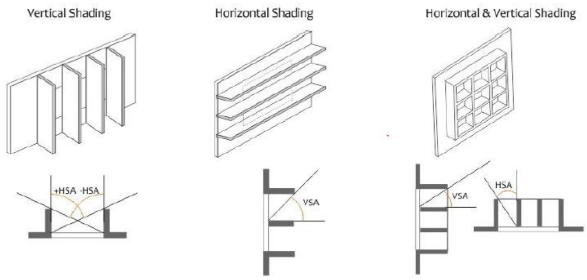


Fig.8 examples of external shading devices

3.1.2. Retrofitting internal loads

To achieve an energy saving inside any building, some elements are suggested to be retrofitted to achieve energy efficiency as follows:

a) Lighting retrofitting

The old lighting elements could be retrofitted into LED elements or to add a timer or a sensor on the elements that are only used, making the lights to be turned off automatically when they are not in use. Literature have shown that by retrofitting the lighting system the lighting level of the elements themselves can increase while reducing up to 70% of the total energy demand. (Meisen, 2011)

b) Retrofitting Electrical equipment

Based on the government's measures, it is preferable to replace high consumption electrical equipment with devices containing the energy efficiency label, to ensure achieving the maximum reduction of energy in the residential building.

3.1.3. Retrofitting building electromechanical systems

The retrofitting process also extends to include the electromechanical systems of the building.

a) Solar systems

Solar Technologies can be used for thermal purpose (heat). Sunlight can be directly converted into electricity using photovoltaic (PV) and various experimental technologies. This part will be explained extensively because it is the nucleus of the zero energy concepts and techniques.

4. Net Zero Energy Buildings Strategies

A zero energy building (ZEB) or net zero energy building is a general term applied to a building's use with zero net energy consumption and zero carbon emissions annually.

4.1. Net zero energy building definition

A net zero-energy building is a building that has a very high energy performance and the remaining energy should be covered to a very significant extent by renewable sources. (European Commission, 2010)

- Zero energy building (ZEB) produces enough energy from renewable resources to cover its annual energy .consumption, by decreasing the use of non-renewable energy resources. (Peterson, Torcellini, & Grant, 2015)

4.2. Net zero energy building aspects

To sum up the characteristics of nZEBs as stated by the EPBD recast:

• Having a very high energy performance.
• Energy demand should be reduced to nearly zero or very low.
• Energy requirements should be fulfilled to a very significant extent by renewable resources.

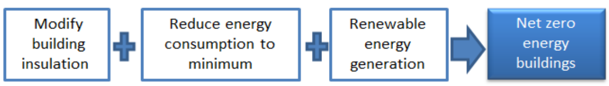


Fig.9 Aspects of reaching net zero-energy building.

The first aspect depends mainly on enhancing building insulation, which can be reached, for example, through restricting the U-values of the building envelope or controlling the windows thermal transmittance.

The second aspect is ambiguous to a great extent because it is hard to determine what the "very low" amount of energy means. At the same time, the amount of energy consumed in a building depends on intangible factors like the user's behavior and expected thermal comfort level, regardless of how energy efficient the building is.

As per the third aspect, it simply aims at calculating the electricity demand and managing to cover it through renewable in-site or off-site sources.

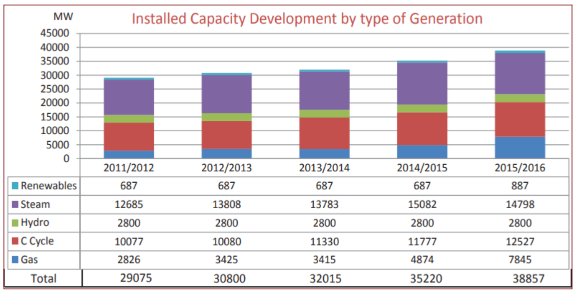
4.3. Overview on Renewable Energy

- Renewable energy is energy which comes from natural resources such as sunlight, wind, rain, ocean, hydropower, tides, and geothermal heat, which are renewable (naturally replenished).
- Renewable energy sources have an important role as they can meet the increasing world's energy demand. They recently supply around 15 % to 20 % of world's energy demand.

