THE UTILIZATION OF GREEN ENERGY IN GAZA-STRIP SCHOOLS FOR IMPROVED IEQ

BY

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TO MY PARENTS

AND ALL FAMILY MEMBERS

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All praise and glory to Allah for giving me the good health, courage and patience to complete my master degree.

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LIST OF ABBREVIATIONS

ASHRAE	**:**	American Society of Heating, Refrigerating and Air-conditioning Engineers
A-Si	**:**	Amorphous Silicon
BIPV	**:**	Building Integrated Photovoltaic
CdS/CdTe	**:**	Cadmium Sulphide/Cadmium Telluride
CFL	**:**	Compact Fluorescent Lamp
CIGS	**:**	Copper Indium Galium Selenide
CU	**:**	Coefficient of Utilization
DGBP	**:**	Directory General for Buildings and Projects
EPBD	**:**	Directive on Energy Performance of Buildings
EPI	**:**	Energy Performance Indicator
Es	**:**	Electric Energy Specific Consumption per Student (kWh per student per year)
Ev	**:**	Electric Energy Specific Consumption per unit Volume (kWh/m^3 per year)
GHG	**:**	Greenhouse Gases
IAQ	**:**	Indoor Air Quality
IEAS	**:**	Energy Independence and Security Act
IEC	**:**	Israeli (Occupation entity) Electricity Company
IEQ	**:**	Indoor Environmental Quality
IESNA	**:**	Illuminating Engineering Society of North America
LCA	**:**	Life Cycle Assessment
LED	**:**	Light-Emitting Diode
LPD	**:**	Lighting Power Density
LZC	**:**	Low and Zero Carbon building
NPV	**:**	Net Present Value

NREL	**:**	National Renewable Energy Laboratory
PCBS	**:**	Palestinian Central Bureau of Statistics
PEC	**:**	Palestinian Electricity Company
PV	**:**	Photovoltaic
RET	**:**	Renewable Energy Technology
UNFCC	**:**	United Nation Framework on Climate Change
UNRWA	**:**	United Nation Relief and Works Agency
W.B	**:**	West Bank in Palestine
ZEB	**:**	Zero Energy Building
ACS	**:**	Adaptive Comfort Standard
LLF	**:**	Light Loss Factor
LLD	**:**	Lamp Lumen Depreciation

ABSTRACT

Full Name : MOHAMMED AWAD QANNAN

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A sharp increase in global energy demand has a negative impact on the ecosystem. Many researches assure the importance for renewable sources to be allocated in both private and public facilities. Photovoltaic (PV) systems are good enough to produce clean energy with reasonable environmental and financial investments. Before applying any renewable energy system, an energy conservation plan must be studied in order to reduce the level of energy consumption to the maximum. Many researches emphasized the relevance between better indoor environment quality (IEQ) and the level of health and productivity for schools' occupants linked by energy efficient strategies. The study was conducted in the Gaza Strip in Palestine. The energy demand increases about 7% annually in the Gaza Strip. More than 63% of electricity and energy sources for the Gaza Strip come from the occupying entity (Israel) which can be banned at any time. Recent studies show the importance of developing a model for energy-efficient schools while achieving IEQ standardized levels. The main objectives of the study are to develop energy-efficient and cost-effective schools in the Gaza Strip utilizing energy conserving measures and renewable energy strategies while improving the IEQ. To achieve the objectives, a typical school in the Gaza Strip designed and constructed by the Ministry of Education was selected to implement modeling and simulation techniques. The outcome of the study was the development of a model for an energy-efficient school that is self-energy producing with improved indoor visual and thermal comfort levels.

The study assured that a reduction of 65% could be achieved in the annual school energy consumption by replacing the existing T8 flourescent lighting system (16,000 kWh) with the dimmable (CREE A19) dimmable LED (5600 kWh) equipped by daylight

photosensors. The sensors were calibrated to receive the targeted standardized illumination level for each space and operating withen the full (Ideal) operation schedule.

Moreover, keeping the existing window-wall ratio (35.20%, 14.70% for the exterior and interior windows, respectively), the glazing type (single clear 3-4 mm) as well as the envelope system at the same conditions was the optimum selection in terms of visual/thermal and energy consumption.

A complete PV system with detailed technical, environmental, and feasibility studies was suggested and investigated. A mix of off-grid and grid-tied systems with 32 "Suntech STP300S-20/ Wew" modules out of maximum school's roof capacity (256 modules) was allocated to provide the building with its daily requirements "Phase I". About 18,710 kWh was the total annual generation; 6732 kWh was stored in 22 batteries (24 V, 150 Ah) to meet the school's requirements, and 11380 kWh was transferred to the grid to be sold. The annual reduced amount of GHG emissions was 12.9 tCO_2 as the average of all IEC different fuels. The total system life cycle (25 years) cost was 34,750 USD, while money could be refunded after 8.8 years and turned into an income of 55,000 USD.

However, another suggestion was studied to investigate the feasibility of utilizing the full roof's capacity -after avoiding the shadows- with PV modules (Phase II). The first attempt was with keeping the three stairwells covered to avoid their shadows. After calculating the maximum shadows lengths during the year by obtaining the Gaza Strip sun-path chart, 159 modules were filled to the maximum roof capacity. Another attempt to demolish the covers and enable more modules to be installed was made. An extra 97 modules were able to be mounted, hence the maximum number of modules was 256. Both "Phase I" and "Phase II" proved that the PV system was both environmentally friendly and financially feasible. By gathering both phases and dealing with them as one unit, and despite the project's high initial cost (141,550 $), money could be retrieved after the first seven years of the project life cycle and turned into profits reaching 450,000 USD by the end of the system's life cycle.

ملخص الرسالة

الاسم الكامل: محمد عوض قنن

عنوان الرسالة: استخدام الطاقة الخضراء في مدارس قطاع غزة نحو جودة بيئة داخلية محسنة

التخصص: الهندسة المعمارية

تاريخ الدرجة العلمية: ديسمبر 2016

إن الازدياد الحاد في الطلب على الطاقة له تأثيرات سلبية على النظام البيئي. أكدت الكثير من الدراسات أهمية تواجد مصادر طاقة متجددة للاستخدام في المرافق العامة والخاصة. تلعب المدارس دورا أساسياً في تعليم وتثقيف المجتمعات، وإذا ما تم تطبيق نظام طاقة متجدد فيها، سيساهم ذلك في نشر ثقافة هذه التكنولوجيا بطريقة سلسة من خلال رواد ومستخدمي المدارس. تعتبر أنظمة الخلايا الشمسية جيدة بما يكفي لتوليد طاقة نظيفة بالإضافة لكونها استثماراً في الجانبين البيئي والمالي. وقبل تطبيق أي نظام طاقة متجددة، يجب وضع خطة لترشيد استهلاك الطاقة لأقصى حد مع مراعاة جودة البيئة الداخلية، حيث أكدت العديد من الدراسات على العلاقة ما بين جودة البيئة الداخلية وصحة وانتاجية طلاب وشاغلي المدارس. تم إجراء هذه الدراسة في قطاع غزة ذات المناخ المعتدل إلى الحار صيفاً، والدافئ إلى البارد شتاءً. يعاني قطاع غزة من نقص في الوقود خلال العشر سنين السابقة، ويزداد الطلب سنوياً على الكهرباء بما نسبته 7 % علماً أن 63 % من مصادر الكهرباء والطاقة تزود من الاحتلال الإسرائيلي والتي من الممكن أن تمنع في أي وقت. يهدف هذا البحث إلى تطوير نموذج لمدرسة ذات كفاءة عالية من حيث استهلاك وإنتاج الطاقة مع مراعاة تحسين الجودة البيئية الداخلية، ويكون هذا النموذج مكتفي ذاتياً من إنتاج الطاقة اللازمة لتشغيل وأداء الوظيفة التعليمية وأيضاً توفير قدر من الطاقة لبيعها وتوزيعها من قبل شركة الكهرباء. ولتحقيق هذا الهدف تم اختيار نموذج تصميم متكرر والمعتمد بناؤه في قطاع غزة من قبل وزارة التربية والتعليم لتطويره من ناحية كفاءة استهلاك الطاقة وتحويله إلى مبنى مكتفي ذاتياً من خلال النمذجة والمحاكاة باستخدام وسائل الاستفادة من الطاقة المتجددة.

خلصت الدراسة إلى أن استبدال نظام الإضاءة الحالي (T8 Flourescent) بنظام (LED) من نوع (CREE A19) مزودة بحساسات للإضاءة النهارية معيرة وفق درجات الإضاءة المطلوبة أدى إلى تخفيض استهلاك الطاقة الكهربائية من 16,000 kWh إلى 5600 kWh سنوياً، ما نسبته 65% مع ضمان التشغيل الأمثل والكامل للمدرسة.

كذلك فإن الإبقاء على كل من مساحة النوافذ إلى الجدران (35.20% للنوافذ الخارجية، 14.70% للنوافذ الداخلية)، ونوع زجاج النوافذ (4 مم زجاج شفاف ذو طبقة واحدة)، والنظام الإنشائي للمبنى على حاله يضمن تحقيق الاستهلاك الأمثل للطاقة موازاةً مع جودة بيئية أفضل.

تم إجراء دراسة تقنية ومالية كاملة لتوظيف الخلايا الشمسية في المدرسة على مرحلتين. في المرحلة الأولى، تم استخدام نظام منعزل ومرتبط بالشبكة مكون من 32 لوح شمسي فقط من أصل 256 لوح على كامل مساحة السطح من نوع " Suntech STP300S-20/ Wew" وذلك لتغطية احتياج المدرسة السنوي من الطاقة الكهربائية وإمداد الشبكة بفائض يقدر ب 11,380 kWh سنويا. تم تخفيض معدلات إنتاج غاز ثاني أكسيد الكربون حتى 12.9 tCO_2 كبديل عن مصادر الوقود النفطية والمولدة

في شركة الكهرباء الإسرائيلية. معدل عمر المشروع مقدر ب 25 سنة حيث أن تكلفة المشروع خلال تلك الفترة مقدرة ب $ 34,750 يمكن استردادها بعد 8.8 سنوات لتتحول إلى أرباح مقدرة ب $ 55,000 عند السنة الأخيرة.

المرحلة الثانية تضمنت دراسة لتعبئة السطح بالألواح الشمسية على الحد الأقصى مع تجنب المساحات المظللة بهدف بيع الطاقة المولدة إلى شركة الكهرباء. بعد الحصول على الرسم البياني لمسار حركة الشمس في قطاع غزة، بلغ الحد الأقصى لعدد الألواح الشمسية الممكن تركيبها إلى 159 لوح، في حين أن مساحة السطح ازدادت لتتسع إلى ما يقارب 97 لوح إضافي في حال هدم بيوت الأدراج وتحويلها إلى أغطية مع مستوى سطح المدرسة، وبالتالي، الطاقة الاستيعابية للسطح بلغت 256 لوح. بدمج تكاليف وأرباح المرحلتين الأولى والثانية، بلغ إجمال التكاليف الأولية للمشروع إلى $ 141,550 في حين أنه يمكن استرداد المبلغ شاملا تكاليف التشغيل والصيانة السنوية بعد مضي سبع سنوات من عمر المشروع لتتحول الخسائر إلى أرباح تقدر ب $ 450,000 عند السنة الأخيرة من عمر المشروع.

CHAPTER 1

INTRODUCTION

1.1 Background

This chapter presents the background of the research subject along with problem statement, the significance of the study, the objectives, scope of work and limitations. The research methodology was used to achieve targeted objectives in a systematic manner.

No one can deny human necessity to harness energy and use it to his benefits. With time passing parallel to population growth resulted in the expansion of cities lifestyle, increasing in energy production and consumption were necessitated. Fossil fuels are one of the most common energy resources produced by natural processes by anaerobic decomposition of buried dead organisms. The three major states of fossil fuels are coal, oil and natural gas. According to **[1]**, one of the critical challenges faces the humankind is providing more energy while emitting less carbon dioxide (CO_2). The sharp growing in energy use in which causes rapid depletion of energy resources affects the ecosystem negatively, ex; global warming, ozone layer depletion, climate change …etc.

Both residential and commercial buildings contribute toward steady increasing in energy consumption ranges between 20% - 40% in developed countries **[2]** and exceeded in the other buildings sectors: industrial and transportation.

Currently, it is estimated that 50% of the world's population are living in cities, which represent 75% of total energy use **[3]**. Urban areas with their buildings, industries, power stations, and facilities are responsible for about 60 - 70% of global CO_2 emissions **[4]**. Alone, residential buildings consume 63% out of the net energy consumption in the European building sector and they are responsible for 10% of the total greenhouse gas emissions (GHG) **[5].**

There is no doubt that schools play an essential role in educating and civilizing societies. Schools, as buildings, consume a considerable amount of energy in order to perform their functions efficiently. Gilligan **[6]** Summarized the importance for schools in any community in seven points. These points need to be clearly understood especially in developing areas in order to elevate and improve their status. They are: School as ally, school as guarantor, school as capacity builder for children, school as secure base, school as integrator, school as gateway to opportunities in adulthood and school as a resource to parents and communities.

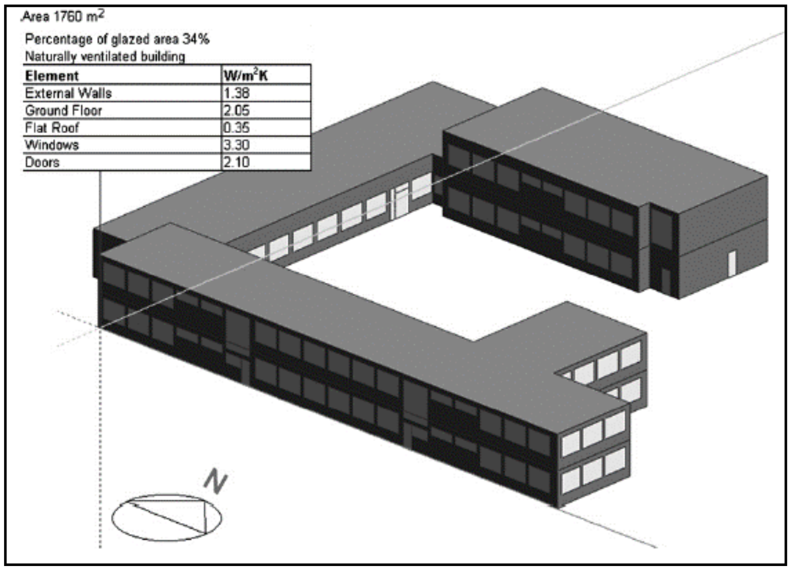
Many researches emphasized the relevance between the Indoor Environmental Quality (IEQ) and the level of health and productivity **[7-12]**. Different studies **[13, 14]** clarified the linkage between IEQ, occupants' health and productivity with energy efficient buildings. By experimental studies, many researchers proved the positive relationship between pupils' productivity, attendance and better IEQ with a provision for energy-efficient plan in schools **[15, 16]**. IEQ aspects constitute major corner in every sustainability rating system such as; visual\thermal comfort and Indoor air quality (IAQ). Hence, to identify IEQ levels in any facility, those indicators must be measured and analyzed. Better levels of IEQ affect occupants' productivity and health positively with enhanced building energy characteristics. As known that harmful CO_2 and greenhouse gas emissions levels are negatively affected with non-efficient energy utilization. For example, **[17-20]** assured the necessity for provision of better IAQ in schools in order to enhance pupils' health, productivity and attendance levels.

Visual comfort has an effective impact on students' productivity and achievements. Many studies shed light on the negative implications when visual comfort standards are not applied and vice versa **[21-24]**.

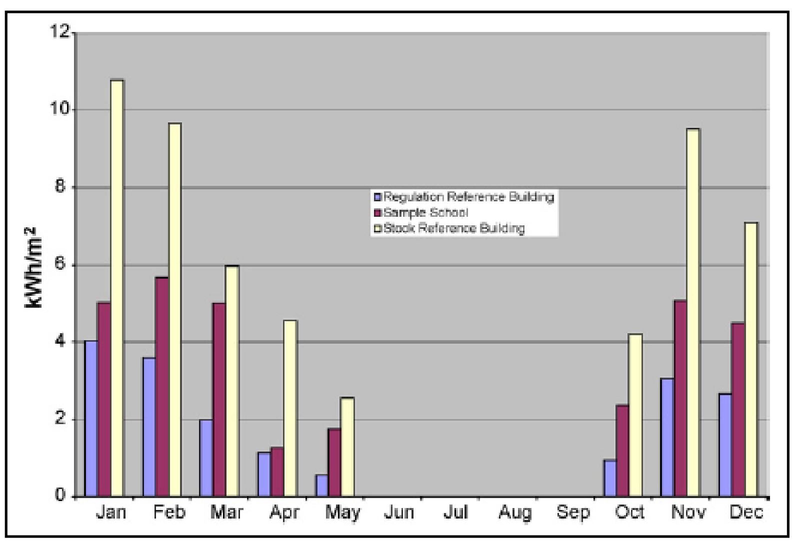
On the other hand, it is not easy to observe energy characteristic in non-domestic buildings precisely. In developing countries, with the absence of systematic methodology or assessment tools to check energy performance, the observation becomes more complex **[25]**. As a result, suggested systematic method for defining and benchmarking of building energy consumption should be provided. The systematic method is a step-by-step checklist starting from data collection and benchmark preparation for construction, activities, and statistical energy performance. **Figure 1.1** shows a sample of school energy modeling with its thermal characteristics and a graphical comparison between three scenarios: regulation reference building, sample school, and stock reference building in terms of calculated thermal energy (kWh/m^2) in Dublin\Ireland **[25]**.

There are several procedures to investigate the energy performance of a building, varying from annual or monthly calculation procedures to detailed dynamic simulation models. The operational rating method procedure is the simplest and often requires less effort and data. Hernandez et al. **[25]** indicated that The EPLABEL EU part-funded project (www.eplabel.org) has developed an operational rating system, which has only three steps:

Step 1: calculate the building's energy performance indicators (EPI) through collecting quality data. **Step 2:** select suitable benchmarks with which the EPI can be measured and compared. **Step 3:** evaluate the energy efficiency of the selected building by comparing the EPI the benchmarks.



(a)



(b)

Figure 1.1 Sample of school model in Dublin, a) Building thermal characteristics, b) Comparison between different calculated thermal energy (kWh/m^2) **[25]**

Due to a misunderstanding regarding the actual factors that affect positive\negative energy use, a significant gap should be bridged between building energy modeling estimation and actual energy performance. Demanuele et al. **[26]** summarized that operational issues and occupants' behavior play an essential role in the conflict between modeling results and actual energy use.

Rising energy costs, limited school budgets, and improved IEQ levels for students have increased the pressure on school stakeholders who are trying to raise students' performance levels. Fortunately, well-studied energy-efficiency measures enhanced with an IEQ plan are considered as a suitable solution that alleviates these issues. These plans should be characterized by a fully integrated approach including all building life-cycle phases from feasibility studies, design, construction, operation and maintenance up until the renovation and demolishing phase. Green-energy or high-performance schools are effective in terms of establishing a complete sustainable plan. These schools have several advantages in enhancing the outdoor and indoor environmental quality for students, staff, and administrators. Furthermore, energy-efficient schools are more cost-effective than non-studied (traditional) schools during the whole life-cycle (e.g., environmentally, they reduce pollution and landfill waste). Generally, and according to a conducted study **[27]**, there are several criteria for assessing sustainability in buildings through different life cycle phases. These criteria include:

- Green site and landscape planning that provides better outdoor learning environment for pupils;

- Efficient-tight building envelope design. Optimum windows, doors, walls, and ceilings with high R-value insulation are recommended;
- Effective lighting system through utilizing integrated artificial-natural lighting that has a positive impact on student productivity and achieving comfort levels;
- Healthy IAQ in which toxic substances, allergens, and other harmful pollutant sources are eliminated;
- The use of proper materials to minimize as much as possible sources of toxins, allergens, and other harmful pollutants;
- Provision for efficient heating, cooling, and ventilation systems;
- Benefiting from on-site renewable energy sources, such as photovoltaics, that can be used as a learning tool to improve student interest in alternative energy sources.

Obviously, sustainable school buildings benefit the whole district and community environmentally, socially, and economically. **Figure 1.2** shows the three constituent parts for sustainability.

In the early stages of design, the necessity for an energy-efficient plan should be added to engineers' considerations. Limited supply of fossil fuels and their damaging impacts on the planet push stakeholders to think seriously about utilizing renewable alternatives. Rezaie et al. **[29]** explained that more than 60% reduction in global carbon emissions could be achieved by providing energy-efficient buildings which is equal to 1.35 billion tons. Renewable energy technologies (RETs) (also known as low and zero carbon technologies

[LZCs], renewables or green technologies) are increasingly implemented as an essential way to reduce (GHG) resulted by fossil fuel use.

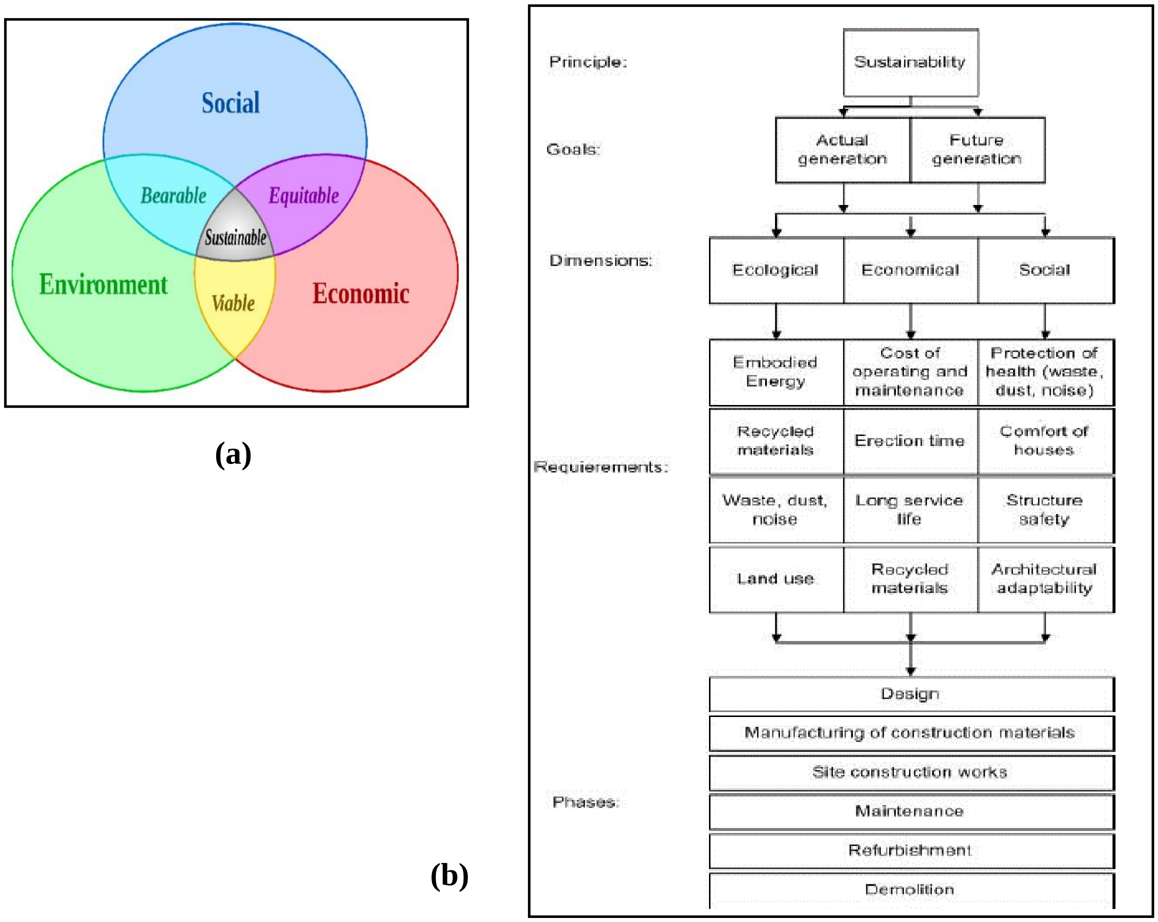


Figure 1.2 Sustainability structure, a) Sustainability major parts, b) Detailed sustainability structure in buildings **[28]**

Well-use of RETs should be parallel with an integrated energy conservation strategy. Day et al. **[30]** studied various international policies and regulations for using RETs to achieve LZCs buildings. A plan was indicated in the UK Climate Change Act 2008 (DECC 2008) in order to decrease carbon emissions by 80% by 2050 compared with 1990 levels. In addition, the ‘EU 20-20-20’ aims for a 20% cut in both GHG and energy consumption, as well as a 20% increase in renewable energy utilizations by 2020. Ambitious standards regulated by Part L of the UK Building Regulations (DCLG 2010) plan state that by 2019, all nondomestic buildings must be zero-carbon-emitting.