4.3.1. Renewable Energy in Egypt

Egypt possesses an abundance of land, sunny weather and high wind speeds, making it a prime location for renewable energy sources.

Moreover, Egypt is lying at the solar belt region. Solar Atlas reveals that the average .of vertical solar radiation is between 2000-3200 KWh/m2/year which provides solar rise ranges between 9-11 hours/day.



	2011/2012	2012/2013	2013/2014	2014/2015	2015/2016
Renewables	687	687	687	687	887
Steam	12685	13808	13783	15082	14798
Hydro	2800	2800	2800	2800	2800
C Cycle	10077	10080	11330	11777	12527
Gas	2826	3425	3415	4874	7845
Total	29075	30800	32015	35220	38857

Fig.10 Installed Capacity development by type of generation.

5. Net Zero Energy Buildings techniques

Systems designed to provide a renewable resource of energy, are essential in the delivery of ZEB concept. All the forms of renewable energy like; solar, wind, hydro, geothermal, and heat, are available and can be used and applied within the Egyptian context for ZEB applications and techniques. ZEB strategy includes four important techniques.

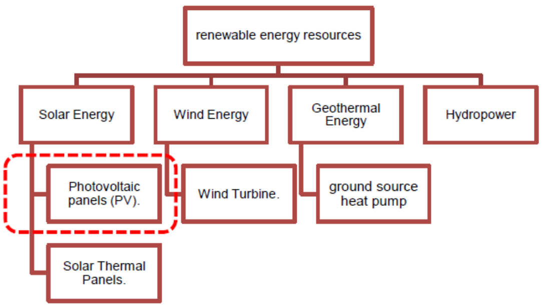


Fig.11 Net zero energy building techniques from renewable energy resources

(The highlighted part is the technique that is applied in the simulation section in this research.)

5.1. Photovoltaic panels (pv)

One of the most promising renewable energy technologies is photovoltaic panels (PV). It is a truly elegant means of producing electricity on site, directly from the sun, without concern for energy supply or environmental harm.

a) Working principle

It is the ZEB technique that is responsible for energy production by converting the sun energy directly into electricity through converting light (photons) to electricity (voltage)

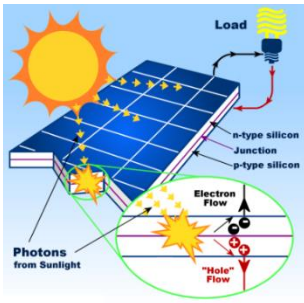


Fig.12 Photovoltaic panel working principle

b) Requirements

- Performance of PV modules depends on the amount of solar irradiation received which varies by location and season.
- The PV panels require a shadow free area, the required shadow free area for installing systems is about 10 ~ 12 m2 per kWp. This number includes provision for clearances between solar PV array rows.
- The solar panels may be installed on the roof of the building with a south facing tilt angle that varies from 25 º till 33 º.(Egypt PV)

5. Case study

Modern School of Egypt 2000 (MSE 2000) is located in Fifth settlement, South Police Academy, New Cairo city, Egypt (Lat., 30° 02' 15"N., Long., 31°25' 47"E)
The school consists of two main buildings; the first is U shape building (which will be the focus of the study).

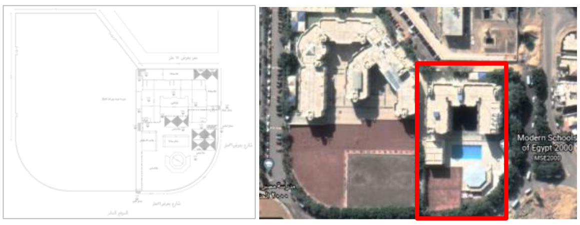


Fig.13. (MSE 2000) layout

(The highlighted part is the building on which the simulation takes place)

The building consists of four floors (Ground floor and 3 typical floors). Each classroom occupied by an average of 25-30 students .The majority of class rooms were cooled by air conditioning in addition to natural ventilation.