The London mayor implemented a hierarchal plan for emission reduction; it was classified under three categories: 'be lean, be clean, and be green' as shown in **Figure 1.3 [30]**. In essence, new buildings emission reduction is compared to a baseline (be lean), and after applying an energy-efficient plan the term is turned into (be clean), finally, and after an appropriate RETs is installed, the building will be turned into (be green).

During the last decades, the concept of the zero energy building (ZEB) was perceived as the concept for the remote future, but not anymore. Nowadays, the ZEB concept is considered as a logical and realistic solution for CO_2 emissions alleviation by reducing the energy use in the building sector. Marszal **[31]** reviewed several international ZEB goals. The Energy Independence and Security Act (EISA) 2007 in the USA initiated a target for the net-zero energy commercial building. By 2030, all new commercial buildings will be net-zero energy, and all U.S. new buildings by 2050. An ambitious target set by the Directive on Energy Performance of Buildings (EPBD) at the European level aims to turn all public buildings to near-zero energy by 2018 and for all new buildings by 2020.

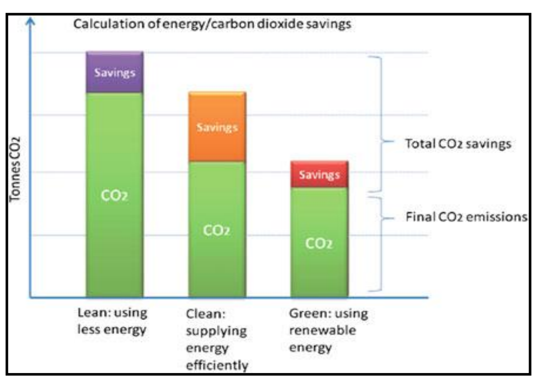


Figure 1.3 The London mayor's energy hierarchy **[30]**

This study will be carried out in the Gaza-Strip. The climate is characterized by moderate wet summers and warm dry winters. A typical school designed and constructed by the ministry of education will be selected for modeling and simulation purposes. For the last ten years, the people living in the Gaza Strip have suffered from harsh life conditions; further, the occupation entity controls most of the energy sources and resources. A shifted on-off eight-hour electricity schedule is applied to all cities and sectors. With 360 km^2 and a population of 1.8 million, the Gaza Strip is considered as one of the highest population density regions over the world. The energy demand increases up to 7% annually due to the rapid growth in technologies and urbanization **[32]**. More than 63% of energy fuel is supplied by the occupying entity (Israel) which can be banned at any time. **Figure 1.4** demonstrates Gaza Strip electricity energy sources. The Gaza Strip has 694 schools (Ministry of Education, Palestine, 2012-2013); 264 schools function in both morning-evening shifts, with more than 463,567 students. Recent statistics show the importance of developing a model for energy-efficient schools; this may allow stakeholders to think about self-powered, renewable-source feeds and allow them to sell extra generated energy to other surrounding buildings.

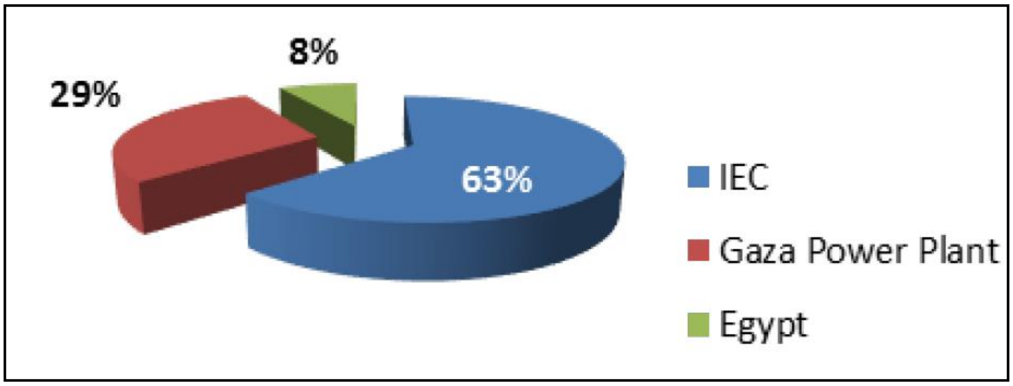


Figure 1.4 Gaza-Strip electrical energy sources **[32]**. *IEC: Israeli (Occupation entity) Electricity Company

1.2 Statement of the Research Problem

Schools in Gaza-Strip suffer from a major shortage in electricity supply. Gaza-Strip relies on unstable power supply where the electricity is offered for only about one-third or less of the day due to the unavailability of the required fuel. As a result of limited energy supply, the education process in Gaza-Strip schools is negatively affected as electricity is necessary to run both the lighting system and the required appliances. Moreover, the fuel that is used to generate electricity is imported from outside the Gaza-Strip which could be banned at any time. To solve this problem there is a need to depend on renewable emery resources that are freely available in the Gaza Strip such as solar energy.

Schools are major institutions that serve a large proportion of the total population in any country. These institutional facilities require sufficient and efficient resources for their operational purposes. Good visual and thermal comfort conditions are essential for educational institutions. Providing a better educational environment is connected directly to the need for power. Poor existing IEQ levels impede the students' productivity to reach the required levels. Classrooms' illumination levels provided from both artificial and daylight sources should be re-calculated carefully. High\low illumination levels affect strongly both energy consumption and IEQ conditions. For example, minimizing the window-wall ratio for buildings located in hot climatic conditions almost enhances the thermal comfort levels but defects daylight. The provision of adequate daylight reduces the required artificial luminaires, hence, reduces the energy consumption. However, maximizing the window-wall ratio helps in gaining more heat. For this reason, Gaza Strip schools need to be balanced between both required supplied energy and provided IEQ standardized levels. Currently, this kind of optimization is not provided.

After three brutal aggressive attacks made by the occupation entity, and after more than ten years of an unjust siege, schools have played a major role in providing shelter to families who have lost their homes, in addition to fulfilling the main educational functions to students in two morning-evening shifts. Accordingly, there is an urgent need to establish a systematic renewable power plan to provide the schools with stable and continuous energy. Unfortunately, Israel has the authority to control whether or not to provide Gaza-Strip with fuel, which leads to an unstable power supply.

1.3 Significance of the Research

The research significance is to find other solutions to operate schools in the Gaza Strip by renewable fuel sources and achieve the acceptable standardized IEQ levels.

Schools are critical and vital buildings; special care is required because of their impact on pupils and hence the society. Providing renewable fuel sources in a school, such as a photovoltaic (PV) system, will help in creating a continuity in the education process. Moreover, students will learn about those friendly environmentally technologies and discover their roles in serving the ecosystem and society.

No one can deny the accelerated pace in pollution matters. With a massive population density, the evolution in residents' needs and with the necessity to educate them about their role toward our plant, it is strongly recommended to establish a systematic renewable power plan in the Gaza Strip. Schools should be the first step in this trend and continuous improvement is required to include other building types. With large, free roof areas, the opportunity to equip schools with PV modules becomes greater. This positive culture should be transferred from students to their families, and therefore to the whole community.

Renewable technologies have several advantages if they are operated and maintained efficiently. Schools in the Gaza Strip have almost the same design and characteristics. With the absence of HVAC systems in the schools, energy consumption will be sharply reduced which will strengthen the opportunity to apply renewables. Chances for providing near-zero, zero and even plus-energy school models will be investigated by an appropriate energy-efficient plan and by renewable fuels. If applicable, it will serve the neighboring buildings of schools with a stable proportion of electricity.

The study will represent to stakeholders that renewable technologies are long-term investments. It is expected that any PV project's initial cost will be paid back over a couple of years (related to PV operational life) and be turned into profits (rather than their other social, environmental, and educational advantages locally and globally).

It is anticipated that the final outcomes of the study will open great tracks for other researchers to continue examining similar strategies for other building types (residential, commercial, industrial etc.).

1.4 Objectives

The main objective of the study is to develop an energy-efficient and cost-effective school model in Gaza-Strip utilizing (a) conserving measures and (b) renewable energy strategies while improving both visual and thermal comfort levels.

The research has the following sub-objectives in order to achieve the main objective:

a. Assessing the base-case model in terms of both energy consumption and IEQ conditions.

b. Devise energy conservation strategies to optimize the consumption of school energy with respect to IEQ levels.

c. Apply photovoltaic technology and select the best alternative.

1.5 Scope and Limitations

The study will be limited to the following criteria:

- The study will be limited to Gaza Strip schools only, so the results may not be applicable to other building types even under the same climatic conditions. However, strategies could be beneficial for other researchers to continue studying other building types and\or in other climatic conditions.

- School samples will be selected through the typical design approved by the Palestinian Ministry of Education.

- The most common L-Shape design will be investigated only.
- As a green energy source, the PV system will be investigated only, so neither wind nor other renewable sources will be considered.

1.6 Research Methodology

Well-studied energy-conserving and renewable energy plan should be provided with respect to IEQ levels. The research phases are described sequentially as follows:

Phase 1. Conduct an extensive literature review to address related studies carried out in the same field:

- A state-of-the-art literature review will be conducted to identify the Gaza Strip power sector (supply and demand);
- Sustainability trends and obstacles facing the Gaza Strip will be investigated;
- Typical school designs will be described with a provision of detailed drawings;
- For the base case formulation, sources of electricity consumption for typical school designs will be identified;
- Future of the power sector in the Gaza-Strip;
- Energy conservation strategies in schools will be studied carefully, such as energy efficient designs, lighting systems, and plug loads with applicable statistics from appropriate case studies;

- Both visual and thermal comfort standards will be studied;
- A thorough review of solar PV technology in buildings especially in schools with all system components will be conducted;
- Financial and environmental studies containing strategies for PV systems will be reviewed;
- Benefits and limitations for PV utilizations in buildings will be indicated;
- Related case studies will be selected and analyzed in regards to applying PV systems in schools;
- In order to model the base case and simulate different alternatives in the field of conserving and renewable energy strategies, suitable simulation software will be selected.

Phase 2. Base Case Modeling and Formulation: At this phase, the required data will be collected in order to model the base case. Gaza Strip typical school drawings and load profile charts will be obtained through selected school samples. Visual and thermal comfort conditions will be also be obtained from simulation results.

Other technical data, such as weather data files, solar irradiance, and statistics will be gathered from related studies and manuals.

Phase 3. Devise energy conservation strategies to improve the consumption of schools' energy with respect to IEQ levels: Suitable and practical energy conservation strategies will be investigated and an appropriate solution will be selected through different criteria:

efficiency, cost, durability, life expectancy, operation behavior and regimes, and maintenance. These strategies will be in parallel with related IEQ aspects.

Phase 4. Apply PV technology: After determining the acceptable energy saving strategies, an appropriate PV system will be technically, feasibility, and environmentally studied in respect to both minimum building energy utilization and acceptable IEQ levels.

Phase 5. **Identifying an acceptable energy-efficient school model through different alternatives:** Different alternatives will be evaluated and the most suitable models will be nominated before the final selection for the optimum one. Findings and recommendations will be highlighted for future studies. The detailed methodology process is explained in **Figure 1.5**.

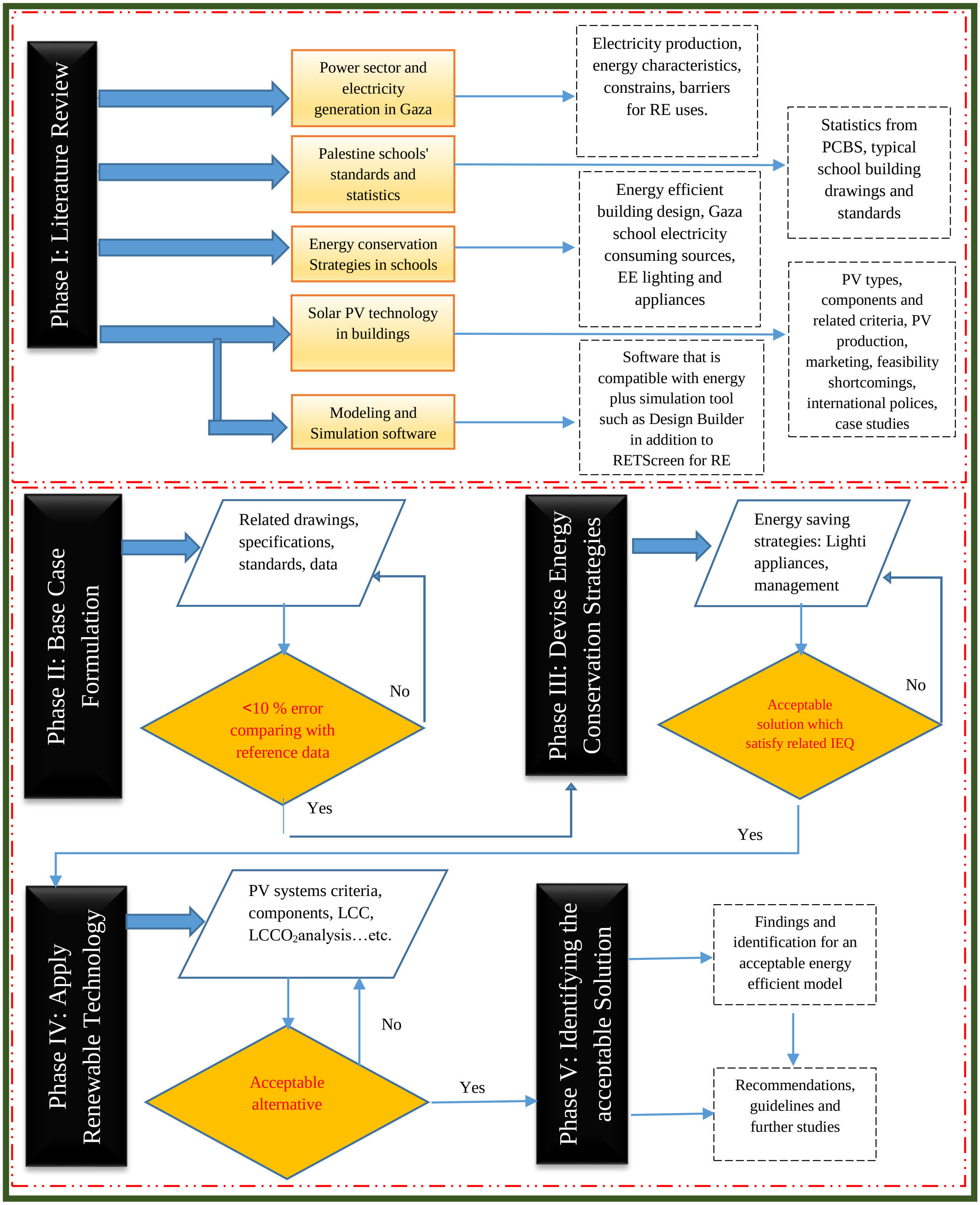


Figure 1.5 Research methodology flowchart

CHAPTER 2

LITERATURE REVIEW

2.1 Power and Electricity Sector in Palestine

2.1.1 Background

The provision of appropriate infrastructure is linked to the availability of other basic rights. One of those rights is the provision for enough energy. The Palestinian government has sought through the Energy Authority to develop the energy sector in Palestine. This kind of cooperation helped in promoting the comprehensive development process, especially on economic and social levels. Considerable progress has been noticed in the development of the energy sector. Many power networks and distribution lines have been rehabilitated and developed, and major conversion and power plants have been constructed. A plan to establish other power plant projects has been necessitated. Moreover, some renewable energy projects were applied with a thorough and deep conducted investigations and studies **[32]**.

Since 1948, the Palestinian infrastructure has suffered from a long period of neglect. Practically, production of electricity is not independent, as 97% of electricity needs are imported. The level of electricity consumption in 1999 in all of Palestine was 583 kWh/person, which is the lowest consumption level in the region; in Israel, electric consumption exceeds 6000 kWh/person **[33]**. This can be explained mainly by inadequate electric infrastructure, high transmission losses (25%), and high electricity prices.

2.1.2 Electricity Production

The Gaza power plant is the only Palestinian electricity production source, with total production capacity of 140 MW, which covers a part of the Strip and other surrounding areas. According to **[34]**, The Palestinian Electric Company (PEC) was established in 1999, with a cost of 60 million USD. Around 33% of its assets are for public shareholders and 67% are for private shareholders.

With a main production capacity of more than 10 GW, IEC is considered a monopoly of electricity production in the West Bank (WB).

Two agreements were made at the end of 2006: one with the Egyptian government to supply Rafah (south of Gaza) with a 33 kV OH line – 17 MW, and the other one is with Jordan to supply Jericho in the WB with a 33 kV OH line – 20 MW.

2.1.3 Characteristics of Palestinian Electrical Energy

According to "Mediterranean Solar Plan report" **[34]**, the following points identify some of the Palestinian electrical energy facts:

- 31% of total consumed energy is for Electricity;
- Palestine electricity (especially W.B) is completely dependent on the IEC (88%);
- Insufficient supplied quantity compared with total demand;

- Unavailability of any purchase agreement with the IEC;
- The generated electricity from Gaza Power Plant costs too much, parallel to the inability to exploit the full power of the plant;
- 18% of renewable energy contribution is in thermal utilizations;
- 75% of consumption is in domestic sector;
- High annual growth of electricity consumption (around 7%);
- High IEC tariff compared with neighbor countries;
- The absence of a unified electrical system;
- Large number of distributors (municipalities and companies);
- Inefficient collection system;
- High rate of electricity losses (26%);
- Net lending issues.

Figure 2.1 shows the sources of consumption percentages. It can be noticed that around one-third of consumed energy is in a form of electricity.

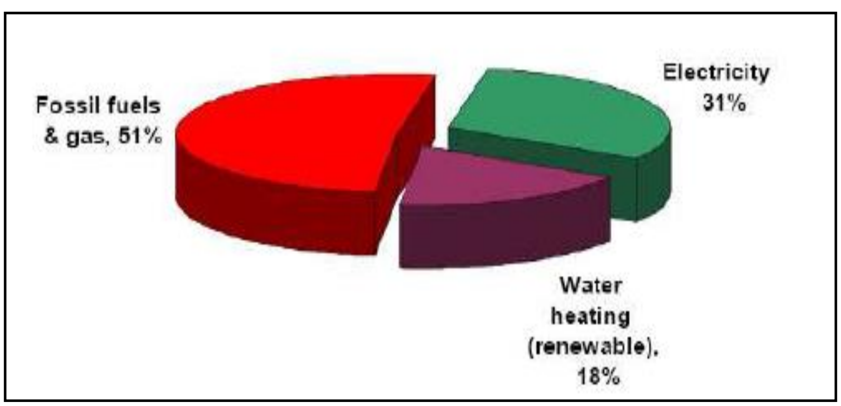


Figure 2.1 Consumption of energy in Palestine **[34]**

2.1.4 Constraints of the Electricity Sector

As indicated in "Paving the Way for the Mediterranean Solar Plan" report for Palestine **[34]**, many obstacles impede the efficient operation of the electricity sector. The following constraints have the most significance:

- IOE. They put many barriers in supplying the sufficient amount of required fuel for electricity production in Gaza-Strip, as well as in the expansion plans in W.B. Since 2006. After the occupation stroke and destroyed the only electricity company in Gaza and Palestine, and until the moment, electricity production amount reduced to one-third of normal situation;
- Local production capacity does not meet the total needs;
- Absence of an integrated electrical system;
- Difficulties in control and coordination due to Large No. of electricity distributors;
- Delay in completion of distribution companies' projects, which postpones the enhancement of electricity supply plan;
- Lack of legislation and laws regulating renewable energy;
- High initial cost for renewable energy technologies, and absence of long-term investments culture;
- Absence of any approved national strategy to promote the use of renewable energy;
- Government and private sector deficit to invest in renewable energy research;
- Lack of knowledge and trained personnel in renewable energy field;
- It is not mandatory to include any green building code in any construction project;
- Unstable political conditions of the city;
- Difficulties in importing new electrical equipment.

2.1.5 Barriers for the Promotion of Renewable Energy

A clear comprehensive and general policy for the development of renewable sources is still undeveloped. This is mainly due to a poor and separated institutional framework.

The essential policy obstacles for renewable energy promotion are **[34]**:

- Lack of legal and institutional frameworks and shortage of cooperation and coordination between stakeholders to identify and regulate renewable energy policies and utilizations;
- Lack of proper financing and incentives for such projects;
- The absence of Electrical Engineering standards regulates and identify the essential equipment for the implementation of renewable energy facilities. Thus, every contractor has the authority to choose any kind of cheap equipment for installation purposes. Developers may be tempted to choose low-cost equipment in preference to better components;
- The lack of studies and required data such as wind data and solar irradiation, which may convince the investor about the feasibility of renewable energy technologies;
- The occupation of the Israeli army along different Palestinian territories impedes the establishing of large on-grid renewable power plants, which represent the most feasible structure for these technologies.

Recently, tax exemption has been the solution for renewable energy promotion. This strategy results by the unavailability of a clear regulatory framework for renewable sources and an absence of stable and clear feed-in-tariff policy.

According to the recent status of renewable energy investments in Palestine, it will be necessary to provide additional financial support for implementing these technologies. As Palestine is not a member of the United Nation Framework Convention on Climate Change (UNFCC), it is not eligible for grants for such projects. Hence, it is strongly recommended to search for other fund resources.

2.2 School Buildings Statistics and Standards in Palestine

2.2.1 School Statistics

According to "Gaza Strip Governorates Statistical Yearbook, 2013," **[35]** the number of schools in Palestine reached to 2,753 in 2012/2013**.** 2,059 schools in WB and 694 in Gaza-Strip.

In the same year, the number of students reached 1,136,739: 990,244 students in the primary stage and 146,495 in the secondary stage. The Palestinian Central Bureau of Statistics (PCBS) **[35]** indicated that for each section there are 30.20 students in governmental schools, 36.70 students in United Nation Relief and Works Agency (UNRWA) schools and 23.40 students in private schools. The number of students per section in the secondary stage is 27.50 students in governmental schools and 17.80 students in private schools. The number of teachers reached 52,960 in 2012/2013: 21,408 are male teachers and 31,282 are female teachers.

As collected by PCBS 2012/2013, **Figure 2.2** and **APPENDIX A** show some statistics about schools and kindergartens in Palestine.

Notes:

- Symbols Legend:

- (–) Not existed
- (. .) Data not available

Statistics does not include schools and kindergartens supervised by Israeli Municipality and Culture Committee.

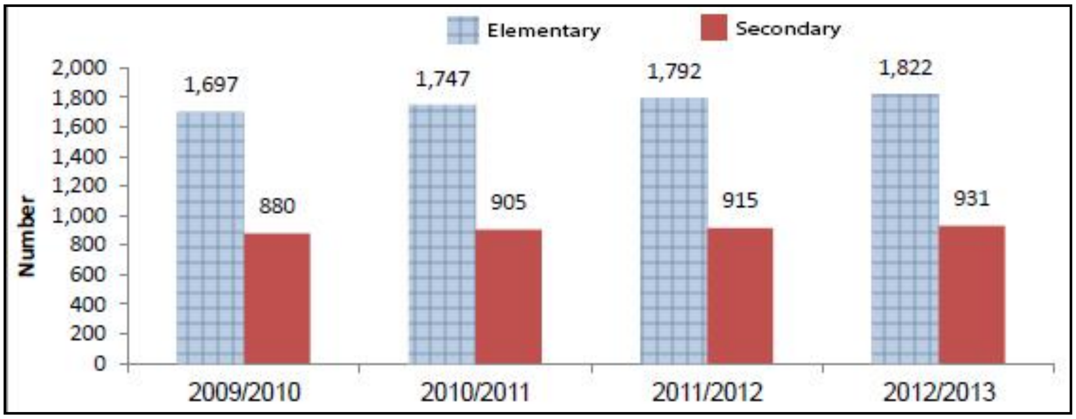


Figure 2.2 Number of schools in Palestine by scholastic year and stage

2.2.2 School Building Standards

School buildings in Palestine are typical, repeated and standardized by the Directory General for Buildings and Projects (DGBP) in the Ministry of Education. Each classroom has an area of almost 48 m^2, with 8.00 x 6.00 m and 3.4 m clear height. They are naturally ventilated and formed out of the three common shapes “I”, ”L” and “U.” Windows are distributed side-by-side among classrooms, and the exterior is almost larger than the interior windows. An opened corridor faces the classrooms from the front side and is shaded by a continues arcade. Other details such as architectural drawings and construction standards for a typical classroom, a bio-lab, a home-economic-lab and window details are shown in **APPENDIX B.**

2.3 Energy Conservation Strategies in Schools

2.3.1 Energy Efficient Design

Energy-efficiency measures can be improved and developed for both new buildings in the design phase, and for existing buildings, where such refurbishment activities are required. Chwieduk **[37]** Indicated the importance and possibility of energy savings through the implementation of traditional and modern strategies based on:

- Improvement of the building envelope, with the focus on thermal insulation and glazing;
- Improvement of residential hot-water boilers;
- Improvement of other installed equipment, e.g. Lighting and air conditioning;
- Introduction of renewable energy sources;
- Introduction of bioclimatic building design and orientation.