Fig.14. Shows the four floors with a large number of HVACs

5.1. Weather data analysis for Cairo (30°N, 31°E)

Cairo average annual temperature of 22.2 C°, 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 44 C° and an extreme minimum of 3C°. Being classified as hot and arid, Cairo has a recorded maximum direct solar radiation in the month of July of 597w/m2 and a minimum of 304w/m2 in January (Osman, M., 2011).

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.

6. Methodology

This paper will utilize an actual school building as a case study. The building has certain energy performance level and needs a certain amount of electricity to perform. If the energy performance could be enhanced and the electricity could be generated through PV panels, then the building can be a zero-energy building. Design Builder simulation software is used to analyze and measure the feasibility of integrating energy efficiency retrofitting techniques to reduce energy demand, and renewable energy systems to generate energy on the school building.

Simulation stages

- Stage one: determine the actual energy performance and the user's electric consumption (base case study) this would be considered the worst case. The objective is to identify the maximum energy consumption kWh.
- Stage two: applying the simulation on the base case study. Three energy efficiency retrofitting techniques are applied; insulation and glazing in the building envelope, and retrofitting of lighting systems. Aiming to reach the maximum energy reduction.
- Stage three: renewable energy sources such as PV panels are integrated to produce enough energy to cover the remaining energy from stage two.

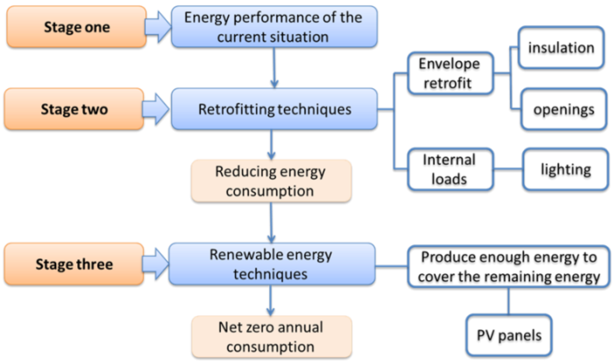


Fig.15. simulation stages

6.1. Stage one: current situation (base case study)

- The building has a concrete structure with single hollow clay brick walls. There wasn't any insulation in the exterior wall.

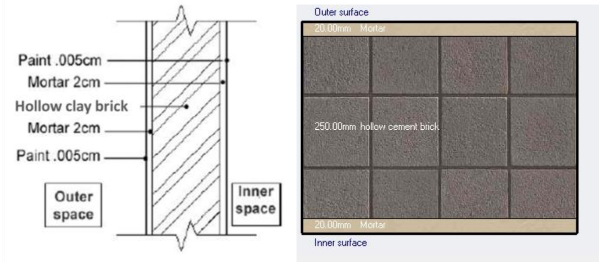


Fig.16. Current situation for the exterior walls

Heat transmission (U-value total) for exterior wall = 1/R value total

Where, thermal resistance (R total) =R paint+ R mortar+ R concrete blocks + R mortar + R paint + R outside air + R inside air.

Table 1 Physical Properties for external walls

Layers	Thickness (cm)	Thermal conductivity (w/m2k)	Density (kg/m³)	Thermal Resistance (m2k/w)
Mortar	2	0.88	2800	0.0227
Hollow clay brick	25	1.6	1140	0.156
Mortar	2	0.88	2800	0.0227
paint	0.2	0.2	1050	0.01

(U-value total) for the wall= 2.69 w/m2.k.
(R-value total) for the wall= 0.372 m2.k/w

- The roof is made of clay tile, and it is only insulated by the traditional thermal insulation on the roof of the top floor.

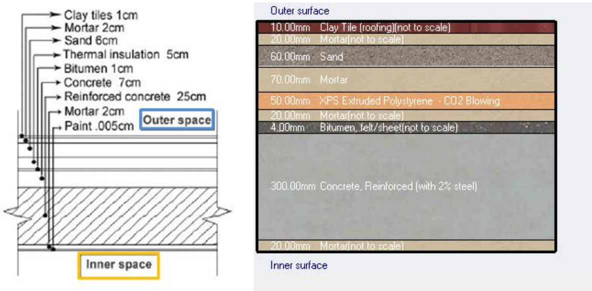


Fig.17. Current situation for the roof

Heat transmission (U-value total) for roof = 1/R value total

Where, thermal resistance (R total) =R paint+ R mortar+ R reinforced concrete + R concrete +R bitumen + R thermal insulation + R sand + R mortar+ R clay tiles+ R outside air + R inside air .