Any energy-efficient building has an airtight envelope, its thermal characteristic should be in a proper way, all heating and electric systems should operate efficiently and under control. All of these factors help buildings to consume less energy. However, applying energy conservation strategies is not enough. The most critical issue is what type of fuel is used to produce energy, and as a result, how much the environment is polluted because of the energy production process from the station, transmission and reaching to the end-user.

A significant improvement for IEQ could be achieved through correct energy management in school buildings **[38]**. In the field of energy conservation in schools, the interest towards this type of buildings is strongly motivated; schools have a standardized energy demand, and high levels of IEQ have to be guaranteed.

A study **[38]** conducted for thirteen schools in central Italy, concluded that a considerable amount of energy saving if E_v (Electric energy specific consumption per unit volume (kWh/m^3 per year)) and E_s (Electric energy specific consumption per student (kWh per student per year)) could be applied to all the schools. The study put some basis in order to analyze the energy consumption in school buildings:

- Availability for identified thermal and electrical consumption parameters with respect to IEQ aspects;
- Initiating the steps for a real energy diagnosis;
- Selecting optimum energy saving solutions through different alternatives and priorities.

Different criteria determine the characteristics of any school energy performance; different activities during school’s day, the hourly occupation profile and different functions for school volumes; classrooms, teacher rooms, administration rooms, laboratories, exercise rooms and toilets.

The National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy **[39]** conducted a detailed and thorough study to achieve 50% energy saving in schools in 2013. They end up with the following valuable recommendations:

- To help achieve energy savings, user-friendly design assistance\manual and recommendations should be distributed to related firms

- Taking appropriate design with respect to climate zone for building envelope, lighting systems (electrical lights and daylighting), building automation and controls, HVAC systems and solar water heating;
- Alternative strategies for HVAC and renewable energy systems could exceed 50% savings.

The most precise parameter used to evaluate any investment is the net present value (NPV) **[38]**. To Calculate NPV, the following steps must be studied: investment life, as the number of years while each system component is expected to perform efficiently, the interest rate, the initial cost for the investment, the cash flow diagram behavior as the degradation of costs during the life. By subtracting the initial investment from the cash flow during investment life, NPV will be obtained. The higher positive value for NPV, the more economically profitable will be the investment.

2.3.2 Energy Consumption Sources in Gaza-Strip Schools

Identifying the energy consumption sources in any school in Gaza-Strip is not complex. Non-provision of cooling and heating systems; HVAC or boilers (or whatever related), limits the energy consuming sources to the electricity only. Sources of electricity consumption can be classified into two main categories as the following:

2.3.2.1 Lighting

Under this category, typical lighting types are used with known characteristics **[36]**. Usually, a 2 x 36 W Fluorescent T8 Luminaire is used in classrooms with 20 degrees of protection. For the blackboard lighting, a 36 W single Fluorescent fixture with reflector is commonly used. The highest power wattage lighting is used for wall mounting purposes with 75 W. **Table 2.1** represents more detailed information about commonly used lighting in Gaza schools.

Gaza-Strip schools run in two morning\evening shifts annually. This necessitates the need for identifying the lighting operational profile. A well-studied plan for lighting system should be provided and investigated technically, comfortably and economically in order to achieve occupants lighting comfort requirements.

Table 2.1 Common used lighting in Gaza-Strip schools (Ref: Approved Typical School Drawings by Ministry of Education)

BOQ	LAMINAIR	LAMPS			DESCRIPTION	DEGREE OF PROTECTION	SYMBOL
ITEM NO.	TYPE	TYPE	NO.	NOMINAL POWER			
13.1	A	FLUO.	2	2X36W	FLUORESCENT FIXTURE MOUNTING: CEILING SURFACE MOUNTED HOUSING: OF SHEET STEEL , WHITE ENAMELED BALLAST SOUND PERFORMANCE SUITABLE FOR AN AMBIENT NOISE LEVEL INTERIOR OF: 42 Db	IP20	
13.	B	FLUO.	1	36W	FLUORESCENT FIXTURE WITH REFLECTOR FOR BLACK BOARDS MOUNTING: CEILING SURFACE MOUNTED HOUSING: OF SHEET STEEL , WHITE ENAMELED BALLAST SOUND PERFORMANCE SUITABLE FOR AN AMBIENT NOISE LEVEL OF INTERIOR OF: 42 Db	IP20	
13.10	C	INC.	1	75W	WALL SURFACE MOUNTED. BODY : POLYMADE WITH 30% FIBERGLASS. DIFFUSER MADE OF WHITE POLYCARBONATE, ALUMINUM REFLECTOR COLOR WHITE	IP45	

Figure 2.3 shows typical lighting fixtures distribution, (a), (b) and (c) represent different selected spaces in a school.

Almost 6-8 luminaires are installed in each typical classroom with 12-16 single bulbs, each bulb is rated at 36 W and ceiling mounted. All luminaries are distributed equally among the space, however, the illumination level is not identified. High\low illumination levels should be avoided, and the selection for lighting type, distribution map and luminaires quantities should be directly linked to the target illumination level.

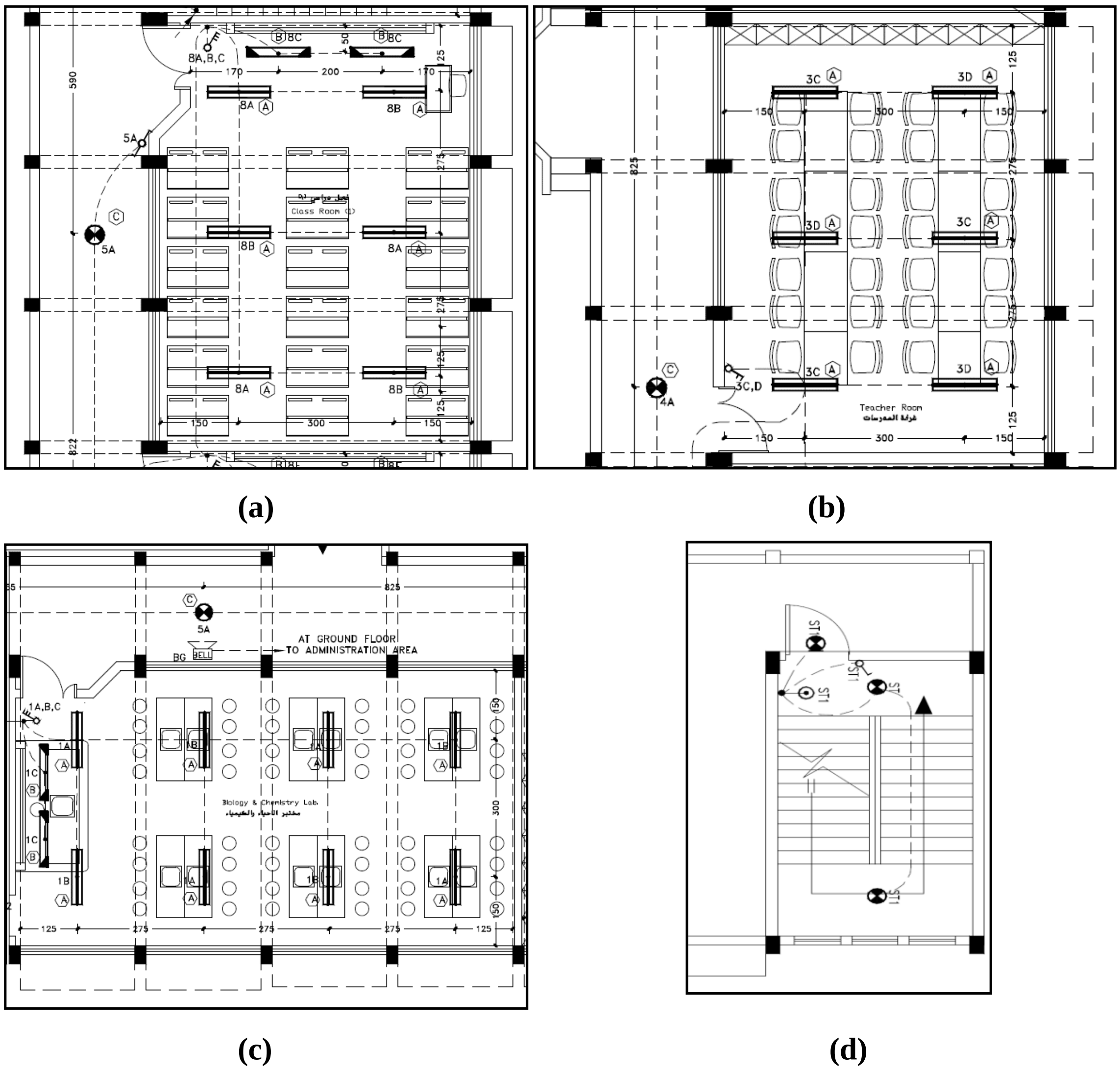


Figure 2.3 Typical distribution for lighting fixtures, (a) Classroom, (b) Teachers room, (c) Laboratory, (d) Stairs.

2.3.2.2 Appliances

This category is the second major electricity consumption source. In order to achieve educational requirements, different appliances should be applied in a proper way and sufficient amounts. The Variation in appliances types and operational profiles leads to difficulties in studying electricity consumption characteristics. There are priorities in appliances utilization. Some of them are part of core educational objectives, such as computers, printers, LCDs … etc. Other appliances play a secondary role as a part of occupant satisfaction, requirements and comfort, such as; ceiling fans, kitchen appliances … etc. **Table 2.2** Summarizes possible used lighting fixtures and appliances with both quantities and wattages in each space for Gaza-Strip schools.

Table 2.2 Sample of lighting fixtures and used appliances quantities and wattages for each space in Gaza-Strip schools (Ref: School drawings)

Space	Number of space	Light	Number of unit	Power(watt)	Appliances	Number of unit	Power(watt)
Classes	12	Duoble fluorescent tube	6	36			
Classes	12	Single fluorescent tube	2	36			
Computer lab	1	Duoble fluorescent tube	8	36	Computer	20	300
	1	Single fluorescent tube	2	36			
Science Lab.	1	Duoble fluorescent tube	8	36	LCD	1	500
		Single fluorescent tube	2	36	Computer	1	300
					Refrigerator	1	380
TeacherRoom	1	Duoble fluorescent tube	6	36	Laptop	3	150
					Telephone	1	25
					Alarm	1	50
					Printer	1	100
					Changer	5	66
					Radio	1	26
Library	1	Duoble fluorescent tube	8	36	Computer	1	300
Headmaster Room	1	Duoble fluorescent tube	4	36	Computer	1	300
					Charger	1	66
					Telephone	1	25
Secretary	1	Duoble fluorescent tube	2	36	Printer	1	450
					Telephone	1	25
					Computer	1	300
					Small printer	1	100
					Charger	1	66
W.C.	1	B.L. light	4	15	Water heater	1	1200
Buffet	1	B.L. light	2	15	Refrigerator	1	380
					Kettle	1	1500

Note: Total lighting power = 21.384 kW.
Total appliances power = 12.259 kW.

2.3.3 School Energy Efficient Lighting system

Benya **[40]** recommended six points for efficient utilization of any school building lighting system as the following:

1. Use different daylighting strategies. Design an integrated day\artificial lighting system with response to changes in received daylight levels.

2. Select the best light source fits each application. Considering the color rendering quality from the light source, used materials and furniture colors.

3. Use the most appropriate luminaires. For instance, modern technology for direct-indirect luminaires are 85 to 90 percent efficient. Less in accumulated dirt by using open bottomed fixtures.

4. Select luminaires that produce better coefficient of utilization (CU). The CU takes into account the characteristic of the installed fixture (especially the indirect luminaires) within a space.

5. Design with the assistance of latest international standards such as Illuminating Engineering Society of North America (IESNA).

6. Use smart and modern lighting controls. Different lighting control strategies could be applied varying from occupancy sensors, dimming lights, energy management systems, smart switches control and daylight sensor.

Providing less than 13 W/m^2 for school interior design is considered within a high-performance school **[40]**. UK lighting systems in schools **[41]** Indicated that UK's government allocated 110 million £ to reduce carbon emissions by 60% in all new schools. Reaching to this extent requires using an energy-efficient lighting system with a provision for an appropriate control system (if applicable). Designers must be careful when they select lamps, luminaires, control systems, and illuminance levels.

At around 28%, artificial lighting is considered as the largest source of energy consumption in schools **[41]**. For that reason, optimum solution for lighting installation offers the greatest potential for saving energy parallel with responsible management, design, specification and controls. Furthermore, automatic lighting controls can save 30-40% of electricity consumption comparing with manual switching.

2.3.3.1 Daylighting

Daylighting reduces the energy consumed by artificial lightings in schools from 30-70 % **[27]**. Issa, et al. **[42]** reviewed some studies which investigated the indirect effectiveness for daylighting and student performance. More than 20% improvement in math tests and 26% in reading test for pupils could be achieved by efficient and sufficient daylighting. In addition, 13% increase in students' mental function by adequate daylight.

Daylighting standards have been changed Through the last decades. Wu and Ng **[43]** Summarized these changes in the UK as shown in **Table 2.3**. Daylight should be integrated with artificial lighting in order to satisfy the required illumination level for each school space. IESNA 9th edition handbook specified the required illumination level for different buildings. As shown in **Table 2.4**, an amount of 300 lux is required for kids' students and 400 lux for adults as well as for lecture halls at 0.8 m height from the ground **[44]**.

Several reflections occurred while a portion of 28000 lux (whole sky luminous) penetrates through space openings. Furniture, walls and ceiling are the most critical factors with regard to skylight reflections. By the presence of furniture and pin-up material, it is recommended that the reflectance of the wall surface finish should not be less than 0.6 and at least 0.7 for ceiling **[45]**.

Table 2.3 A summary of schools' daylight regulations and standards in the different periods in Britain **[43]**

Code	Recommended daylighting in classrooms
The London Building Acts 1894[59]	One-fifth the floor space for vertical lights in classrooms. Recommended illuminances in classroom is 9 footcandles (91 lux)
British Standards Codes of Practice, 1945[14]	A minimum 2% daylight 'sky factor' in classrooms, and 5% sky factor where possible in the classroom
IES lighting code, 1955[62]	The level of maintained illuminance and the daylighting factor in classrooms should be not less than 10 lumens per square foot (100 lux) and 2%, respectively
CIBS lighting code, 1977[63]	The minimum illuminance on working plane should be not less than 300 lux
The Education (School Premises) Regulations 1981[64]	For the daylight illuminance to be adequate for the task, it is necessary to achieve a level of not less than 300 lux. When the lighting of a space is achieved by a combination of daylight and artificial light, the regulations insist on a minimum illuminance of 350 lux.
CIBSE code for interior lighting, 1984[66]	Same as the Education (School Premises) Regulations 1981. Recommended illuminances in classroom is 300 lux.
CIBSE code for interior lighting, 1994[67]	Same as the Education (School Premises) Regulations 1981. Recommended illuminances in classroom is 300 lux.
Guidelines for environmental design in school, 1997[68]	The school premises: recommended illuminances in classroom shall be not less than 300 lux on the working plan. Recommended constructional standards: whenever possible, a daylit space should have an average daylight factor of 4–5%.

Table 2.4 IESNA 9th Edition Handbook lighting standards for educational buildings **[44]**

Building Type	Space Type	Maintained Average Illuminance at working level (lux)	Measurement (working) Height (1 meter = 3.3 feet)
Educational buildings	Classrooms	300	at 0.8 m
	Classrooms for adult education	400	at 0.8 m
	Lecture hall	400	at 0.8 m

2.3.3.2 Artificial Lighting

Bonnema, et al. **[39]** Used standardized lighting power densities (LPDs) to model artificial lighting. These values were determined by using the space-by-space method in (ASHRAE 2004b) standard. However, with the contribution of daylighting, an efficient lighting system was achieved by using hour-by-hour lighting dimming schedules for certain spaces types. **Table 2.5** shows the LPDs used in the low-energy models compared to standards.

Table 2.5 Low-Energy LPD by Space Type **[39]** (Note: $1 ft^2 = 0.0929 m^2$)

Space Type	Baseline LPD (W/ft^2)	Low-Energy LPD (W/ft^2)
Auditorium	0.9	0.5
Art room	1.4	0.8
Cafeteria	0.9	0.7
Classroom	1.4	0.8
Corridor	0.5	0.4
Gym/multipurpose room	1.4	1.0
Kitchen	1.2	0.8
Library/media center	1.2	0.8
Lobby	1.3	0.7
Mechanical	1.5	0.4
Office	1.1	0.6
Restroom	0.9	0.5
Calculated whole building Primary school	1.2	0.7
Calculated whole building Secondary school	1.1	0.7

Table 2.6 Lighting Sources for School Uses **[40]**

Light Source/System	Mean Lumens per Watt	Luminaires	Types of Spaces in a School
Fluorescent T-5 linear with programmed start electronic ballasts (24-, 36-, 48-, and 60-inch lengths)	91	Specialty lighting, such as under-cabinet, suspended indirect, wallwashing	Classrooms, offices, multipurpose rooms, libraries
Fluorescent T-8 second-generation linear with electronic instant start ballasts or programmed start ballasts (24-, 36-, 48-, and 60-inch lengths)	92	General lighting in troffers, suspended lighting systems, wraparounds, strips	Classrooms, offices, multipurpose rooms, lockers, toilets, stairs, libraries, utility areas, hallways, corridors, labs, music rooms, shops, studios
Fluorescent T-5 HO linear with programmed start electronic ballasts (24-, 36-, 48-, and 60-inch lengths)	81	Specialty lighting applications where high lumen output is needed	Gyms, pools, libraries, offices, multipurpose rooms
Compact fluorescent triple tube lamps (18, 26, 32, and 42 watts) with electronic ballasts	50–72	Downlights, sconces, wallwashers, utility lights, wall brackets, table and task lamps	Lobbies, offices, multipurpose rooms, toilets, halls and corridors, utility spaces, exterior canopies, walls, bollards, utility applications
Pulse start metal halide lamps (250 watts or higher)	55–78	Industrial style downlights, parking lot lights, roadway lights, large wallwashers, specialized uplights, floodlights, sports lights	High-ceiling interior spaces (some gyms, pools), parking lots, sports fields, other pole-mounted exterior lighting
Pulse start ceramic metal halide lamps (150 watts or lower), with electronic ballasts	35–65	Track and recessed display lighting	Feature displays
Halogen IR lamps (60 to 100 watt PAR-38, 50 watt PAR-30) or low voltage halogen IR lamps (37 watt MR16)	20–30	Track and recessed display lighting, surface and recessed downlighting	Feature displays and house lighting for theaters, performance spaces, and multipurpose rooms

Lighting fixtures used in schools should be commercial grade, similar to the equipment used in other building types that satisfy occupants with less energy consumption. Efficiency, glare control, durability, cost, and maintainability should be investigated carefully. **Table 2.6** shows possible lighting sources for school uses.

Schools in Hong Kong basically use fluorescent tubes, compact fluorescent lamp (CFL) and halogen lights with well-lighting control systems such as: Daylight and motion sensors and enhanced lighting control point **[46]**. **Table 2.7** lists recommendations for lighting and control systems. While **Table 2.8** demonstrates general retrofit guidances for existing school improvement in Hong Kong.

Table 2.7 General lighting & control recommendations in Hong Kong schools **[46]**

Area Served	Lighting	Control
Classroom & Office	• T5 tube • LED tube • LED panel	• Motion sensor with more lighting control point • Daylight sensor incorporating high frequency ballast transformer (dimmable) for T5 shall be considered for lighting near window area
Auditorium / Indoor Sport Ground	• T5 tube • CFL • LED flood light / spot light	• Manual ON/OFF control
Corridor	• T5 tube • CFL	• Daylight sensor
Exit sign light	• LED	• N/A (as 24/7)
Toilet	• T5 tube • LED tube • CFL	• Motion sensor
Display Area / Cabinet	• LED spot light	• Timer control
Outdoor Sport Ground	• LED flood light	• Timer control with manual override
Landscape Area	• LED flood light • Hybrid Lamp • Solar Bollard Light	• Built-in daylight sensor

Table 2.8 General retrofit guidances for an existing school in Hong Kong **[46]**

	Fluorescent Tube	CFL	Halogen Light
Retrofit Option	T8 to T5	CFL to LED bulb	Spot Light (MR12) / Flood Light to LED
Retrofit complexity	Luminaires and ballasts might need replacement*	Simple bulb replacement	Simple lamp replacement
Estimated Annual Saving per Lamp	16 kWh (25-Watt light bulb for 600 hours)	30 kWh (25-Watt light bulb for 1,700 hours)	78 kWh (25-Watt light bulb for 3,120 hours)

Loe **[45]** Illustrated the standard maintained illuminance (lux), uniformity ratio and limiting glare index for schools lighting system as shown in **Table 2.9**.

Table 2.9 Illuminance, Uniformity Ratio and Limiting Glare Index for different school areas **[45]**

		Standard Maintained Illuminance lux	Uniformity Ratio	Limiting Glare Index
1.	General Teaching Spaces	300 *	0.8	19
2.	Teaching Spaces with close and detailed work (eg, art and craft rooms)	500 *	0.8	19
3.	Circulation Spaces:			
	corridors, stairs	80 - 120	-	19
	entrance halls, lobbies & waiting areas	175 - 250	-	19
	reception areas	250 - 350	-	19
4.	Atria	400 *	-	19

A study conducted in South Korea **[46]** indicated that the most effective energy efficiency scenario through different alternatives is replacing the existing lighting with light-emitting diode (LED) fixtures with respect to LCC analysis.

The lighting costs for a building can be categorized into two parts **[41]**:

- Capital cost, including the cost of installation. This will typically be around 3% of the total construction cost of the building.

- Running costs, including both energy, maintenance and replacement costs.

2.3.3.3 Lighting Control Systems

Hong Kong Green School Guide **[47]** Introduced some of most efficient lighting control systems used in Hong Kong schools. They include:

- Daylight sensor or photocell sensor that has two functions: Control the operation for artificial lights or dims them according to daylight levels in order to achieve required illuminance levels;

- Motion sensor or infrared sensor that controls the operation of the lighting according to occupancy; and

- Lighting control point or zoning which means that for each zone there is one control point. This strategy helps to consume less electrical energy through operating the required luminaires only.

Other control systems were investigated by **[41]** such as: Time switch which could be used for switching off the main lighting automatically with known occupancy schedule. **Figure 2.4** shows different lighting control systems. **Figure 2.5** shows an example of optimum classroom lighting components and distributions.

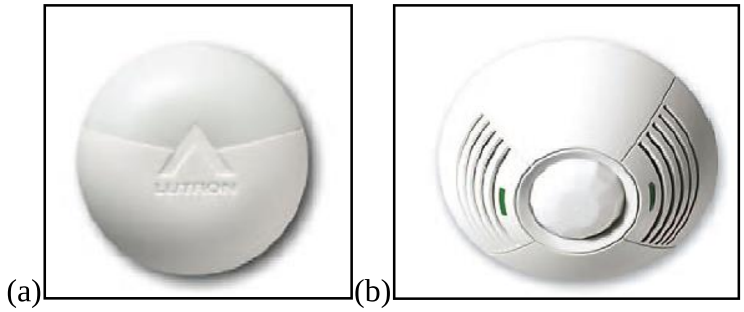


Figure 2.4 Lighting control systems. a) Photoelectric lighting sensor, b) Occupancy sensor

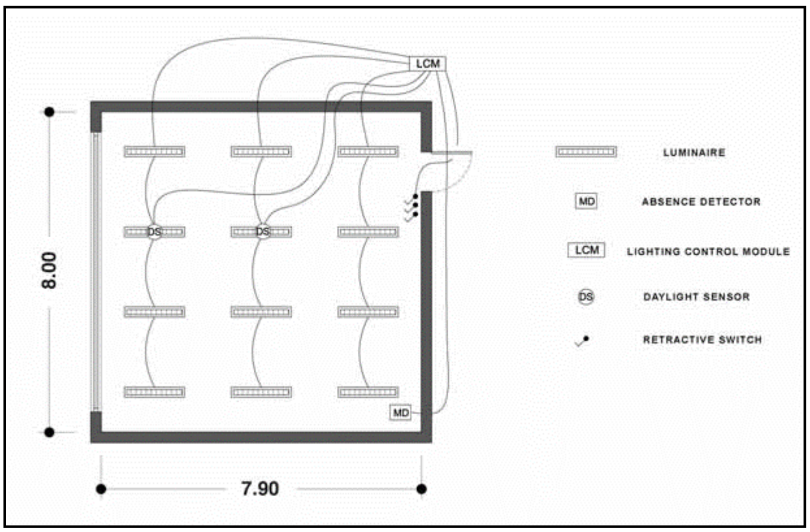


Figure 2.5 Plan view of classroom with luminaires perpendicular to the window, complete with switching arrangement **[41]**

2.3.4 Plug and Process Loads

Energy efficient appliances, smart plugs control and identified and standardized each occupant electrical equipment utilization can improve the energy performance of schools efficiently. A reduction of 40 % was achieved by applying the following strategy for plug and process loads in USA schools **[39]**:

- Low-energy computer lab loads: 3.8 students per computer was assumed. As well as assuming 30 W laptops or mini-desktops and 18 W LED-backlit flat panel monitors.