Table 2 Physical Properties for roof

Layers	Thickness (cm)	Thermal conductivity (w/m2k)	Density (kg/m³)	Thermal Resistance (m2k/w)
Clay tiles	2	1	2000	0.02
mortar	2	0.88	2800	0.023
sand	6	0.33	1520	0.18
mortar	2	0.88	2800	0.023
Xps extruded polystyrene	5	0.034	35	1.47
mortar	2	0.88	2800	0.023
Bitumen	0.4	0.23	1100	0.017
Reinforced concrete	30	2.5	2400	0.12
mortar	2	0.88	2800	0.023

(U-value total) for the roof =0.479 w/m2.k.
(R-value total) for the roof= 2.088 m2.k/w

- All windows have a single clear 6mm panel, window frames were made of aluminum as shown in fig 19.

Table 3 Physical Properties for window

Glazing properties	solar heat gain coefficient (SHGC)	Light transmission (LT)	Heat transmission (U-value)
Single clear	0.81	0.88	6.12

Fig.18. Current situation for the windows

- HVAC: there wasn't any central cooling or heating system installed, and the cooling system depends on multi-split air conditioning unit in every room.
- Lighting: Each class room has a range from six to eight light units; each unit consists of two Led lamps 25w.

6.1.1. Simulation results for the base case

The annual energy consumption shows that; July has the highest energy consumption due to the increase in temperature, and January has the lowest energy consumption due to the lack of air conditioning loads that used in the cooling process. The finding reveals that the cooling energy has the highest energy consumption loads 109.25MWh per year.

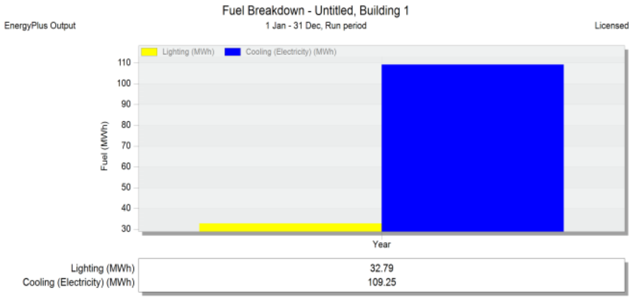


Fig.19. annual energy consumption for the base case

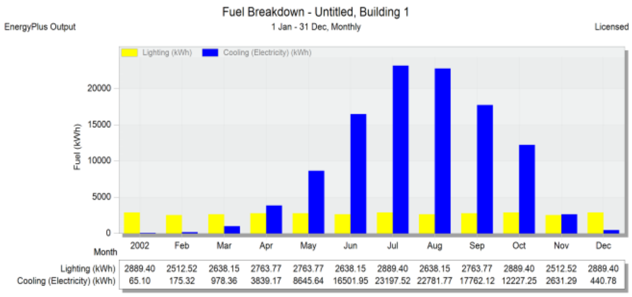


Fig.20. monthly energy consumption for the base case

6.2. Stage two: retrofitting techniques

6.2.1. Wall retrofitting

The wall retrofitting depends on, increasing the thermal resistance (R-value), and decreasing the heat transmission (U-value) of the external walls. Extruded polystyrene (XPS) insulation was applied and selected due to its common use in the Egyptian market.

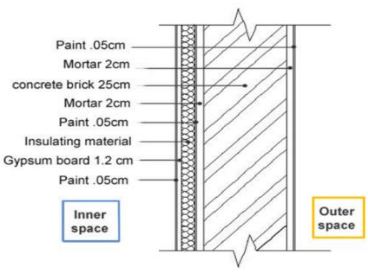


Fig.21. retrofitted wall with insulation

The insulation has been tested in different thicknesses to reach the optimum thickness for achieving the maximum energy reduction, where:

Thermal resistance for any material (R-value) = Material thickness / its thermal conductivity (K-value). (R-value) m2.k/w for the retrofitted wall=R base case +R insulation +R finishing material.