- Low-energy staff computer loads.

- Low-energy staff miscellaneous loads: Each staff member (if any) has an energy-efficient 80 W TV and a 40-W VCR/DVD player. For every two staff members, a 125 W refrigerator and a 1,000 W microwave. Four staff members with one 1500 W space heater.

- Low-energy office loads: An additional estimated 85 W per staff member for items such as phones, task lights, printers, and other office equipment.

2.4 Solar PV Technology in Buildings

2.4.1 Background

Recently, the world energy consumption exceeded 10 terawatts (TW) annually, and it is projected to be more than 30 TW by 2030. Hence, about 20 TW of clean energy is required to be efficiently used by the mid-century **[49]**. A scenario was indicated to replace carbon-based fuels by 10 TW of PV and the same amount of hydrogen for transportation and 10 TW fossil fuel for heating purposes. Thus, PV will be considered as a cornerstone in the world future demand

By using solar cells, PV systems directly convert direct and indirect sunlight into electricity. Furthermore, PV is considered as one of the most utilized on-site renewable energy. It has several advantages **[48]**: Capable of reducing a sufficient amount of GHGs emissions and other pollutants, support national and international economic growth through market development and job creation and improve power and supply quality and reliability.

A PV system consists of several components like cells, batteries, converters, inverters and other electrical and mechanical connections and parts. These systems are rated in peak kilowatts (kWp) which are the amount of delivered electrical power from the direct overhead sun **[50]**. **Figure 2.6** shows different PV components and their arrangement.

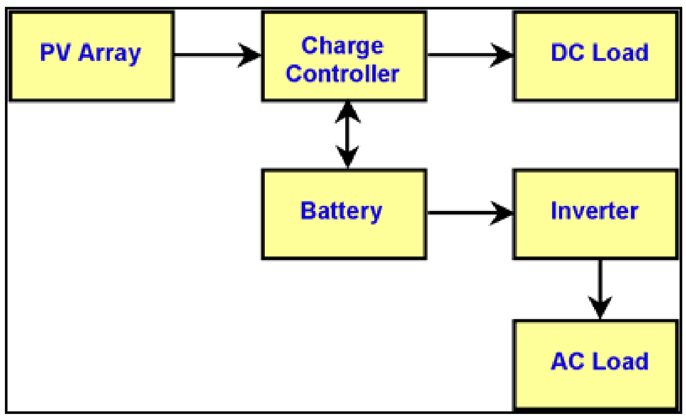


Figure 2.6 PV system components **[51]**

At the 1980s, PV marketing started in growth because of the application of PV huge power generation plants. Similar to computer and telecommunication sectors, nowadays, PV market grows rapidly (30-40%), reached in 2009 to a production of 10.66 GW globally **[49]**. **Figure 2.7** shows the characteristics of PV production in GW in different locations.

PV system has sensitive and specific criteria in order to run efficiently. Usually, they behave in the field with less quality than in laboratories. However, Manufacturers provide technical and operation parameters at only ideal conditions.

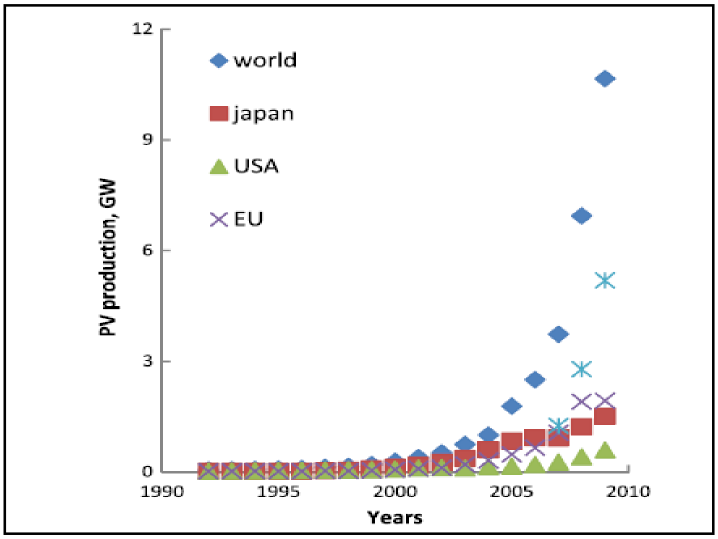


Figure 2.7 PV production trend in different locations **[49]**

It should be noticed that PV panels could operate over wide range conditions in which different readings could be obtained **[52]**. As a result, a tool to predict the real energy production at a specific location is required.

Mean daily inputs such as: Temperature, humidity, wind speed and solar irradiance were collected as required data for modern online forecasting models for PV power system by using Radial Basis Function (RBFN) **[53]**. This method essentially helps in an efficient planning for PV power systems operation.

2.4.2 PV System Components and Effective Criteria

2.4.2.1 Solar Radiation and Insolation

In any PV system design, it is too important to know the amount of sunlight at particular time and location. Solar radiation and insolation are two methods in which characterize sunlight. The solar radiation or radiance is "an instantaneous power density received by one square meter area at specific time and location (kW/m^2)" **[54]**. The variation of solar radiance is from 0 kW/m^2 at night to 1 kW/m^2 at mid-day in which the peak reading is usually obtained. The solar insolation is "the total amount of solar energy received at a particular location during a specified time period, often in units of kWh/(m2/day)" **[54]**. Solar radiance is commonly used in complicated PV systems, while solar insolation for simple ones.

2.4.2.2 Temperature

It is clear that PV cell efficiency decreases with an increase of temperature **[56]**, and as such cooling system is required. Monocrystalline silicon is affected by temperature influence more than other PV cell types; it decreases by 15 % while 5% decreasing in the thin film solar cell. Dust is also affecting the PV efficiency because it may block the coming sunlight onto PV modules.

2.4.2.3 Common Materials for Solar Cells

The brief overview of different solar cell materials is shown in **Figure 2.8**. Due to its high efficiency, silicon is the pioneering technology in PV material production. However, and because of its manufacturing high cost, other materials for solar cell were investigated. Thin film technology has low costs because it uses less and thinner materials than crystalline cells. However, the efficiency of this type is not enough comparing with other common solar silicon cells. Under thin film technology, two materials arose, and they are; Cadmium Sulphide/Cadmium Telluride (CdS/CdTe) and Copper Indium Gallium Selenide (CIGS), and huge efforts are exerted to increase their efficiency.

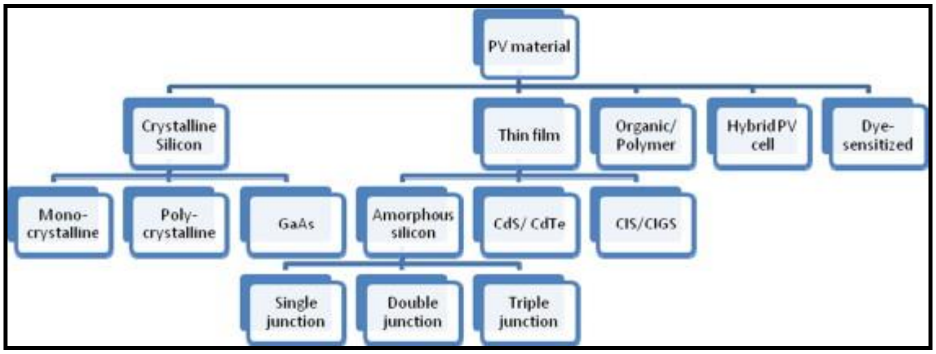


Figure 2.8 Common solar cell materials **[57]**

2.4.2.3.1 Silicon

Silicon technology has been considered as the dominant one for PV power production. Multi-crystalline silicon and monocrystalline silicon being classified under high-efficient solar cells while the thin film still in growth **[50]**. Tyagi, et al. **[55]** indicated that silicon cell lifetime ranges from 20–30 years. Two major categories are classified under silicon technology, and they are:

a. Amorphous Silicon (a-Si)

Amorphous (uncrystallized) silicon is the most used and efficient thin-film with 5–7% cell efficiency, and it was exceeded to 8-10% by double and triple junction technologies **[50]**. However, it is exposed to degradation through the life cycle. Some of the classifications of a-Si are amorphous silicon germanium (a-SiGe), amorphous silicon carbide (a-SiC), microcrystalline silicon (c-Si), and amorphous silicon-nitride (a- SiN).

- *A-Si, double or triple junctions*

This technology allowed for increasing (a-Si) cell efficiency to at approximately 12% **[55]**. However, single junction a-Si modules usually have a degradation characteristic after exposing to sunlight ranges from 4-8%. This kind of degradation motivated researchers to study the opportunity for multiple-junction a-Si to increase solar module efficiency.

b. Crystalline Silicon

This type of solar cells offers better efficiency amorphous silicon. The most two popular technologies under this category are:

- *Mono-crystalline*

Mono-crystalline cell has the most proportion of PV market with 80% from other solar cell types. The maximum efficiency of this type has reached to 24.7% **[55]**. According to NREL, it was announced that a 20.4% solar panel efficiency was achieved and it is expected to have better life and price.

- *Poly-crystalline*

A great effort was exerted in order to reduce the mono-crystalline price. This led to a development for non-pure silicon cell, which has a good efficiency (around 15%), and low production cost. Initially, poly-crystalline was the most popular solar cell with high cost $340/kg **[55]**. Although poly-crystalline cell has less efficiency than mono-crystalline, it is more attractive due to its low manufacturing and marketing cost.

2.4.2.3.2 Cadmium Telluride (CdTe) and Cadmium Sulphide (CdS)

CdTe has many advantages, it has the ideal band-gap (1.45 eV) parallel to its high and direct absorption coefficient and recognized as a promising PV material for thin-film technology **[55]**. CdTe with the small-utilized area and 15% efficiency have been demonstrated. Unlike other thin film solar cells, these types can be used in large-scale PV power plants, ex: 5 MW, 10MW, 40MW in Ohio (USA), Germany, Abu Dhabi (UAE) respectively.

2.4.2.3.3 Organic and polymer cells

Thin films (100 nm) are the base material for manufacturing organic and polymer solar cells. This type reached the highest 4–5% efficiency currently using conductive polymers **[55]**. However, its mechanical flexibility gives a great value to this material. In contrast with conventional types, the manufacturing process for organic and polymer cells is cost effective with less technical obstacles and challenges.

2.4.2.3.4 Hybrid solar cell

This type for solar cells is made from the combination of crystalline and non-crystalline materials. Higher efficiency to cost ratio was achieved by mixing amorphous silicon with crystalline silicon **[55]**. Sanyo (famous Japanese solar cell manufacturer) has achieved 21% efficiency and it plans to commercialize this technology

2.4.2.3.5 Dye-sensitized solar cell

A competent technology, which it is planned to overcome efficiency, cost and environmental problems. It is considered as a good competitor to recent materials in producing solar cells. Dyesol (Australian solar developer) is seeking to benefit from this low-cost solar cell to be an efficient material in solar integrated building design such as glazing, sun breakers and roof sheets **[58]**.

2.4.2.4 Batteries

Storage batteries are substantial in every standalone PV system. Two factors affect strongly the overall PV system efficiency: Batteries efficiency and lifetime. High cycling stability and deep discharge rate are required for any PV battery system. An experiment **[59]** proved that fully discharging for regular lead acid battery affects strongly its lifetime. This issue requires a controller system for charging process to protect batteries from deep discharging and overcharging in order to extend their lifetime and improve feasibility for any PV system. In addition, the watt-hour (Wh) efficiency of a battery is normally less than the ampere-hour efficiency, which leads to the necessity to depend on watt-hour while designing such storage system.

Other new batteries types such as high-speed flywheel and the vanadium redox battery are considered as a potential alternative for common Lead-acid battery type.

2.4.2.4.1 Lead-Acid batteries

The charge-discharge process of this type of batteries is essentially volatile. With non-provision for any harmful chemical action and with low energy density and specific energy, the lead-acid battery can perform efficiently over a wide temperature range. Moreover, low manufacturing cost with good performance, make a lead-acid battery to take the lead for most energy storage systems. However low cycle-life is a limitation for this type.

2.4.2.4.2 Nickel-Cadmium batteries

This type is the most popular alkaline secondary battery (which used aqueous alkaline solution (KOH or NaOH) as the electrolyte). Many advantages could be gained vary from available several sizes, long-cycle life, excellent long-term storage, good charge retention and low maintenance. However, it has a low energy density and high cost comparing with lead-acid batteries.

2.4.2.4.3 Nickel-Iron batteries

Nickel-Iron batteries were used in mining and underground vehicles, railroad, stationery applications and some trucks. With its nickel-plated steel, it could be used efficiently in difficult rugged construction sites. Several advantaged of this type such as: long-life and durability are not enough to overcome disadvantages such as: low specific energy, temperature problems and high cost **[59]**.

The Handbook of Secondary Storage Batteries and Charge Regulators in PV Systems **[60]** indicated more detailed data for different types of batteries and their characteristics and life-cycle cost. Batteries cost in any PV system may vary from 10-50% from total cost depends on PV system size and type. Batteries prices are not stable because of the fluctuated material prices with market forces. Two types in which battery energy costs could be expressed: Dollars per battery subsystem and dollars per kilowatt-hour ($/kWh). Divya and Ostergaard **[61]** Illustrated more details about battery technologies and their characteristics and some other specifications as shown in **Table 2.10**.

2.4.2.5 Charge and Voltage Regulators

Charge regulators or controllers are essential in PV system, which a battery storage exists. The main function is to regulate the current comes from PV array to the battery in order to control received current and save batteries. The output of the voltage regulator determined by the electrical characteristic for batteries. Proper charge conditions for batteries could not be achieved without charge controllers. As known, excessive overcharge would reduce battery life and reduce system cost feasibility, regulators are necessary in order to avoid such problems.

Table 2.10 Summary of battery technologies and some related specifications **[61]**

Battery type	Largest capacity (commercial unit)	Location & application	Comments
Lead acid (flooded type)	10 MW/40 MWh	California-Chino Load Leveling	η = 72–78%, cost [d]50–150, life span 1000–2000 cycles at 70% depth of discharge, operating temperature −5 to 40 °C [a], 25 Wh/kg, self-discharge 2–5%/month, frequent maintenance to replace water lost in operation, heavy
Lead acid (valve regulated)	300 kW/580 KWh	Turn key system [b] Load Leveling	η = 72–78%, cost [d]50–150, life span 200–300 cycles at 80% depth of discharge, operating temperature −5 to 40 °C [a], 30–50 Wh/kg, self-discharge 2–5%/month, less robust, negligible maintenance, more mobile, safe (compared to flooded type)
Nickel Cadmium (NiCd)	27 MW/6.75 MWh [c]	GVEA Alaska Control power supply Var compensation	η = 72–78%, cost [d]200–600, life span 3000 cycles at 100% depth of discharge, operating temperature −40 to 50 °C, 45–80 Wh/kg, self-discharge 5–20%/month, high discharge rate, negligible maintenance, NiCd cells are poisonous and heavy
Sodium Sulphur (NaS)	9.6 MW/64 MWh	Tokyo Japan Load Leveling	η = 89% (at 325 °C), life span 2500 cycles at 100% depth of discharge, operating temperature 325 °C, 100 Wh/kg, no self-discharge, due to high operating temperature it has to be heated in stand-by mode and this reduces its overall η, have pulse power capability of over 6 times their rating for 30 s
Lithium ion			η ≈100%, cost [d]700–1000, life span 3000 cycle at 80% depth of discharge, operating temperature −30 to 60 °C, 90–190 Wh/kg, self-discharge 1%/month, high cost due to special packaging and internal over charge protection
Vanadium redox (VRB)	1.5 MW/1.5 MWh	Japan Voltage sag Peak load shaving	η = 85%, cost [d]360–1000, Life span 10,000 cycles at 75% depth of discharge, operating temperature 0–40 °C, 30–50 Wh/kg, negligible self-discharge
Zinc Bromine	1 MW/4 MWh	Kyushu EPC	η = 75%, cost [d]360–1000, operating temperature 0–40 °C, 70 Wh/kg, negligible self-discharge, low power, bulky, hazardous components
Metal air			η = 50%, cost [d]50–200, Life span few 100 cycles, operating temperature −20 to 50 °C, 450–650 Wh/kg, negligible self-discharge, recharging is very difficult and inefficient, compact
Regenerative fuel cell (PSB)	15 MW/120 MWh (under development)	Innogy's Little Barford station UK	η = 75%, cost [d]360–1000, operating temperature 0–40 °C, negligible self-discharge

[a] Operating at higher temperature will reduce the life and operating at lower temperature will reduce the efficiency.
[b] At Milwauke, Wisconsin.
[c] Provides 10 MVar even when the battery is not discharging.
[d] Capital cost in Euro/kWh.

2.4.2.6 Inverters

Inverters essentially used to convert received PV DC current to AC type. In last 20 years, too many systematic researches and great-exerted efforts have been conducted in many industrialized countries to make PV applications more reliable and efficient. **Figure 2.9** shows the key role for inverters in any PV system. In these systems, inverters must operate over wide DC voltage, be user safety, regulate output frequency and voltage, provide high-quality AC power, attract maximum-power-point from PV array and operate in wide range temperatures **[62]**.

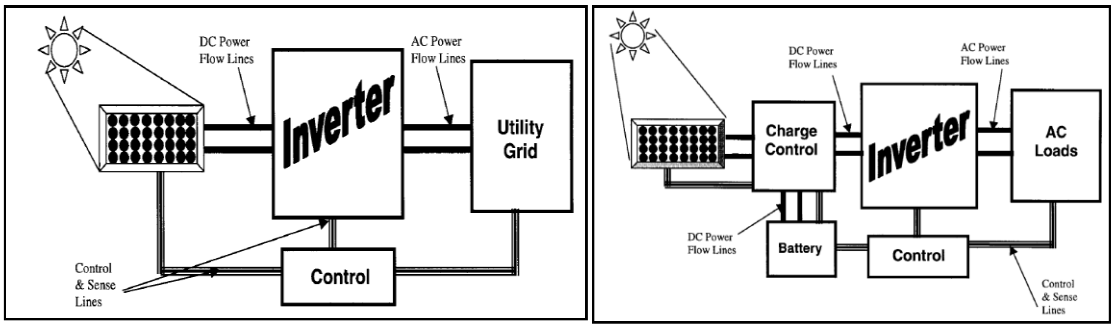


Figure 2.9 Key role for the inverter in PV system, a) Grid-connected PV system, b) Stand-alone PV system **[62]**

2.4.2.7 PV Mounting

PV mounting systems are the ways in which solar panels are fixed, such as roofs and building facades or on the ground. Roof mounting is the most popular way to fix PV modules in a building. PV modules orientation and inclination angles must be clearly determined in order to distribute PV panels space-efficiently. Other aspects such as the provision of walkability for maintenance staff and PV structure load must be considered.

Ground mounting commonly used for large-size power plants in which PV arrays feed the power station directly. This fixing type is rarely used in residential and commercial utilization due to non-area provision, shading problems and security issues. Other mounting ways like building-integrated PV (BIPV) system and PV as shading devices have several advantages. Initial and life-cycle costs for the contemporary materials are indications for more feasible and cost-effective projects. **Figure 2.10** shows different methods for PV mounting.

(a) (b) (c) (d)

Figure 2.10 Different PV mounting methods, a) Roof mounting, b) PV as shading device, c) Ground mounting, d) BIPV

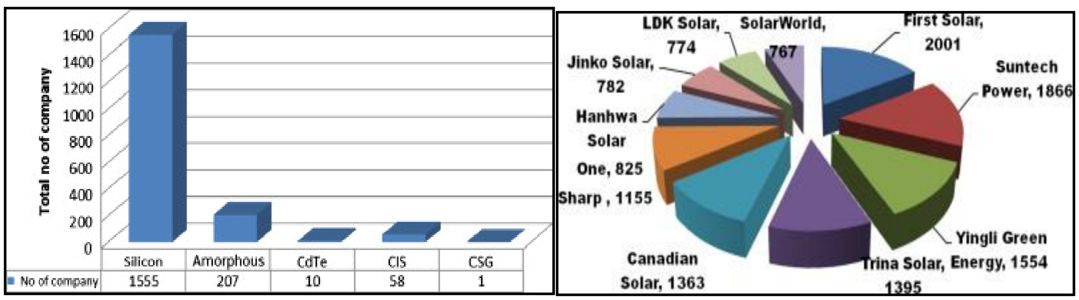
2.4.2.8 Dynamic PV Generators

The solar-tracks has the capability to move PV modules in order to follow direct sunbeam. A study **[63]** Reviewed literature about the comparison between fixed and dynamic photovoltaic systems. In particular, most researchers estimate the increase of PV power production gained from the use of a one-axial tracker to be between 8-16% depending on location parameters and maximum orientation angle. However, an increase by 28- 40% could be reached by using the biaxial tracker. By using dynamic PV generators, an increase in energy production is guaranteed; however, initial and life cycle costs are the big challenge for spreading these systems widely.

2.4.3 PV Production and Marketing

The global power production from PV cells in 2010 vary between 18 GW and 27 GW **[56]**, as well as a reduction by 40% in PV electricity system prices was achieved from 2008 to 2011. As the rapid increasing in PV material technologies, the use of PV worldwide increases. The mono-crystalline and silicon materials constitute around 80% PV market while the thin film, polymer/organic and hybrid solar cell materials are in the growth phase.

Presently, several manufactories are producing PV cells worldwide and China has most of them. More than 100 companies are producing polycrystalline solar PV cells [56]. **Figure 2.11** shows different worldwide PV cell materials companies. First Solar and Suntech have the biggest proportion of PV energy production by different cell types.



(a) (b)

Figure 2.11 PV market in 2011, a) Total number of PV companies, b) Top PV cell manufacturer by production (MW) **[55]**

2.4.4 PV Lifecycle Assessment and Cost Estimation

Life Cycle Assessment (LCA) is a comprehensive strategy for identifying total system cost during life-cycle including operation, environmental assessments and maintenance profits and losses.

2.4.4.1 Life Expectancy

The expected life expectancy for different PV components during the whole system life-cycle are in the following points **[64]**:

- Modules: 25-30 years for most module technologies;

- Inverters: 15 years for small-scale PV plants (residential); 30 years for large-scale PV plants with 10% part replacement every 10 years;
- Transformers: 30 years;
- Structure: 30 years for both roof and facades mounting methods, and ranged between 30-60 years in metal-based ground mounting;
- Cabling: 30 years.

2.4.4.2 Performance Ratio

The performance ratio normally increases with decreasing temperature and monitoring and efficient maintenance for PV system. One of two methods is required in order to determine any PV performance ratio, site-specific or 0.75% as a default ratio for roof mounting and 0.80% for ground mounting **[64]**.

2.4.4.3 Degradation

There is no system performs in stable efficiency during the whole lifetime. In PV systems, degradation affects the efficiency negatively. The recommended degradation rates could be summarized in the following point **[64]**:

- Assume a stable degradation up to 80% from the initial efficiency at the end of a 30 years PV lifetime (Approximately 7% per a year) unless site\actual data exist.

2.4.4.4 Back-up Systems

Back-up systems are not mentioned or considered in LCA for PV systems. If a backup system is available, it should be clearly mentioned.

2.4.4.5 System Boundaries

In this section, definitions of what should be included in PV LCA and should be excluded as shown in following points **[64]**:

- Including every PV system component: PV panels, inverters, charge controllers, mounting system, cabling, the inverters, and all further equipment and tools required for the system;
- Including consumed energy and material through manufacturing and storage processes, cooling systems (if any), lighting for some halls, on-site emissions and onsite waste treatments;
- Excluding of any commuting work (transportation to and from working site);
- Excluding administration and management works such as sales, distribution and research activities;
- If available, examination of the environmental impacts while producing PV manufacturing equipment. If included, three impacts should be listed separately.

2.4.4.6 Cost Estimation

Tyagi, et al. **[56]** conducted a comparison between the mono-crystalline solar cell and other types; the last one has good efficiency but still costly due to its complex manufacturing process. The watt cost of crystalline material was around $6.50 in 1996 as shown in **Figure**

2.12, while the high prices for both thin film and concentrator technologies assumed to be turned into reasonable choices by 2020. The poly-crystalline silicon solar cell material is less expensive than mono-crystalline as well as the manufacturing process is also more simple. **Table 2.11** shows some PV manufactories and estimated PV modules prices per produced power through different PV cell technologies.

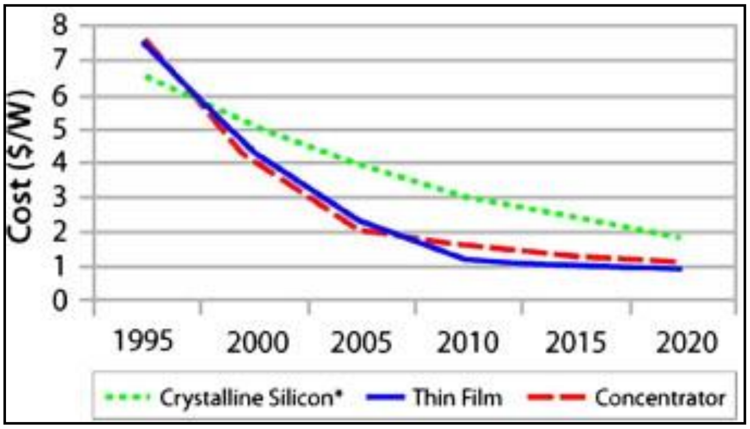


Figure 2.12 Wattage Cost of different PV cell material from 1995-2020 **[56]**.

Table 2.11 Different PV companies and estimated power costs by different technologies **[56]**.

Company	Technology	Power (W)	Price (€)
Avancis	CIS	110	196
Q Cell	CIS	95	174
Kyocera	Polycrystalline	135	247
Solarpark	Polycrystalline	240	374.9
Solar world	Polycrystalline	225	288.68
LG	Monocrystalline	250	382.9
Sanyo	Heterojunction with intrinsic thin layer	214	418.9
Schott solar	Monocrystalline	190	308
UNI-solar	Amorphous	124	179

Table 2.12 shows the PV installed cost per power at different locations with different project scales. It is noticed that Thin-film technologies have a reasonable price per watt for utility scale projects. Japan has the least installed PV price from others in residential scale with 4.70 $\$/W_p$.

Table 2.12 Installed cost for different PV technologies in different locations and different project scales **[56]**.

Solar PV technology	Installed cost [$/$W_p$]	Project scale
Crystalline (Europe)	5.00	Utility
Crystalline (China)	4.42	Utility
Crystalline (Japan)	5.02	Utility
Thin-film CdS/CdTe	4.28	Utility
Thin-film a-Si/μ-Si	3.52	Utility
Crystalline and thin film (USA)	7.50	Capacity weighted average (2009)
Crystalline and thin film (Germany)	7.70	Residential (2–5 kW) (2009)
Crystalline and thin film (Japan)	4.70	Residential (2–5 kW) (2009)
Crystalline and thin film (USA)	5.90	Residential (2–5 kW) (2009)
Crystalline and thin film (CA,USA)	7.30	Residential ≤(2–5 kW) (2009)
Crystalline and thin film (CA,USA)	6.10	>100 kW (2010)

For estimating the initial cost of any PV project, precious and clear cost proportions different system categories should be determined and identified in a proper way. Such assumptions are required if the real data are not available. As shown in **Figure 2.13**, PV modules have the biggest proportion (45%) out of other system components followed by the installation process with 21%. A percentage of 5% should be allocated for other casual expenses **[65]**.

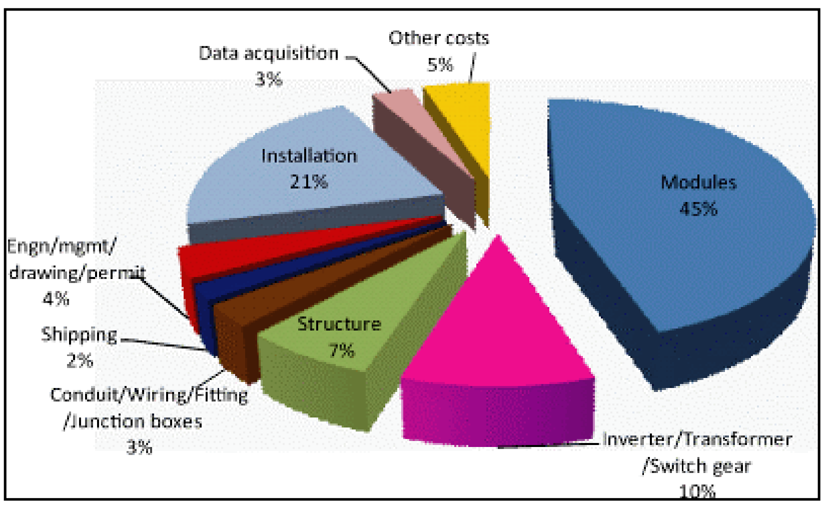


Figure 2.13 PV system cost categories **[65]**

2.4.5 PV Advantages Vs Disadvantages

The pros Vs cons of generated electrical energy from PV systems, fuel, coal and nuclear energy are shown in **Table 2.13**. The comparison between PV system and other renewable technologies is given in **Table 2.14**. From tables, PV has a potential opportunity to play a main role in environment protection with reasonable and credible energy production. From less produced GHG emissions to continues supplement source, PV has a real chance to be future promising technology. However, some of the disadvantages of PV technology could be summarized in land provision (can be solved by implementing BIPV strategy), temperature influence (passive cooling systems or integrated solar heating with PV modules are good options to cope this issue) and other high initial costs (several researches approved that PV technology has –to some extent- attractive initial costs and feasible life-cycle (see **section 2.4.6**).

Table 2.13 Advantages/Disadvantages for different energy resources **[56]**

Advantage/ Disadvantage	PV technology	Nuclear energy	Coal and fuels
Advantage	Low emission of CO_2	Not expensive	High efficiency
	Free source—sun	High efficiency	Conventional electrical energy source
	Infinite source	No air pollution	Power plant can be built anywhere
	Environmental friendly	Reliable	Not expensive
Disadvantage	High start-up cost and investment	Very dangerous	High emission of CO_2 and other hazardous gas
	Low efficiency	Source of uranium are depleting	Source are depleting
	Large area required to install PV system	–	Price increased year by year
	Performance depend on whether and location	–	Source of greenhouse gas

Table 2.14 Advantages/Disadvantages for different renewable energy sources **[56]**

Advantage/ Disadvantage	Solar power	Tidal power	Wind power	Wave power
Advantage	Low emission of CO_2	No air pollution	Free source	No air pollution
	Free source—sun	Cheap maintenance	No air pollution	Free source of energy
	No moving parts required	Reliable	Economic	Low cost, low maintenance
	Environmental friendly	Use no fuel	May attract tourist	High efficiency
Disadvantage	High start-up cost and investment	Very expensive start-up cost	Whether dependent	Depends on the energy of waves
	Low efficiency	Low efficiency	Noise pollution	Noisy
	Large area required to install PV system. Land use.	Can be install only at certain place	May kill bird that pass by	Need to be built at place where wave can hit strongly
	Performance depend on weather and location	–	–	Need to be able to withstand unpredictable weather

2.4.6 Case Studies

A study conducted in Kuwait **[66]** for two different schools based on 12 months of field data. It was indicated that by an average of 0.75 CIGS PV system performance ratio, the minimum monthly energy yield of the PV systems was about 104 kW h/kWp. Moreover, the annual average daily final yields of the PV systems were 4.5 kW h/kWp/day. **Table 2.15** shows PV modules electrical and mechanical characteristics in standard testing conditions (1000 W/m2, 25 ^{o}C, AM 1.5) and other system details.

Due to the installation of an automated cleaning system, the effects of soiling were reduced 45.8% for the first school sample and 42% for the second one over three months' time. It was recommended for regular cleaning in order to decrease system degradation by accumulated dust and aerosols.

Table 2.15 PV system details and description **[66]**

System description	Azda	Sawda
System size (kW_p)	85.05	21.6
Area of array (m^2)	607	154
Modules in series	27	24
Number of strings	21	6
Inverters	(2 × 10000TL-10 and 5 × 17000TL-10)	(2 × 10000TL-10)
Module tilt (°)	20	
Power module (W_p)	150	
Open circuit voltage (V_{oc})	27.9	
Short circuit current (I_{sc})	7.39	
Maximum power voltage (V_{MPP})	22.7	
Maximum power current (I_{MPP})	6.62	
Module nominal efficiency (%)	14	
Weight of module (kg)	18	

Another case study conducted in 172 urban schools in Portugal showed a total PV energy production by 25 GWh/year in 144000 m^2 of potential PV area **[67]**. From this study, the total PV production at all schools was expected to represent 0.06% of the electricity consumption in Portugal, 0.02 % CO_2 reduction from the total Portuguese CO2 emissions.

A study in Greece concluded that the policy to install PV systems on school roofs is an important contributing **[68]**.

Another study was in Uruguay public schools to investigate the implementation for installed PV systems to operate schools' computers and some lighting fixtures **[69]**. It indicated that there is no control system that could be applied to PV system in order to avoid any extra electrical operations. However, results showed that occupants respected the restrictions and understood the limitations of the system. This allows expanding the installation to other schools.

De Santoli **[70]** Indicated the necessity of a provision for PV incentive policy such as feed-in tariff. The analysis carried out in Roman school buildings shows the high potential for photovoltaic installation. With an investment of 80 million €, the required energy for existing school buildings for the next 25 years could be satisfied and equal to the actual electrical budget for nine years of electricity (without deductions and incentives). PV achieved around 55 MW of installed power on the entire school building stock. This amount was sufficient to reduce 763.000 ton of CO_2 emissions during twenty years.

At Romania, a study indicated the necessity of a provision for financing such PV investments, However, it could be solved by accessing the funding sources offered within the European Union programs **[71]**.

A study conducted in Florida-USA investigated solar power applications in schools' shelters **[72]**. The SunSmart Emergency Shelter Program had a goal to educate pupils, school staff and the public on the benefits of solar energy and the use of solar for disaster applications. Although non-provision of an existed verification for PV system performance, schools were better prepared to educate their pupils and communities about solar applications and disaster preparedness.

2.5 Summary of Findings

Recently, it is necessary to find other green solutions to generate energy. Sharp increasing in global energy demand has a negative impact on the ecosystem. Many researches assure the importance of such renewable sources to be allocated in both private and public facilities. Schools play a major role in educating communities. PV technology components were clearly defined and assessed. Detailed data should be provided in any PV project in order to satisfy accurate results. Incentive plans should be available by the government to make these projects more efficient. Before applying any renewable energy system, an energy conservation plan must be studied in order to reduce the level of energy consumption to the minimum. Gaza-Strip suffers daily from lack of energy production. Hence, these studies are necessary in order to find a sustainable solution to energy crises.

CHAPTER 3

ASSESSMENT OF ENERGY PERFORMANCE AND IEQ CONDITIONS FOR A SELECTED TYPICAL SCHOOL

3.1 Introduction

Generally, Gaza-Strip has its own characteristics in terms of the style of construction. Typical building designs with regular and geometrical shapes are commonly repeated around the Gaza-Strip. Schools have simple designs and shapes; multi-typical floors obviously appear from the elevations and plans. The schools are formed out of the three (I, L, and U) geometrical shapes.

Gaza Strip schools are suffering from the lack of conducted essential engineering studies. Classrooms have poor and unexamined IEQ conditions as a result of the absence of the required knowledge. The IAQ condition is mainly a result of the natural ventilation as windows are the only source for supplying air, as well as for providing daylight. Glare, dazzling view, and also dark environments are considered as common problems that directly affect pupils' visual comfort. Non-efficient lighting systems (both artificial and natural) is the reason behind this problem. Luminaires that lighten while enough daylight penetrates inside, cause two major problems; uncontrolled energy consumption and unstandardized visual comfort limits. The Gaza Strip is located in Mediterranean climatic conditions which have moderate characteristics. HVAC systems are rarely installed in the different facilities, while the natural air supplies acceptable ventilation. Side-by-side windows with opened corridors facilitate good air movement; it offers pleasant thermal conditions.

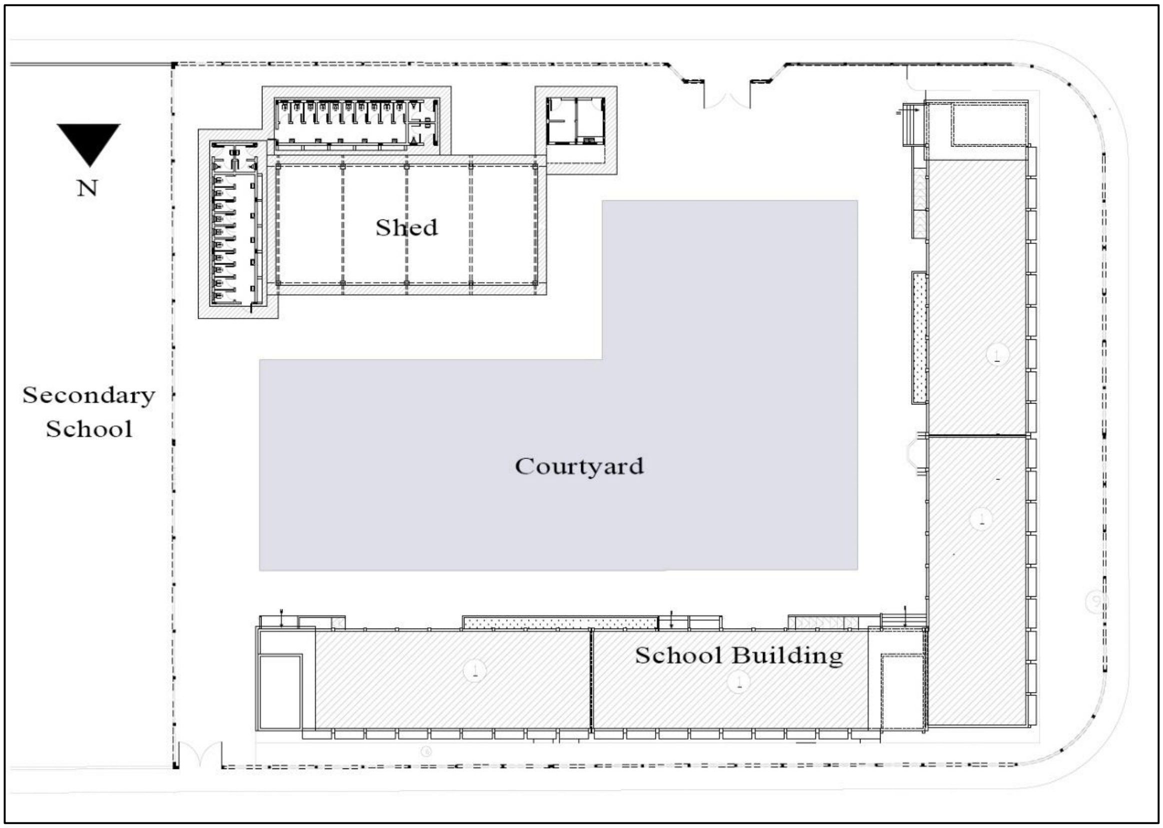
Regarding energy consumption, the schools are responsible for consuming a considerable amount of electrical energy mainly in lighting and equipment. Neither HVAC nor electrical/gas water heating systems exist. As indicated in the literature, schools have two main sources of electrical energy: lighting and appliances. Lighting fixtures are always operated during morning and evening shifts. Some other external lights are switched on during the night for security reasons. The electrical power crisis in the Gaza Strip affects the systems operation, and it has an indirect impact on pupils' performance. There is insufficient illumination during the early morning, late evening and cloudy times. Schools' appliances are not abundant; they are concentrated on computer labs. The absence of heavy consumable machines is an advantage for initiating effective decisions to find a suitable alternative source of energy. In the following sections, a simple L-shape school was selected and modeled to carry out the required energy and IEQ studies.

3.2 General Description for the Selected Typical School

Al-Zahra is one out of nearly 700 schools located in the Gaza Strip. It functions at both morning and evening shifts and occupies around 750 students. According to its design, it has three floors (L-Shape); each has a typical area of 960 m^2 and 2880 m^2 for the whole building. One side is oriented to face the northwest direction, and the other faces the east-west direction (the courtyard faces the school’s southern and eastern sides). Free lands, one-story homes, and a secondary school adjoins the school from north-south, west and east directions, respectively. **Figure 3.2** shows detailed architectural schemes for the school.

The school's layout consists of the main building, student cafeteria, toilets, shed area, and a courtyard with 4800 m^2 as a total area. The ground floor is basically the place for the administration zone; it includes the head room, secretary room, and teacher room with other facilities (toilets, buffet etc.) as well as basic laboratories, such as a computer lab, library, and science laboratory. The ground is raised 45 cm above the 0.0 level and connected by adequate steps and ramps. A long and continuous exposed corridor is allocated in front of the rooms and semi-shaded by an arcade. Most of the interior windows are elevated 1.85 m above the ground and have a height of 0.80 m. Three main stairs are distributed around the school corners to facilitate the vertical transition to the typical floors. Ground, first, and second floors have 3.40 m height for each and 14.65 m is the total height including building staircases. First and second floors were typically designed and contain the same number of spaces. Twelve classrooms are located on each floor and each side has six classrooms. The same concept was followed by the designer in which an opened corridor faces the courtyard and projected in front of the classrooms. Each class has a 6 m width and 8 m length (48 m^2) and is naturally ventilated by side-by-side windows. Each classroom is supplied with six double and two single T8 fluorescent tubes. Regarding the mechanical ventilation, nor HVAC or fan ceilings are provided.

Simple appliances, such as alarms, water pumps, refrigerator, computers, copy machines, fans, telephones, heaters, and water boilers are available and should be considered as sources of energy consumption.



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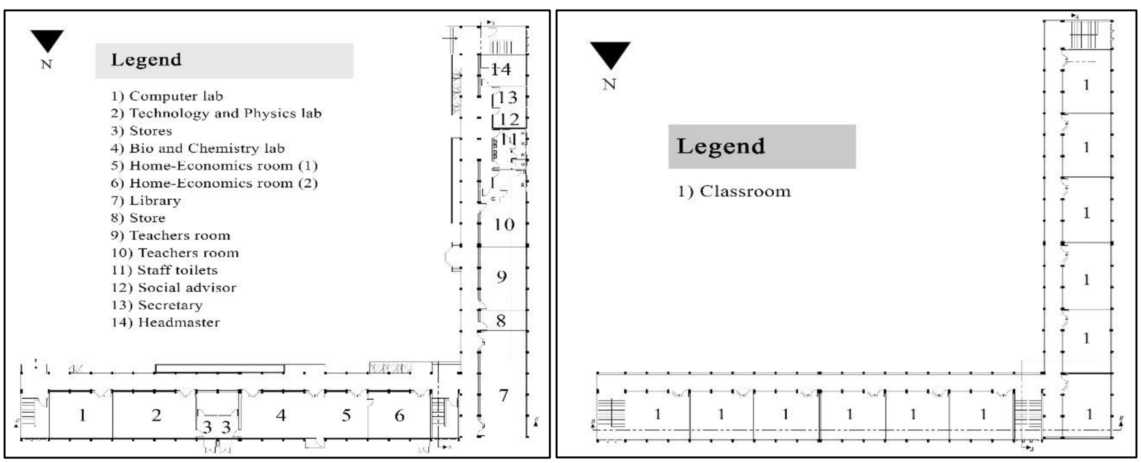


(b) **(c)**

Figure 3.1 Al-Zahra school architectural drawings, a) Site plan, b) Ground-floor plan, c) First-floor plan,

(d)

(e)

Figure 3.2 Continued, d) Elevations, e) Cross section

3.3 Data Collection

In order to model and simulate the selected school, precise and adequate data should be collected from the same or any other typical school. Required data are represented into two categories: monthly electrical bills and operational characteristics. Electrical bills could be considered as one of the most important indicators to study building energy consumption behavior. After the year 2006, and until this moment, the electrical energy in Gaza-Strip suffers from an inefficient amount of fuel, and for this reason, it has a direct negative impact on facilities operation. Schools also have been strongly harmed and affected by this crisis. Especially, the two-shifts schools deal with this issue by powering on the morning shift and off for the evening on one day, and alternate the day after. The irregular power supply affects the monthly electrical bill readings; this complicates the analysis and understanding of the data. However, they could give the researcher the ability to predict how the schools are being run.

Al-Manfalouti school is one of the schools that have a typical L-shape design as Al-Zahra. It has also the same number of floors, classrooms, and lighting fixtures, and is operated on two shifts. The Al-Zahra school building was constructed in 2004, while Al-Manfalouti has an older construction. To understand exactly the energy characteristic for a building, several electricity bills readings must be obtained. As mentioned before, readings for the years before the power crises (2006) must also be available. Eight years were selected with their readings (2000, 2005, 2010, 2011, 2012, 2013, 2014, and 2015); two are before 2006. **Table 3.1** show Al-Manfalouti school general description and represents the collected electricity bills.

Table 3.1 Al-Manfalouti school general description

Number of Classrooms	24 (L-Shape)
Number of Floors	3 (G+1+2)
Classroom Dimensions (m)	$8.00 \times 6.00 = 48$ m^2
Number of Computers	20
Number of Luminaires Per Class	6 Double + 2 Single (14 Single Fixtures)
Single Lamp Power (W)	36
Light (on) times	Almost (on) if the electricity is (on)
Surroundings	East - School
	West - Lands with small buildings
	North and South - Streets

Most of the 700 schools in Gaza-Strip were built before the two last decades, and they have old constructions. For that reason, Al-Manfalouti school readings could be better to represent the data and to be generalized over the rest. Unfortunately, the school's architectural drawings were not kept; they have been lost. Since the two Al-Zahra and Al-Manfalouti schools have the same behavior and elements, Al-Manfalouti readings should be consistent with Al-Zahra and any other schools with the same design. **Table 3.2** shows the collected electricity bills for Al-Manfalouti school. As indicated, eight different years were selected to have more accurate results. The table is split into five different totals and averages rows: total annual consumption, total during academic months (excluding June, July, August), total during vacation months (during June, July, August), monthly average during academic months, and monthly average during vacation months. The energy consumption during vacations is always less than during academic months. The maximum reading was collected in January 2013 and it was 3164 KWh. Moreover, the least reading of all years' peak values was 1038 kWh in February 2000; this could be interpreted because of the less occupancy rate in that year.

Table 3.2 Al-Manfalouti school electricity bills during 8 different years

	[redacted]		2010	2011	2012
Month	KWh	KWh	KWh	KWh	KWh
JAN	288	897	1418	1060	1144
FEB	1038	797	1078	702	1163
MAR	856	1175	1795	1056	1527
APR	723	1294	1633	1233	1858
MAY	590	927	1851	1145	657
JUN	1000	774	1298	1051	1100
JUL	0	1883	1122	852	1164
AUG	198	600	1018	766	0
SEP	364	1418	1024	769	2202
OCT	583	1625	1455	2000	2399
NOV	600	1520	1565	937	1673
DEC	573	1354	1467	924	2079
Total annual consumption (12)	**6813**	**14264**	**16724**	**12495**	**16966**
Total during Academic months (9)	**5615**	**11007**	**13286**	**9826**	**14702**
Total during Vacation months (3)	**1198**	**3257**	**3438**	**2669**	**2264**
Monthly average during Academic months	**624**	**1223**	**1476**	**1092**	**1634**
Monthly Average during Vacation months	**399**	**1086**	**1146**	**890**	**755**

	2013	2014	2015	AVR 6	AVR 8
Month	KWh	KWh	KWh	KWh	KWh
JAN	3164	1000	**1761**	**1342**	**1591**
FEB	2280	737	**1160**	**1119**	**1187**
MAR	2642	2206	**2370**	**1703**	**1933**
APR	2771	1253	**1210**	**1497**	**1660**
MAY	2401	1817	**885**	**1284**	**1459**
JUN	2000	973	**1099**	**1162**	**1254**
JUL	1062	973	**1092**	**1019**	**1044**
AUG	964	1511	**789**	**731**	**841**
SEP	1422	116	**1642**	**1120**	**1196**
OCT	2279	0	**1927**	**1534**	**1677**
NOV	2069	1068	**1837**	**1409**	**1525**
DEC	1114	1246	**1732**	**1311**	**1427**
Total annual consumption (12)	**24168**	**12900**	**17504**	[redacted]	
Total during Academic months (9)	**20142**	**9443**	**14524**		
Total during Vacation months (3)	**4026**	**3457**	**2980**		
Monthly average during Academic months	**2238**	**1049**	**1614**		
Monthly Average during Vacation months	**1342**	**1152**	**993**		
Note: AVR6 (Averages from 2010-2015), AVR8 (Averages for all selected years)					

It can be clearly shown that maximum readings at all selected years occurred at different seasons and months; this reflects the flexibility of the school operation characteristics. Moreover, the varying of the values indicates that the energy consumption behavior at the school is also varied. AVR6 (2010-2015) and AVR8 (2000, 2005, 2010-2015) are the averages for the years after the crises only, and before and after it, respectively.