Table 4 (R-value) for different thickness of insulating material+ gypsum board

Insulating material	thermal conductivity (K-value) (w/m2k)	material thickness (cm)	Thermal resistance (R-value) (m2k/w) Material+ gypsum board
extruded polystyrene	0.03	1 cm	0.69
		2 cm	0.98
		3 cm	1.27
		4 cm	1.57
		5 cm	1.86

6.2.2. Opening retrofitting

Opening retrofitting depends on decreasing the solar heat gain coefficient (SHGC) of all windows glazing, by applying two options containing two types of glazing with four different material and different (SHGC).

Table 5 the applied glazing type's properties

Glazing properties	solar heat gain coefficient (SHGC)	Light transmission (LT)	Heat transmission (U-value)
Single blue	0.58	0.57	6.12
Single Ref-D Tint 6mm	0.42	0.25	6.06
Double blue	0.48	0.50	2.7
Double Ref D-Tint 6mm /13mm air	0.34	0.23	2.7

6.2.3. Shading device retrofitting

Automatic sun tracking solar shading louver systems enable buildings to react to any changes in the weather and to the sun's position, optimizing the flow of heat and light energy through the facade. This will help to reduce the heat load and glare, and will enhance the use of natural daylight, helping to reduce the operating costs of the building.

6.2.4. Roof retrofitting

Roof retrofitting depends on increasing the thermal resistance (R-value) and decreasing the heat transmission (u-value) of the roof. Thermal resistance for any material (R-value) = Material thickness / its thermal conductivity (K-value).

Table 6 (R-value) for the insulating material applied in roof retrofitting

Insulating material	Thermal conductivity (K-value) (w/m2k)	Material thickness (cm)	Thermal resistance (R-value) (m2k/w)
Extruded polystyrene (TEXLOSA)	0.034	4 cm	1.18
		5 cm	1.47
		6 cm	1.76
		8 cm	2.35
		10 cm	2.9

6.2.5. Energy Efficiency Retrofitting Techniques for Internal loads (lighting loads)

In the case study, the school uses LED bulbs, so the light sensor was used to make integration between natural and artificial lighting, and it is available in the Egyptian market at a reasonable price 350 LE per class. Lighting sensors dim or shut off fixtures based on existing daylight within a facility.

6.2.6. Simulation Results for Stage Two

By simulation, the retrofitting actions that achieved the maximum energy reduction in every retrofitting type were applied on the base case (Double Ref D-Tint 6mm /13mm air glass+ 5cm Extruded polystyrene wall insulation+ Automatic sun tracking solar shading louver on south façade+ light control), and the maximum energy reduction achieved when all retrofitting techniques were combined was 70060kwh .The total reduction in energy consumption when all retrofitting techniques were combined achieved 33.52%.

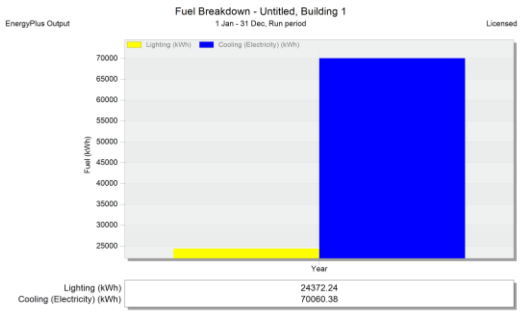


Fig.22. Maximum energy reduction achieved when all retrofitting techniques were combined

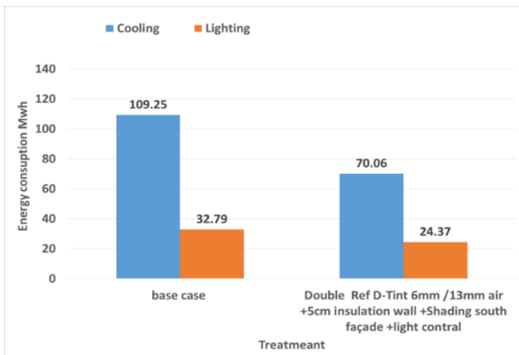


Fig.23. energy consumption of the base case before and after applying retrofitting techniques