AVR6 and AVR8 contain the required data, and provide credible and beneficial information to start modeling the school. Hence, the validation process is easier to be conducted by comparing the actual readings with the modeled data. A range of 1369 – 1517 kWh is the target average that should be reached in the modeling phase during the academic months. However, a range between 970 - 1046 kWh is good enough to represent the consumption during vacation months. As illustrated in **Figure 3.3**, the maximum annual total reading occurred in 2013 with 24168 kWh followed by 17504 KWh in 2015 with a difference of 6664 KWh and reached 12,495 kWh in 2011 as the minimum.

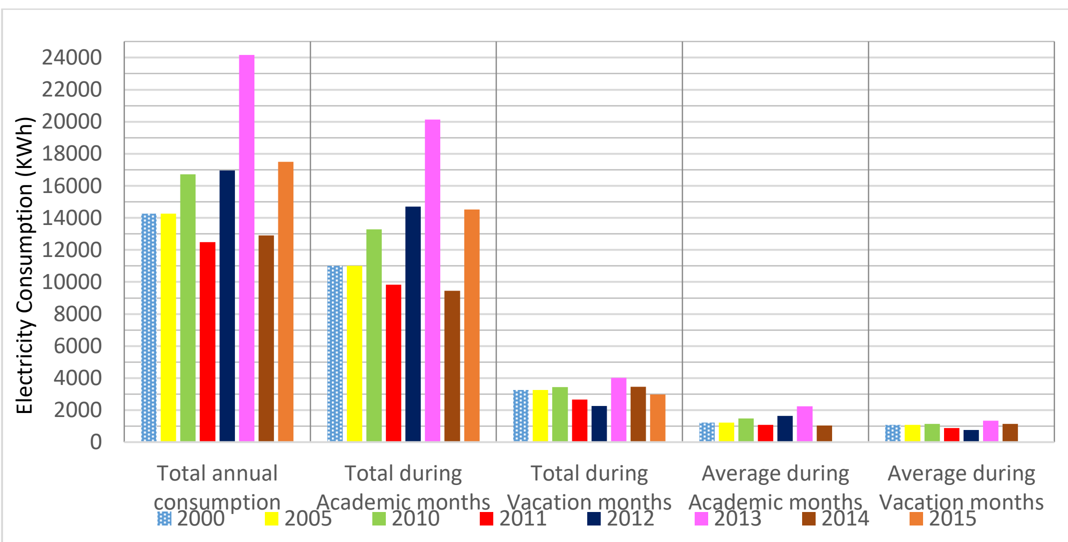


Figure 3.3 Al-Manfalouti utility bills: Totals for the selected 8 years

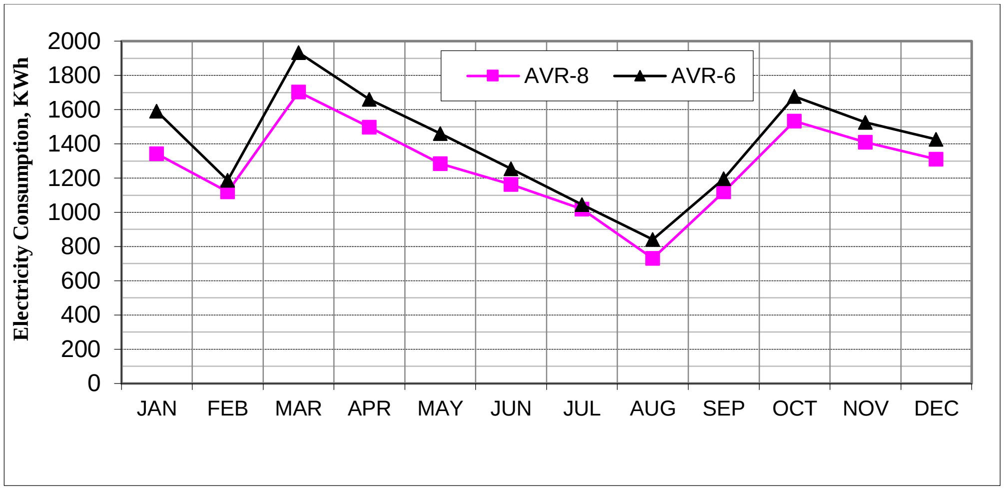


Figure 3.4 Comparison between AVE8, AVE6 readings for Al-Zahra school

The difference between the maximum and the minimum readings could be due to the random school system operation schedules. Some months had 0.0 kWh consumption because either the school was temporary closed or suspended due to some political issues such as; wars and demonstrations.

3.4 Energy and IEQ Modeling for Al-Zahra School: Base Case Formulation

The school was modeled based on the collected data using DesignBuilder 4.6 software. The modeling process was proceeded by filling the required tabs starting from basic activity description until lighting system. The software has a powerful engine called EnergyPlus in which all the data are calculated and manipulated. The flexibility of the drawing items and the plenty of the options give the software a real opportunity to model even complex building\s. **Figure 3.5** shows the modeled school using DesignBuilder.

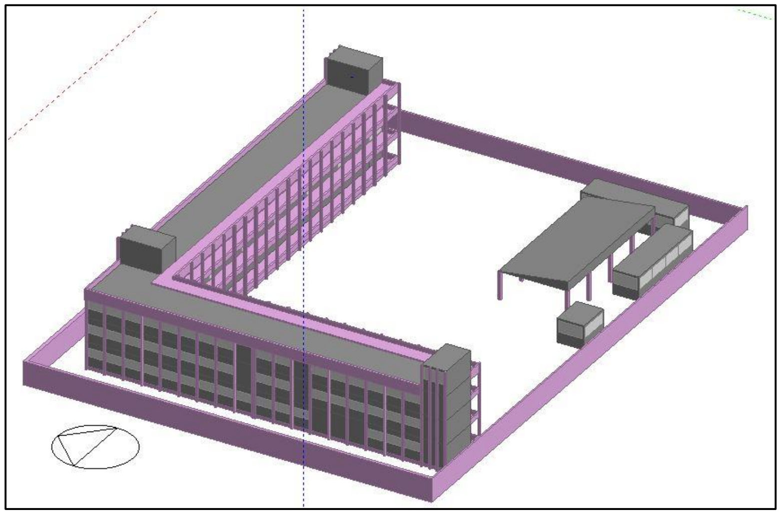
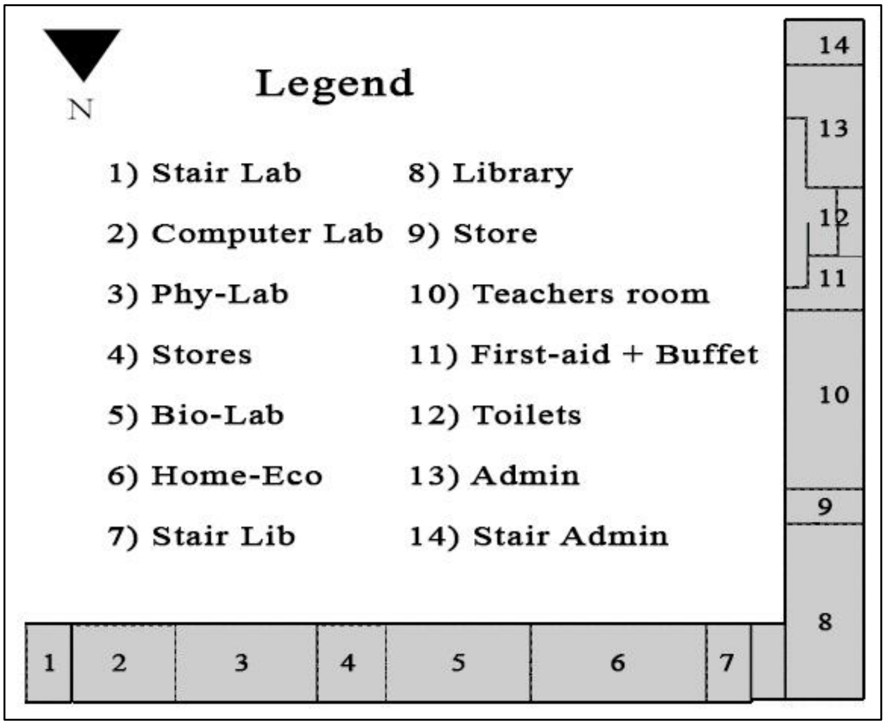


Figure 3.5 3D geometry of Al-Zahra School modeled in DesignBuilder

In order to simplify the modeling data and give them the capability to be generalized, zones must be identified. Al-Zahra school spaces were grouped into different zones, each zone contains single or multi spaces that have the same physical and technical properties. The classrooms that are located on one side and lined up with each other were combined as one zone. It is not necessary that any space has the same physical geometry grouped with others because the location of the space also has a direct impact on the final results. Corridors, arcades, atriums, shading devices and stairwells were modeled also. The impact of neighbors was neglected as there is no environmental impact on the school. **Figure 3.6** shows the distribution of the different zones for the school. Labeling of the zones was chosen based either on the core function of the space or on both function and location. First floor and second floor zones are typical in terms of the allocated area for each zone as well as the space borders. Zones naming\labeling was beneficial for understanding where exactly the simulation was conducted, and helped to group and assign the results to the right locations.



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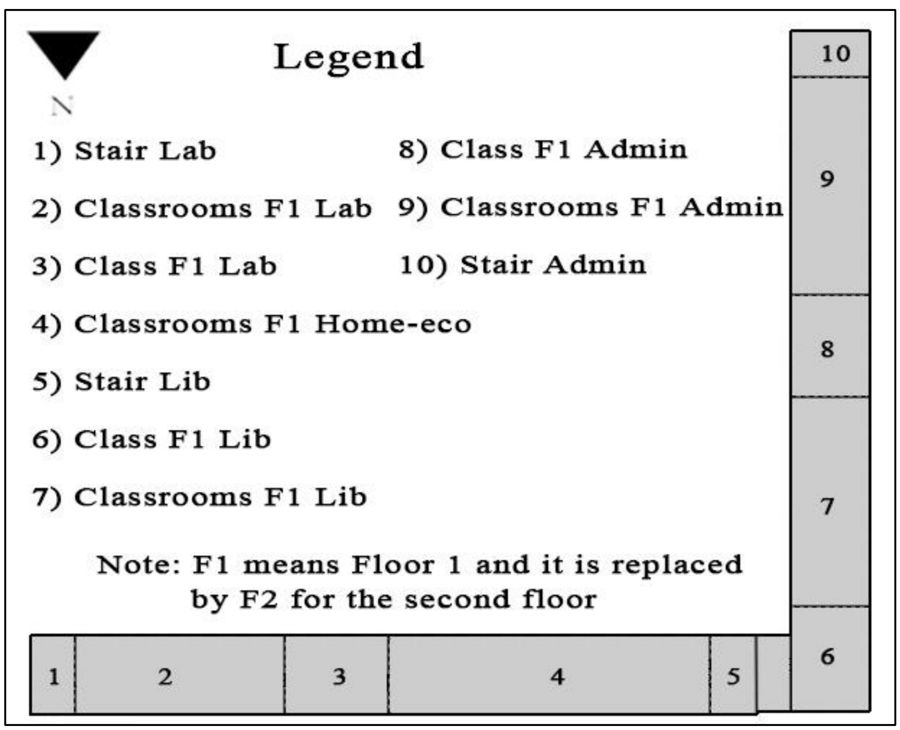


(b)

Figure 3.6 Different zones distribution for Al-Zahra School, a) Ground floor zones, b) Typical floor zones

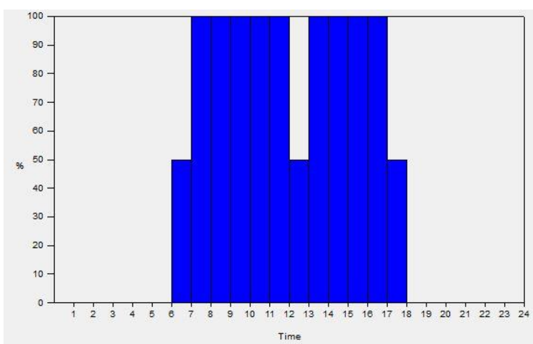
3.4.1 Basic Activity Description

Essential school activities criteria were occupancy density, school general operation schedule, and metabolic properties. As mentioned before, Al-Zahra school has different zones with different specifications and functions. Basically, the whole school building must be described and introduced carefully in this section. **Table 3.3** shows the whole school basic activity description.

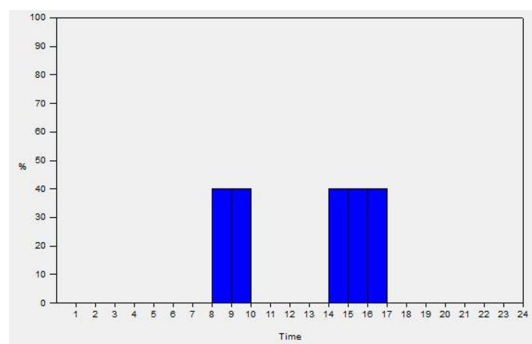
Table 3.3 Al-Zahra school general activity description

Basic Activity Field	Value
Occupancy floor area (m^2)	2880
Occupied volume (m^3)	9800
Density (People/m^2)	0.28

Occupancy Schedule



During Academic Months



During Vacation Months

Annual Holidays

Name	Start date	Number of days
summer	5/25	90
mid	1/1	15
Eid El-Fetr	7/1	8
Eid El-Adha	9/1	8
Labor Day	5/1	1

Al-Zahra school contains 21 main zones (other unoccupied zones such as; stairs, stores, toilets and buffets were neglected). They are distributed as follows:

- Ground floor (7 zones): Admin, Teachers room, library, Home-Eco, Bio-Lab, Phy-Lab and Computer Lab.
- Typical floors (14 zones): 7 zones (Class\Classrooms) on each floor.

Because of the similarity of the function, some zones have the same activity data (e.g., metabolic factor is 0.75, winter clothing is 1.00 clo, and summer clothing is 0.50 clo). Al-Zahra detailed zones basic activity description are illustrated in **Table 3.4**.

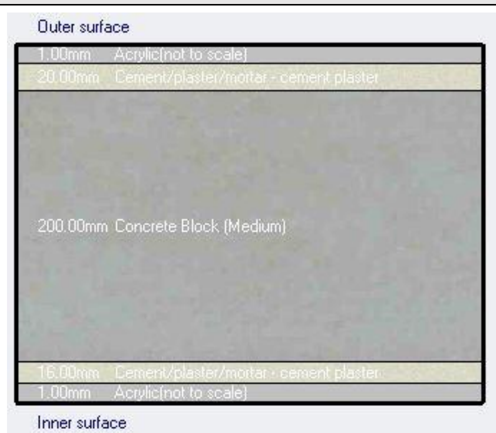
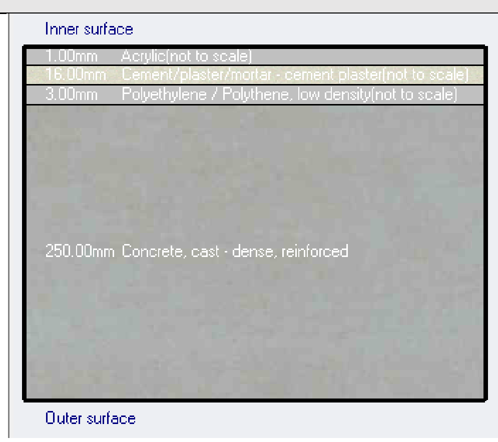
Table 3.4 Different zones basic activity description for Al-Zahra school

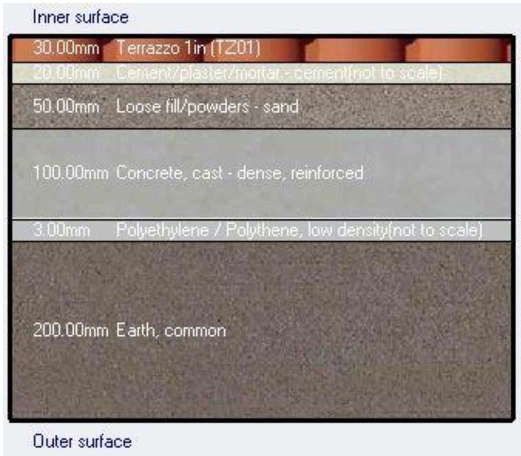
Basic Activity Field	**Value**	**Basic Activity Field**	**Value**
Ground floor, Zone\s: Admin		**Ground floor, Zone\s: Home-Eco, library**	
Zone area (m^2)	45.5	**Zone area (m^2)**	78
Zone volume (m^3)	155	**Zone volume (m^3)**	265
Density (People/m^2)	0.1	**Density (People/m^2)**	0.34
Target illumination (lux)	400	**Target illumination (lux)**	500
Computers gain (W/m^2)	5	-	-
Office equipment gain (W/m^2)	8	-	-
Ground floor, Zone\s: Bio-Lab, Phy-Lab		**Ground floor, Zone\s: Teachers Room**	
Zone area (m^2)	63	**Zone area (m^2)**	78
Zone volume (m^3)	214	**Zone volume (m^3)**	265
Density (People/m^2)	0.47	**Density (People/m^2)**	0.34
Target illumination (lux)	500	**Target illumination (lux)**	400
Ground floor, Zone\s: Computer lab		**Typical floor, Zone\s: classrooms**	
Zone area (m^2)	48	**Zone area (m^2)**	48
Zone volume (m^3)	163	**Zone volume (m^3)**	163
Density (People/m^2)	0.67	**Density (People/m^2)**	0.67
Target illumination (lux)	400	**Target illumination (lux)**	400
Computers gain (W/m^2)	67	-	-

3.4.2 Building Construction

In order to perfectly model the intended building and obtain accepted results, specific and detailed building construction components must be known. External walls, flat roof, ground floor, external floor and internal floor are the required fields to describe Al-Zahra school building construction. **Table 3.5** describes the different construction elements with their layers for the intended school.

Table 3.5 Al-Zahra school building construction systems

System Cross-Section	System Layers	Width (mm)	Conductivity (W/m²K)
External Walls			
	Acrylic	1	0.20
	Cement Plaster	20	0.72
	Concrete Block	200	0.51
	Cement Plaster	16	0.72
	Acrylic	1	0.20
Roof Slab			
	Acrylic	1	0.20
	Cement Plaster	16	0.72
	Polyethylene	3	0.33
	Reinforced Concrete	250	1.90

<table>
<tr><th colspan="4">Slab on Grade</th></tr>
<tr><td rowspan="6">
</td><td>Terrazzo</td><td>30</td><td>2.00</td></tr>
<tr><td>Cement Mortar</td><td>20</td><td>0.72</td></tr>
<tr><td>Sand</td><td>50</td><td>1.74</td></tr>
<tr><td>Reinforced Concrete</td><td>100</td><td>1.90</td></tr>
<tr><td>Polyethylene</td><td>3</td><td>0.33</td></tr>
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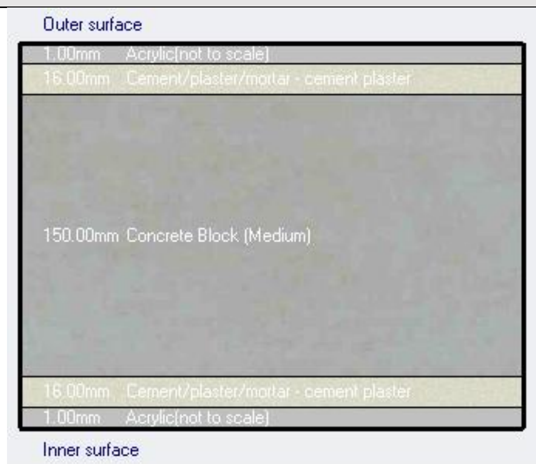
<tr><td rowspan="5">
</td><td>Acrylic</td><td>1</td><td>0.20</td></tr>
<tr><td>Cement Plaster</td><td>16</td><td>0.72</td></tr>
<tr><td>Concrete Block</td><td>150</td><td>0.51</td></tr>
<tr><td>Cement Plaster</td><td>16</td><td>0.72</td></tr>
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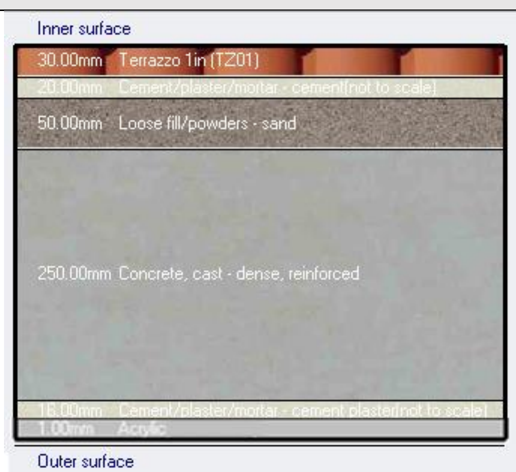
<tr><td rowspan="6">
</td><td>Terrazzo</td><td>30</td><td>2.00</td></tr>
<tr><td>Cement Mortar</td><td>20</td><td>0.72</td></tr>
<tr><td>Sand</td><td>50</td><td>1.74</td></tr>
<tr><td>Reinforced Concrete</td><td>250</td><td>1.9</td></tr>
<tr><td>Cement Plaster</td><td>16</td><td>0.72</td></tr>
<tr><td>Acrylic</td><td>1</td><td>0.20</td></tr>
</table>

3.4.3 Windows and Lighting Systems

As they are considered as one of the building envelope components, windows must be described carefully in terms of their glass type, number of layers, internal and external dimensions, sealing height and border type.

Al-Zahra school has mainly two windows types, and as shown previously in **Figure 3.2**, each space has side-by-side windows projected outdoors (outside the building) and indoor (to the exposed corridor). The windows consist of 4 sliding single clear 4mm glazing for each unit wrapped by 40 mm thick aluminum frame. Exterior windows are elevated 1.4 m from the nearest ground and have a 1.25 m height and 2.50 m width, while 1.85 m is the lower sealing height for the interior windows with 0.80 m height and the same width. All windows were fabricated out of the same materials without insulations. **Table 3.6** shows more detailed data for the school windows.

Table 3.6 Other windows specifications for Al-Zahra School

Specification	Value	Specification	Value
Divider Type	Lite	**Frame Width (m)**	0.04
Divider Width (m)	0.05	**Frame Inside Projection (m)**	0.01
Number of Horizontal Dividers	0	**Frame Outside Projection (m)**	0.01
Number of Vertical Dividers	3	**Opening Position**	Right
Outside Projection (m)	0.02	**% Glazing Area Opens**	70
Inside Projection (m)	0.02		

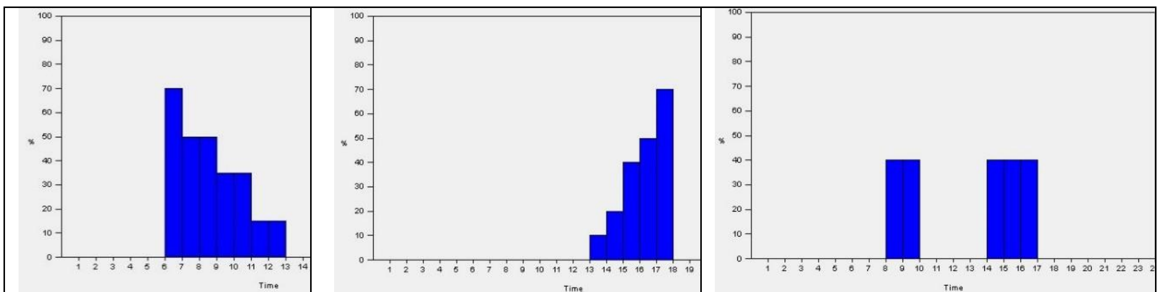
Lighting systems consume the bulk of the energy in Gaza Strip schools. Double T8 fluorescent tubes are the most commonly used luminaires in classrooms as Al-Zahra is. With six doubled and two single units, 14 lamps are installed in each class. They are surface-mounted with 36 W power and 92 lm/W luminous efficacy; each unit provides

3312 lm. To calculate the approximate received illumination in a 45 m^2 classroom, the 3312 lm is divided by 45 m^2, and the result is 73.6 lux (for a single unit). By conducting a simple calculation, and to get the received illumination by the 14 lamps, the two values must be multiplied with each other, 14 × 73.6 = 1030.4 lux (note: 1030 lux also considers the increasing in the value by the reflections occurred by the internal surfaces, and the decreasing by both the luminaire degradation factor and environmental aspects; it means that the actual illumination is almost 3 times that of the visual comfort standard [350-400 lux]). It seems that the existing number of lighting fixtures is more than what should be provided, note that another source of lighting is also provided (daylight) in parallel with the artificial units. Hence, it is necessary to find a way to improve the lighting system for the school and reduce the energy consumption as well. **Table 3.7** shows the technical data for Al-Zahra's existing lighting system in different zones.

Table 3.7 Existing lighting data for Al-Zahra school

<table>
<tr><th>Zone\s</th><th>Lighting Info</th><th>Value</th></tr>
<tr><td rowspan="4">For All Zones</td><td>Lamp Type</td><td>T8</td></tr>
<tr><td>Installing Type</td><td>Surface-mount</td></tr>
<tr><td>Radiant Fraction</td><td>0.72</td></tr>
<tr><td>Visible Fraction</td><td>0.18</td></tr>
<tr><td>Ground Floor (Bio-Lab, Computer lab, Home-Eco, Library, Phy-Lab, Teachers Room)
Typical Floors (all Classrooms)</td><td rowspan="6">Lighting Power Density (W/m²)</td><td>11</td></tr>
<tr><td>Ground Floor (Stores)</td><td>2.5</td></tr>
<tr><td>All Corridors</td><td>2</td></tr>
<tr><td>Ground Floor (Admin)</td><td>4</td></tr>
<tr><td>Ground Floor (First aid + Kitchen) All Stairs</td><td>3</td></tr>
<tr><td>Shed + Students Toilets + Guard Room</td><td>5</td></tr>
</table>

As discussed before, Gaza Strip schools are suffering from an insufficient electricity supply, for that reason, almost one from two morning\evening shifts is operated day-by-day. Moreover, the manual control for the lighting affects strongly on the energy consumption. **Figure 3.7** and **Table 3.8** show the existing hourly, monthly, and annual lighting schedules during the whole day. It was supposed that the operation for the school lightings starts with almost 70% out of full operation and decreases until the middle of the day before escalating until reaching the same operation percentage at the end of the day. This characteristic mimics the actual behavior as at dark early morning and late evening most of the classes switch the lights on, as well as it could be justified because of the consistency with the simulation results (see **section 3.4.4**).



(a) (b) (c)

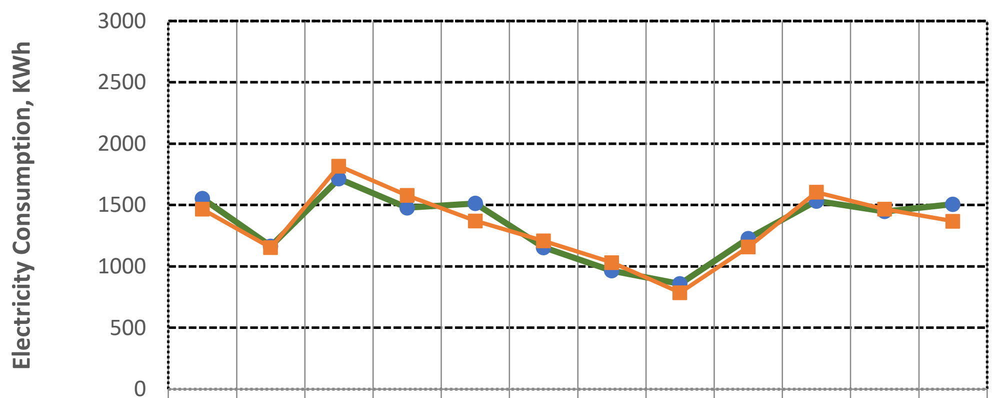
Figure 3.7 Existing hourly lighting schedule, a) Morning shift, b) Evening Shift, c) During vacations

Table 3.8 Annual existing lighting operation schedule

Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Jan	Lighting morning	Lighing Evening	Lighting morning	Lighing Evening	Off	Lighing Evening	Lighting morning
Feb	Lighting morning	Lighing Evening	Lighting morning	Lighing Evening	Off	Lighing Evening	Lighting morning
Mar	Lighting morning	Lighing Evening	Lighting morning	Lighing Evening	Off	Lighing Evening	Lighting morning
Apr	Lighting morning	Lighing Evening	Lighting morning	Lighing Evening	Off	Lighing Evening	Lighting morning
May	Lighting morning	Lighing Evening	Lighting morning	Lighing Evening	Off	Lighing Evening	Lighting morning
Jun	Lighting vacation	Lighting vacation	Lighting vacation	Lighting vacation	Off	Lighting vacation	Lighting vacation
Jul	Lighting vacation	Lighting vacation	Lighting vacation	Lighting vacation	Off	Lighting vacation	Lighting vacation
Aug	Lighting vacation	Lighting vacation	Lighting vacation	Lighting vacation	Off	Lighting vacation	Lighting vacation
Sep	Lighting morning	Lighing Evening	Lighting morning	Lighing Evening	Off	Lighing Evening	Lighting morning
Oct	Lighting morning	Lighing Evening	Lighting morning	Lighing Evening	Off	Lighing Evening	Lighting morning
Nov	Lighting morning	Lighing Evening	Lighting morning	Lighing Evening	Off	Lighing Evening	Lighting morning
Dec	Lighting morning	Lighing Evening	Lighting morning	Lighing Evening	Off	Lighing Evening	Lighting morning

3.4.4 Energy Performance Analysis

In order to assess the impact of any energy conservation measure on energy consumption, the model must behave as the actual in terms of physical parameters, energy performance and any other technical factors. The maximum error ration should not exceed 10%. All gathered information for Al-Zahra school helped to perfectly build the model and gave the capacity to validate it. The actual energy characteristic for Al-Zahra school has been analyzed (see **section 3.3**) and all required information has been collected. After modeling Al-Zahra school and filling all the mandatory data, the simulated energy results for the school were extracted and compared with the mean of AVR8, and AVR6 (AVR7) in order to validate the data with one representative reference as shown in **Figure 3.8**.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Results	1554	1165	1714	1478	1514	1154	965	858	1227	1533	1448	1507
AVR 7	1466	1153	1818	1578	1372	1208	1031	786	1158	1605	1467	1369
Error %	5.64	1.03	-6.07	-6.78	9.40	-4.65	-6.87	8.39	5.65	-4.70	-1.29	9.15

Figure 3.8 Comparison between the simulated energy consumption results with the utility bills average AVR 7

The actual energy consumption for the school varies from month to month. The AVR7 was calculated in order to facilitate interpreting the data. The simulated annual energy consumption (16,117 kWh) was almost the average of both AVR6 (15,229 kWh) and AVR8 (16793 kWh) actual data. The simulated 1554 kWh for January was near to the AVR7 reading (1466 kWh) with +5.40% error ratio. The maximum 9.40% maximum error ratio was obtained in May because the environmental conditions fluctuated and were difficult to estimate during that month.

All of the monthly simulated results were consistent to the actual AVR7 data as no value exceeded the maximum 10% error ratio. The convergence of March, April, and May readings was understandable and could be justified as in these months the Gaza Strip climatic conditions were almost the same. Summer camps, social gatherings, and special remedial courses are examples of the conducted activities in the three vacation months. Around 1000 KWh is an acceptable average of energy consumption during these months. September, October, November, and December months have close results as no system was operated for heating purposes. Finally, the simulated data are acceptable to start implementing the improvements.

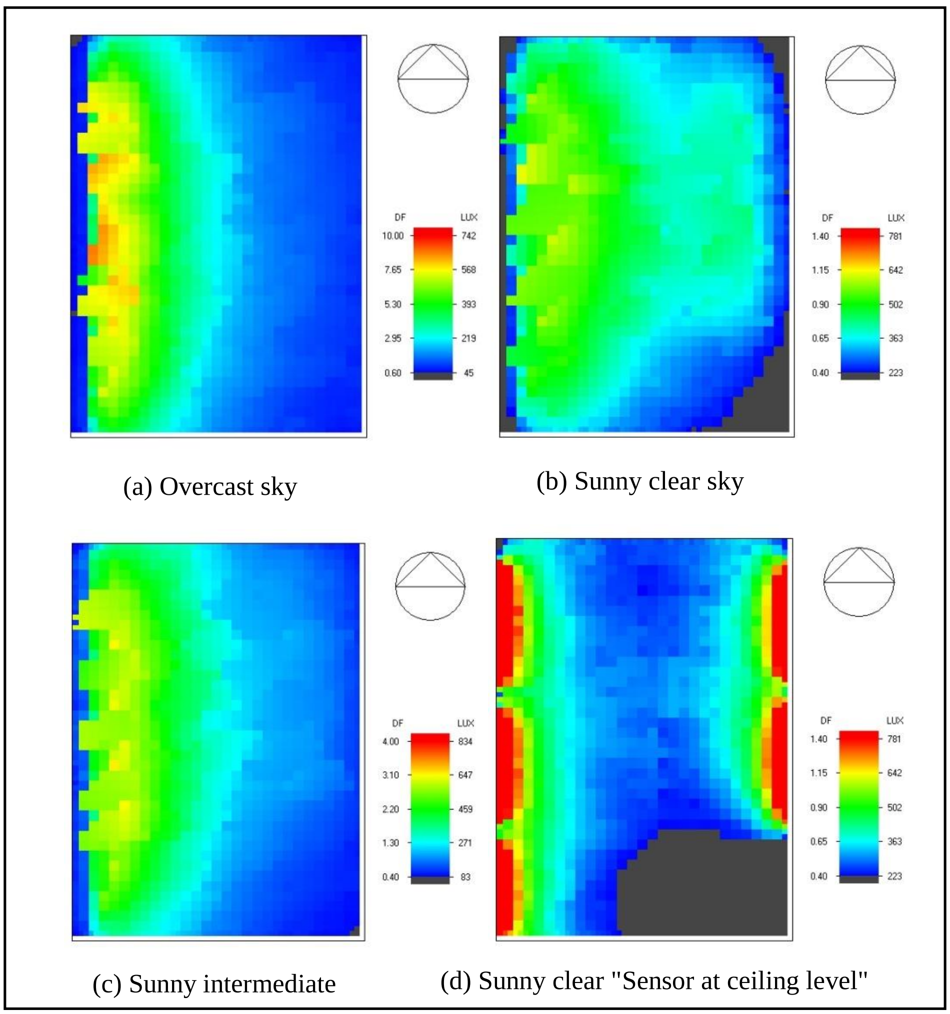
Note that the actual power factor for T8 lamps is almost 95%; this means that the nominal rated 36W tube require 37.8W to operate **[73]**. Around 1.8W are the losses during the shock plate processes and ionizing the internal gas. These losses were considered in the simulation part and calculated.

3.4.5 IEQ Conditions Assessment

In order to study the different opportunities for improving the current IEQ conditions for the selected school, a suitable assessment should be conducted.

3.4.5.1 Visual Comfort Conditions Analysis

The existing luminaires were analyzed and discussed before (see **section 3.4.3**). The focus in this section will be on the daylight behavior in different locations and times. The study for daylight is necessary to suggest a suitable daylight harvesting technology (the term used in the building controls industry for a control system that reduces electric light in building interiors when daylight is available, in order to reduce energy consumption **[74]**). **Figure 3.9** shows different daylight maps for "Class F2 Admin" zone at different times during the year.



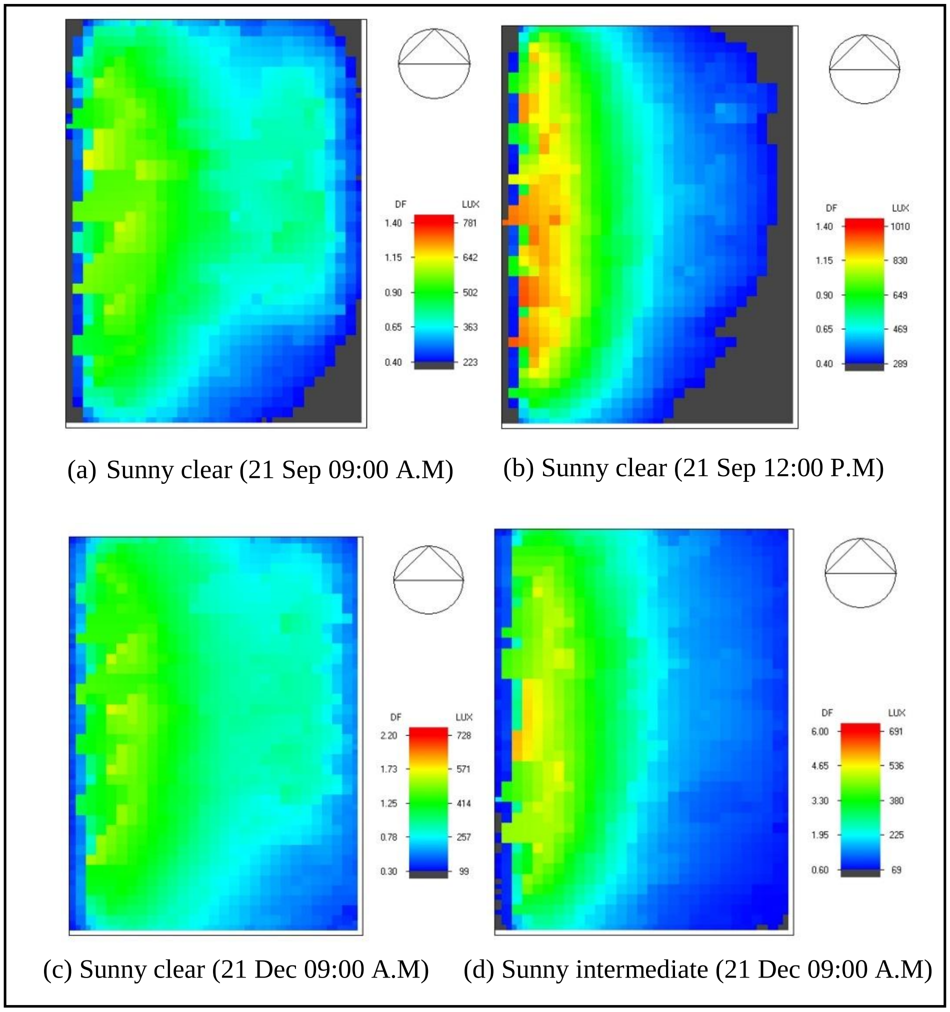
(a) Overcast sky (b) Sunny clear sky

(c) Sunny intermediate (d) Sunny clear "Sensor at ceiling level"

Figure 3.9 Daylight maps for "Class F2 Admin" at different conditions (21 Sep 09:00 A.M at 0.80 height)

Four different scenarios were taken for the selected zone in order to cover the variation in received daylight illumination during the year. (Note: all maps were analyzed on the 21st Sep, 09:00 am and taken at 0.80 m work plain height.) As discussed before, two opposite side-by-side rows of windows are installed in each classroom and are directly\indirectly exposed to the outdoors. The largest 35.2% window-wall ratio is distributed directly to the exterior, while the other windows are projected to an opened corridor (indirect projection to the outdoor environment). It is clearly shown that the area exposed to the larger windows receives more daylight than others. More than 700 lux are provided and distributed beside these windows exactly, and start decreasing gradually reaching the minimum value (less than 100 lux) at the overcast sky status in the opposite corners. Five hundred lux, 300 lux, and 200 lux are the averages for the received daylighting at the mid of the classroom for sunny clear, sunny intermediate, and overcast sky, respectively. The door of the classroom was considered as closed to get the worst-case scenario as a starting point for the improvement phase. However, at most times the door is opened and is considered as a good source for penetrating the daylight. It seems that if the daylight sensor is elevated to the ceiling height, balanced daylight distribution occurs. The reason behind this is that the sensor is directly exposed to both windows' rows level, while at previous a, b, and c scenarios, the sensor was below one row and above the another one. The last "d" case gives a good indication of how the photosensor will respond in real life as it is usually installed at this level.

Other scenarios should be also studied, for example, different semesters and times. To do that, other four maps were captured on 21st December and 21st September but at different times and sky conditions. **Figure 3.10** elaborates these cases. Between 300-400 lux is the average amount of received daylighting at "c" case in December. The units are smoothly distributed over the class as the sun angle during the winter semester is lower than summer, so a direct sunbeam crosses the windows directly and hits the opposite wall at this time.



(a) Sunny clear (21 Sep 09:00 A.M) (b) Sunny clear (21 Sep 12:00 P.M)

(c) Sunny clear (21 Dec 09:00 A.M) (d) Sunny intermediate (21 Dec 09:00 A.M)

Figure 3.10 Daylight maps for "Class F2 Admin" at random conditions at 0.80 m height

This could explain the differences between "a" and "b" scenarios. At 12:00 pm, the sun reached the maximum height and was located vertically on the school roof level. Only indirect sunlight ("diffuse light") provides less than 290 lux at the opposite wall, while it starts sharply increasing to more than 1000 lux at the edge of the exterior windows as a maximum value. It is clearly noticed that at the sunny intermediate case "d", the amount of received daylight by the wall exposed to the corridor is less than at clear sunny status "c". (See **Appendix C** for daylight maps for different zones.)

3.4.5.2 Thermal Comfort Conditions Analysis

The Al-Zahra school building is naturally ventilated so it has to be assessed under different criteria than mechanically ventilated ones. Firstly, ASHRAE Standard 55 defined the purpose of establishing thermal environmental conditions for human occupancy “to specify the combinations of indoor space environment and personal factors that will produce thermal environmental conditions acceptable to 80% or more of the occupants within a space” (ASHRAE 1992). In fact, “acceptability” cannot be the final judgment for defining the current thermal comfort situation; the term "accepted" is usually replaced with “satisfaction” in which it is indirectly integrated with thermal sensations of “slightly warm,” “neutral,” and “slightly cool.”

Thermal sensation is influenced by different environmental factors, such as thermal radiation, temperature, humidity and air speed, and personal factors like activity and clothing. These factors are the cornerstones on which ASHRAE Standard 55 is currently based on. The adaptive model believes that other fundamental physics and physiology factors play an important role in affecting people’s decisions regarding different thermal comfort situations. Thermal sensations, satisfaction, and acceptability are all affected by the match between occupants' expectations about the indoor climate in a particular context, and what actually exists. While the traditional heat balance model is just able to account for some degrees of behavioral adaptation (such as changing one’s clothing or adjusting local air velocity), such systems are not able to include any psychological dimension of adaptation, which may be particularly important in contexts where people's interactions with the environment (e.g., personal thermal control), or diverse thermal experiences, may alter their expectations, and thus their thermal sensation and satisfaction. One context where these factors play a particularly important role is naturally ventilated buildings.

A new adaptive comfort standard was established to complement the traditional PMV-based comfort zone. ASHRAE RP-884 is the system that has the ability to incorporate the ASHRAE Std. 55. **Figure 3.11** shows the differences in indoor comfort temperatures between both adaptive and traditional models.

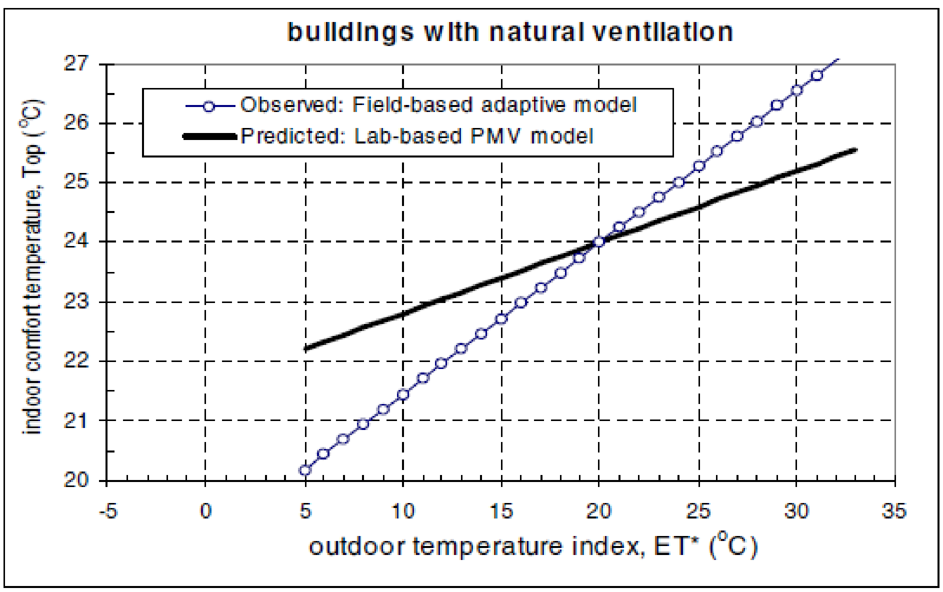


Figure 3.11 Comparison between PMV and ACS models based on both acceptable thermal comfort temperatures (T_{op}). **[75]**

The figure describes that the adaptive comfort standard (ACS) would serve as an alternative to the PMV-based method in ASHRAE Std. 55. The results were taken from different buildings but located in the same outdoor climatic environment "T_{out}" (same dry bulb temperature). The optimum comfort temperature "T_{comf}" could then be re-calculated based on the following ACS equation:

$$T_{comf} = 0.31 \times T_{out} + 17.8\ (^{o}C)$$

Other thorough, expanded, and comprehensive studies were carried out to define the wide range for occupants' satisfaction for thermal comfort in naturally ventilated buildings but located in different climatic conditions. **Figure 3.12** describes the range of satisfaction in which 90% and 80% acceptability limits for occupants were introduced.

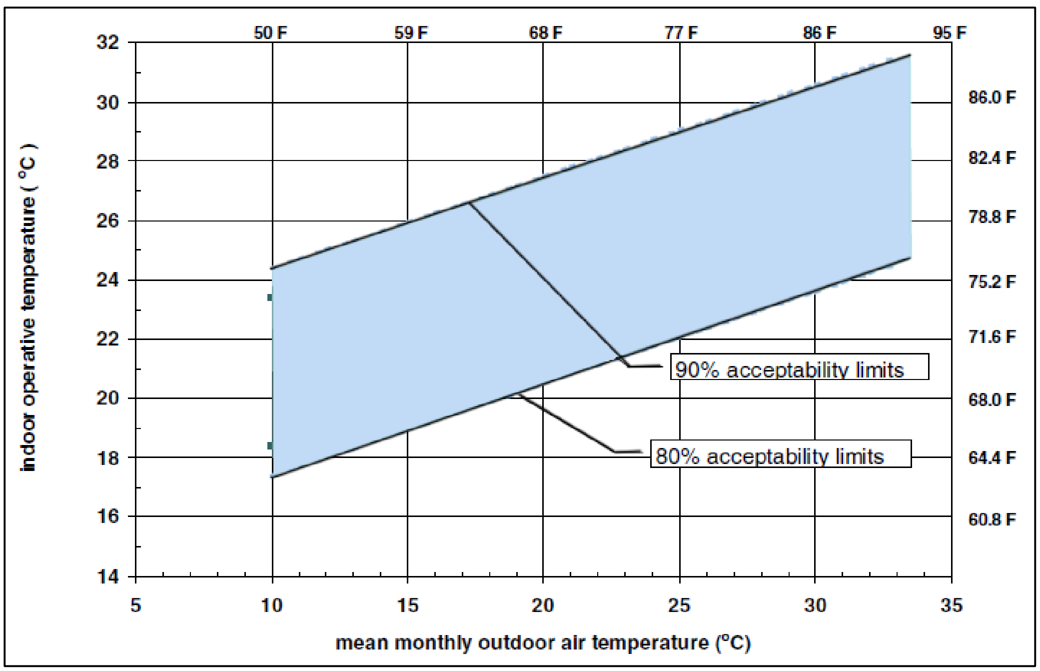


Figure 3.12 80% and 90% acceptability limits for ACS RP-884 with considering different climatic conditions. **[75]**

Note that **Figure 3.12** is different than **Figure 3.11**; the last figure analyzed the comfort conditions in buildings from a range of climates and cultures, including various regions of Pakistan, Australia, Greece, Singapore, Indonesia, and Thailand. As a result, it is difficult to generalize about them or to cast them off as being representative of only a single region. An above mean outdoor temperature of 23°C was calculated in the ACS equation to be in the range of 26-27 °C, however, with respect to the variation in the outdoor climatic conditions, the mean indoor operative temperatures clustered around 30 °C. Moreover, multiple studies show that occupant comfort temperatures were higher in naturally ventilated buildings than mechanically ventilated ones **[76]**. The data suggests that these naturally ventilated buildings were not able to maintain thermal comfort even as defined by the ACS model for many hours of the day. As a conclusion, the proposed ACS for ASHREA std. 55 is the one applicable for assessing naturally ventilated buildings where the thermal conditions of the space are regulated primarily by the occupants through opening and closing of windows. It is specifically noted that the windows must be easy to access and operate.

One of the available solutions for improving the thermal comfort environment in the peak months for naturally ventilated buildings are ceiling fans. They are commonly and widely used in countries with moderate climatic conditions. While 23-26 °C is the acceptable range for mechanically ventilated buildings, 32 °C also satisfies the occupants in India with a provision of appropriate wind movement based on the bureau of Indian Standards Publication SP41:1987 (BIS, 1988) **[76]**. The same reference ensures that multiple studies in the Indian context show that fans increase the comfort temperature level by about 2-4 °C. They approved that thermal conditions with 28-32 °C are accepted under ceiling fans with air velocity exceeds the ASHREA 0.8 m/s limit. The study also indicates that with 20 ACH at night time and 3 ACH during the day in the selected building in India, the discomfort hours' percentage during the occupied times was decreased from 14.91% to

5.89% with a provision of a ceiling fan, as well as 90% reduction in energy consumption compared with using the conventional HVAC systems.