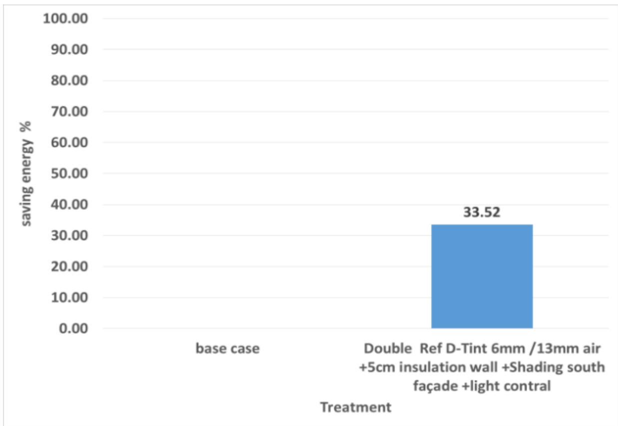


Fig.24. The total reduction in energy consumption when all retrofitting techniques were combined

6.3. Stage three: integrating renewable energy systems (zero energy techniques)

Literature showed that, PV panels are easy to merge into the design of the house, where, PV panels can be implemented on the roof, ground, or they can also be integrated into vertical facade walls or roofing materials. Also, PV panels are recommended for the areas that have many hours of sunlight radiation like Egypt.

For the panel's data:

- The panels' orientation: it is installed facing the south direction based on the previous solar data analysis.
- The panels' type: poly crystalline type with 30 degree
- The roof floor area is 1750 m2, and the photovoltaic dimension is 164x99 cm with electric power 250 watt each (Alaa, P, 2019).
- Then a space of 60 cm must be between each row of panels and the one preceding it.
- The average working hours for the photo voltaic is 6 hours per day. (Abd elrazik & Selim, 2017)

The number of solar pannels needed to achieve zero energy is 128 solar panels, with electric power 250 watt each.

The total energy produced by PV panels per day is calculated as follow:

128 cells * 250 watt * 6 hours = 192000 w.h =192 k.w.h

The total energy produced by PV panels per year is calculated as follow:

192 * 365 day =70080 k.w.h per year

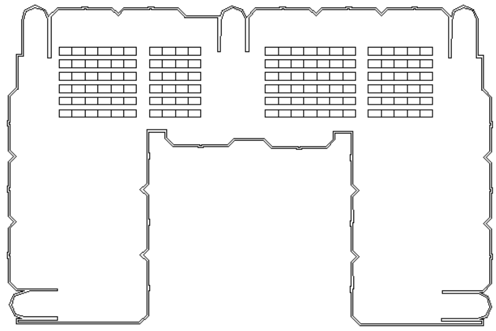


Fig.25. PV panel's numbers and array on school's roof that achieve zero energy

Conclusions

This paper introduced the proposed guideline for existing buildings to reach nZEB. The methodology is then tested by applying the steps on an existing school building. After the methodology is applied, a cost analysis is performed to give actual values for the amount of money saved by retrofitting and installing PV systems. Energy simulation program –DesignBuilder- was used to analyze the energy performance of the existing building sample and compare it to the retrofitted case to show the amount of electricity saved. For the building envelope; the opening retrofitting achieved the best energy reduction with 23.4 %, and the roof retrofitting achieved the least energy reduction with 2.4 %. After applying all energy efficiency retrofitting types including (wall retrofitting, opening retrofitting shading device retrofitting, and lighting retrofitting), the energy reduction for the whole school achieved 33%. And by integrating 128 photovoltaic cells, with electric power 250 watt each, on the roof, the total energy produced by them per year is 70080 k.w.h. The energy reduction achieved 100%. The chapter ends with the conclusion that existing building can be converted to nZEB by means of retrofit actions and installing PV system.

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