In order to correctly model Al-Zahra school thermally, an appropriate annual climate database should be introduced. The limitation for DesignBuilder and the unavailability of Gaza Strip climatic dataset forced the researcher to turn to the nearest similar climatic condition. Tel-Aviv (Tel-Al-Rabie) is an occupied Palestinian coastal city located 60 km to the north of the Gaza Strip. It has the same coastal, moderate, and humid climate and it is elevated 35m above the Mediterranean Sea. The latitude and longitude for the Gaza Strip and Tel-El-Rabie are 31.5° N - 34.45° E and 32.1° N – 34.78 ° E, respectively. The annual mean temperature values, humidity percentages, and radiation levels for Tel-Al-Rabie are simialr to Gaza Strip conditions and have been validated by NASA Surface Meteorology and Solar Energy **[77]**. **Figure 3.13 and Figure 3.14** show the monthly averages for both temperature and humidity values for the two cities.

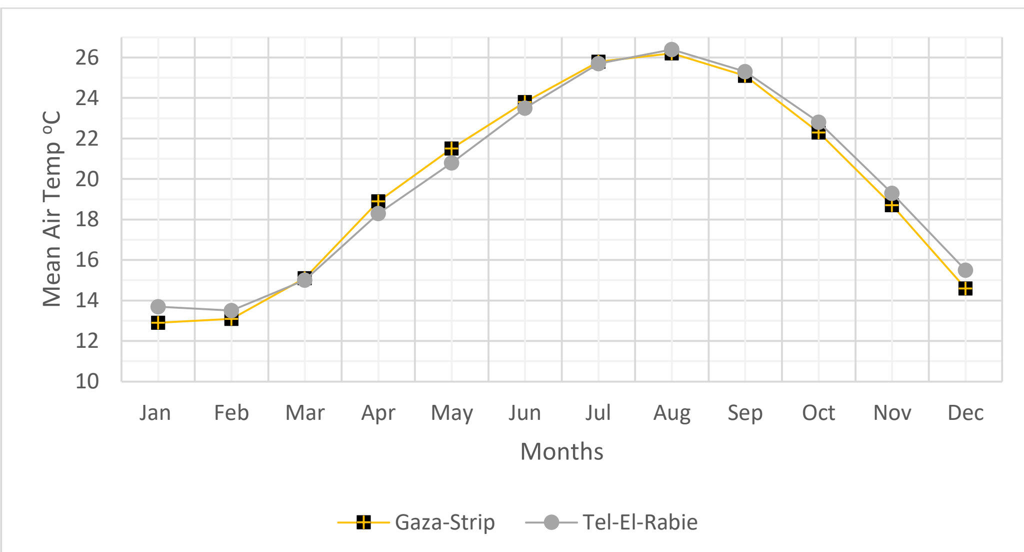


Figure 3.13 Mean air temperature averages in Tel-Al-Rabie and Gaza-Strip

It is shown from **Figure 3.14** that the annual temperature average is around 19.5 °C positioned between 13 °C in winter and a maximum of 26 °C in summer. During very few days, the outdoor temperature could exceed 35 °C, especially in July and August. As it is a coastal city, the humidity values range between 62% as a maximum average and 56% as the minimum.

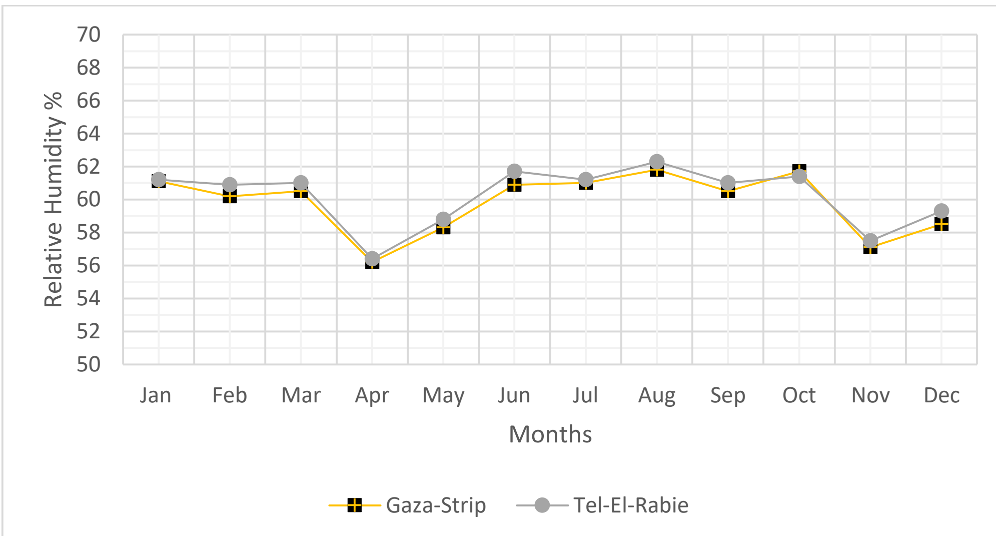
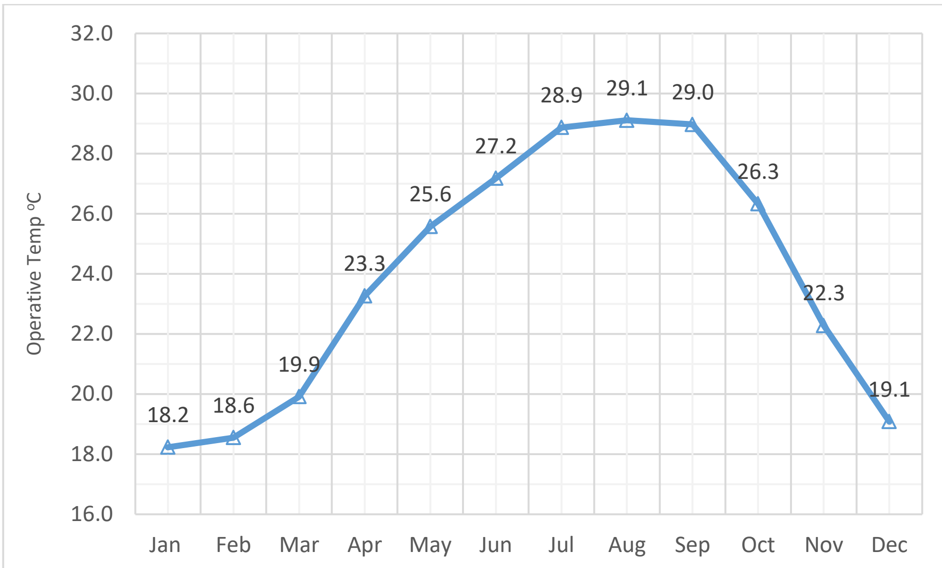
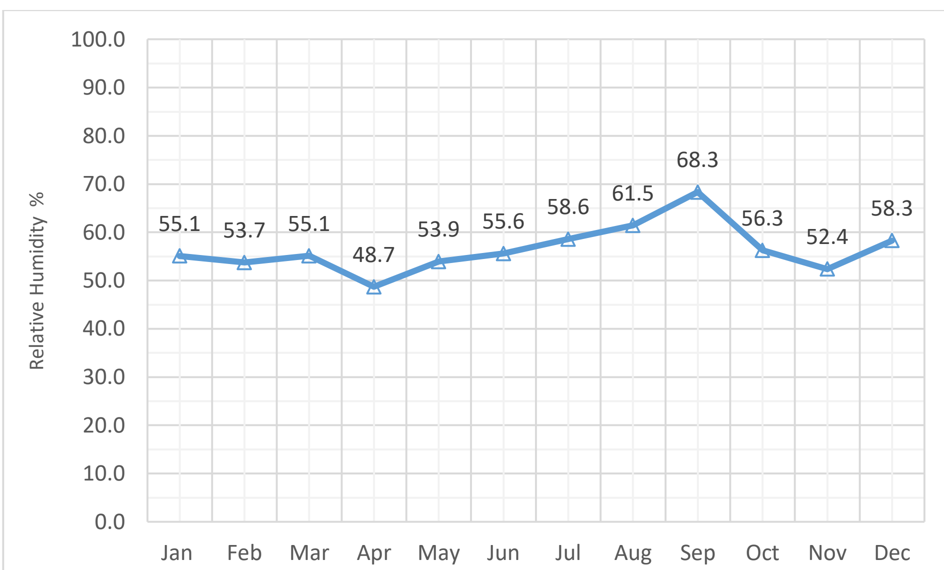


Figure 3.14 Relative humidity averages in Tel-Al-Rabie and Gaza-Strip

To validate the model for the Al-Zahra school, Tel-Al-Rabie annual climate database was installed and implemented through the building. Simulation results for the thermal conditions for the school were obtained and summarized in **Figure 3.15**. The findings show typical values as the actual thermal conditions. Outside dry bulb temperatures averages reach the lowest in January (12 °C) while 25.5 °C was the maximum reading. Regarding the relative humidity, it seems that it has a range from 48% - 61% and is almost similar to the actual readings. Reference to **Table 3.9** and comparing the simulation data with 80% and 90% acceptability for thermal comfort ranges, the lowest 18.23 °C operative temperature in winter and the highest 28.97 °C in September (Three Jun, Jul, Aug vacation months were excluded) are under the acceptability range and meet users' satisfaction. However, these averages do not reflect each zone's thermal conditions separately. Hence, different procedures will be followed in the next chapter in order to study the opportunities for improving the thermal conditions for each zone separately.



(a)



(b)

Figure 3.15 Al-Zahra simulated thermal results, a) Indoor operative temperature, b) Relative humidity

With reference to both **Figure 3.12 and Figure 3.15 (a)**, the monthly ACS acceptability limits for Gaza-Strip climatic conditions could be extracted as shown in **Table 3.9**.

Table 3.9 Monthly ACS acceptability limits for Gaza-Strip climatic conditions

Month	Outdoor Air Temp T_a (ºC)	80% ACS Acceptability Limit T_{op} (ºC)	90% ACS Acceptability Limit T_{op} (ºC)
Jan	13.0	18.2	25.0
Feb	13.0	18.2	25.0
Mar	15.0	19.0	26.0
Apr	19.0	20.2	27.2
May	21.5	21.0	28.0
Jun	24.0	21.8	29.0
Jul	26.0	22.5	29.2
Aug	26.0	22.5	29.2
Sep	25.0	22.0	29.0
Oct	22.0	21.0	28.2
Nov	19.0	20.2	27.2
Dec	15.0	19.0	26.0

3.5 Conclusion

In this chapter, a thorough assessment for Al-Zahra school was conducted. The model was described carefully in terms of basic activity, construction, openings and lighting, energy performance, and both visual and thermal comfort. The results showed almost identical energy characteristic with the actual obtained readings. However, some changes in both existing and simulation readings did not exceed the 10% error limitation and were justified logically and scientifically. A set of daylight maps were extracted in order to understand the behavior of illumination distribution among the selected zone. The results elaborated that the illumination was almost uniformly propagated through the classroom reaching more than 1000 lux at the edges beside the exterior windows and start dimming down until less than 200 lux at the opposite corners. Yet, different scenarios proved that if the sensor is installed at the ceiling level, uniform illumination along the whole class occurs. It was noticed that the daylight readings were suitable with the changes for annual semesters and times. Finally, Tel-Al-Rabie's weather database was evaluated after ensuring the similarity with the Gaza Strip climate. The results showed a clear matching between the simulation thermal data and the actual ones, as well as proved that most of the school's monthly operative temperature averages (excluding May, September, and October) were located in the adaptive ASHREA (ACS) acceptability thermal comfort limits.

CHAPTER 4

IMPACT OF ENERGY CONSERVATION STRATEGIES ON THE TYPICAL SCHOOL MODEL WITH RESPECT TO IEQ LEVELS

4.1 Introduction

In this chapter, a set of strategies were tested and analyzed to obtain the best energy alternative with respect to IEQ levels. Several factors have a direct impact on buildings' energy behavior and they could be classified into three main categories: lighting system, building envelope, and operation characteristics.

The best-optimized combination between the multiple available alternatives would pave the way for implementing the PV system.

4.2 Implementation of Different Energy Conservation Strategies

In this regard, a group of probabilities was taken into consideration. The existing lighting system was replaced by an improved one compatible with the dimming feature. Different scenarios were studied to obtain logical comparisons between both current and new conditions. Daylight harvesting technology was introduced and carefully studied. Different choices of building envelope components were also examined in terms of their impact on energy consumption as well as visual and thermal comfort.

4.2.1 Lighting System

In this section, both existing and suggested lighting systems were studied in different operation regimes. This was necessary to obtain a precise methodology to discuss the differences between all available scenarios in order to help decision-makers to select the optimum solution carefully.

4.2.1.1 Existing Lighting System

The existing lighting system refers to the system that is currently installed at Al-Zahra school (see **section 3.4.3**). In order to conduct a suitable comparison between the existing and improved lighting systems, it is necessary to attain their electrical consumption data monthly and annually. A suggested ideal lighting operation case was introduced in order to understand the energy consumption in the ideal situation. Studying this alternative is beneficial with the provision of such daylight harvesting technology (see **section 4.2.2**). **Figure 4.1** and **Table 4.1** show the existing hourly, monthly, and annual lighting schedule during the whole day. It was supposed that during the early morning and late evening the lights are operated in half due to the occupational profile for these moments. The lights at the break and leaving periods were also considered as semi-operated.

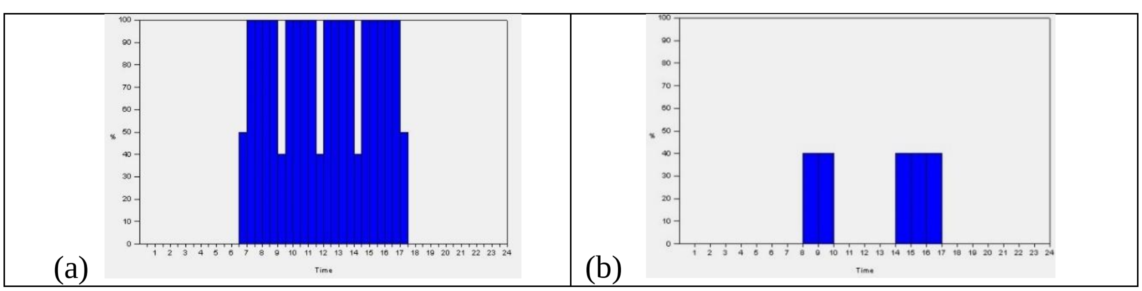


Figure 4.1 Suggested hourly lighting schedule (ideal operation), a) At academic months, b) At vacation months

Table 4.1 Annual suggested lighting operation schedule

Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Jan	full school	full school	full school	full school	Off	full school	full school
Feb	full school	full school	full school	full school	Off	full school	full school
Mar	full school	full school	full school	full school	Off	full school	full school
Apr	full school	full school	full school	full school	Off	full school	full school
May	full school	full school	full school	full school	Off	full school	full school
Jun	Lighting vacation	Lighting vacation	Lighting vacation	Lighting vacation	Off	Lighting vacation	Lighting vacation
Jul	Lighting vacation	Lighting vacation	Lighting vacation	Lighting vacation	Off	Lighting vacation	Lighting vacation
Aug	Lighting vacation	Lighting vacation	Lighting vacation	Lighting vacation	Off	Lighting vacation	Lighting vacation
Sep	full school	full school	full school	full school	Off	full school	full school
Oct	full school	full school	full school	full school	Off	full school	full school
Nov	full school	full school	full school	full school	Off	full school	full school
Dec	full school	full school	full school	full school	Off	full school	full school

Figure 4.2 shows the monthly lighting electrical energy averages for both existing and suggested operation schedules. More than three times are the difference between the two cases during the academic months. The consumption during the three vacation months was expected to be constant. The graph gives a good indication about how much a whole school should consume in the default situation with a comparison with the current operation affected by Gaza-Strip energy crises. While the annual consumption average for the existing operation is 12,197 KWh, around 31,554 KWh is the amount for the suggested one.

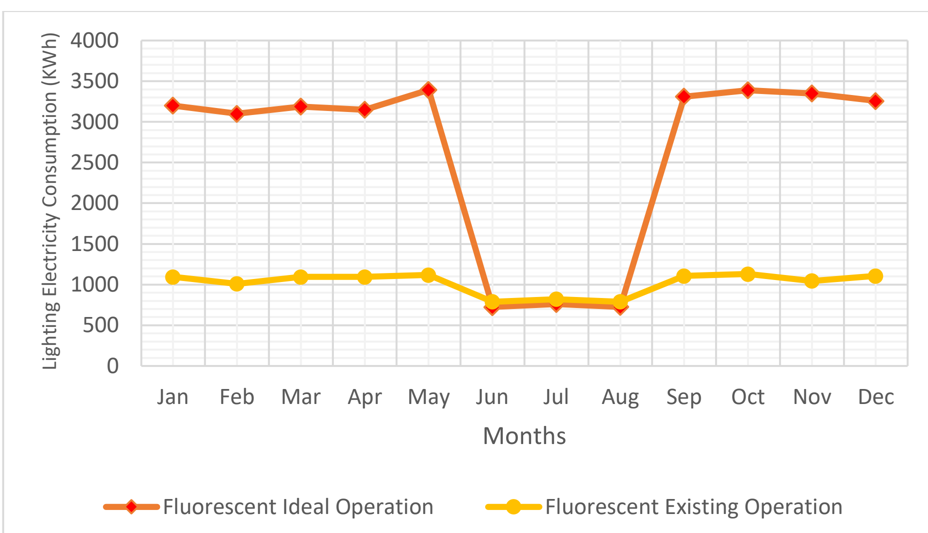


Figure 4.2 Comparison between both current lighting system existing and ideal operations for Al-Zahra school

4.2.1.2 Suggested LED Lighting System

LED lamps have been advocated as the newest and best environmental lighting method. According to the Energy Saving Trust **[78]**, LED lamps use only 10% power compared to a conventional incandescent bulb, while compact fluorescent lamps use 20% and energy saving halogen lamps use 70%. Several advantages make the LED fixtures distinguished, for example, the lifetime cycle reaches up to 50,000 hours. Moreover, linear dimming option is only available with non-gaseous luminaires. Such a feature is beneficial in terms of saving energy, especially if it is automatically controlled by a sensor (e.g., photosensor). The wide range of light temperatures, light distribution methods, lumen/power efficiency factors, and bulb designs are also considered as pros for LED luminaires.

- *Light Loss Factor*

Another feature for LED is the low light loss factor. A basic goal of lighting design is to meet the needs of end users over the life of an installation. One element of that goal is producing the desired amount of light. However, all lighting systems decline in lumen output over time due to reductions in lamp emissions and changing surface properties for the luminaire and the room as well. The light loss factor is a multiplier obtained to measure lights performance declining, and predict future performance based on the initial properties of a lighting system, in a different meaning, the differences between calculations and real-world situations. Using LLF less than 1.0, as is typical, means the initial light level will be above the recommended target value, but as time progresses, the light level will decline toward and potentially below the established criterion. While it may seem a prudent approach for a relatively unproven technology, there are considerable consequences to capping the lamp lumen depreciation (LLD) for LEDs at not greater than 0.70, including substantial implications for energy use. Note that applying the same LLD to all LED products ignores the large variation in performance and leads to uncertainty in the results. For example, designing a lighting system using high LLD of 0.98 for which illuminance is not predicted to drop below the target for the theoretical life of the installation (in this case, 50,000 hours) would result in approximately 40% energy savings versus the baseline case using an LLD of 0.70 **[79]**. **Figure 4.3** shows the differences in target light levels using LLDs between two alternatives. In the first case, (a) (50% of the design lifetime) the method is similar to the current conventional sources. For the second half of the design lifetime, light levels would be below the target. Poor performing LED products could result in substantial reductions in illuminance. However, replacement or re-lamping is required for all sources or would be needed if the product lifetime were shorter than the design lifetime. On the other side, (b) the LLDs for the example light sources are also adjusted to reflect the expected output at the end of the rated lifetime. This method results in the system never being predicted to deliver less than the target illuminance during the design lifetime.

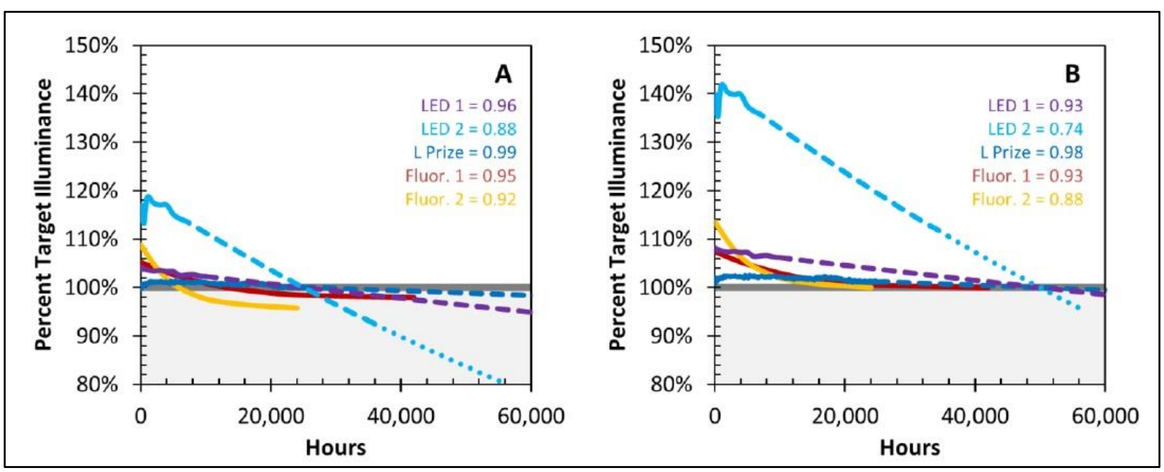


Figure 4.3 Target light levels using LLDs based on, a) 50% and b) 100% of the design lifetime. **[79]**

Note that the five examined lighting types are; an example of an LED package with good lumen maintenance, an example LED package with a shorter rated L70 lifetime, the DOE L Prize®-winning LED A lamp (which has been tested for more than 25,000 hours in a specially designed lumen maintenance test apparatus) and two types of common T8 fluorescent lamps: one 32 W, 70s CRI, 3500 K lamp, and one high-performance, 32 W, 80s CRI, 3500 K lamp.

In conclusion, applying the same LLD to all LED products is not scientifically true and ignores the large variation in performance. LEDs with more than 0.9 LLD are considered as high efficient luminaires during the life cycle. Almost constant light performance saves the target illumination level during the long-term utilization and lows the life cycle cost.

For the Al-Zahra school, a promising and pioneering LED company was chosen to implement one of the best-rated lamps on the different spaces. **Table 4.2** shows the selected LED product and elaborates its main features.

Table 4.2 Selected LED luminaire features for Al-Zahra school

Product Name	CREE A19 LED	**Light Distribution**	Omnidirectional
Limited Warranty	5 years	**Luminous Flux**	800 lm
Luminous Efficacy	Up to 85 lm/W	**Wattage**	9.5 W
Hour\Lifetime	25,000	**Dimming**	Available
Color Temperature	2700 K Warm	**Dimensions**	8 x 5.1 x 2.3 inches
Price\ 8 lamps ($)	26	**Equivalent Replacement**	60 W

The A19 Series is part of CREE company products classified under improved LED lamp family and features a remarkable combination of comfortable omnidirectional light, high color rendering, instant-on and quiet dimming **[80]**. Even better, the A19 lamp is incredibly efficient, lasts up to 6 times longer than the cheap LED bulbs, and provides up to 88% energy savings compared to incandescent.

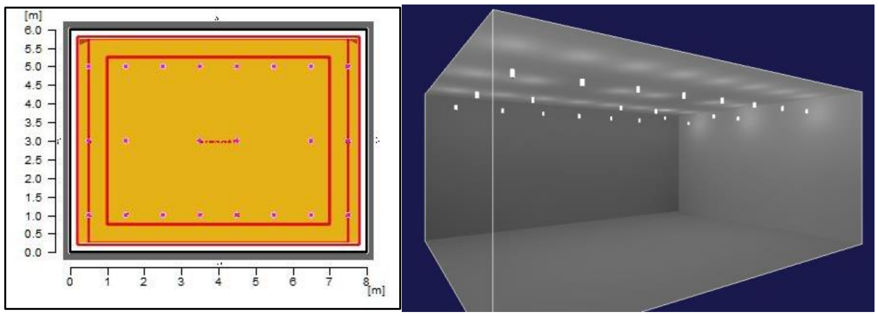
As discussed in the literature, a range of 300-400 lux is the target illumination for a default classroom. Hence, with a provision of 800 lm for the selected LED lamp, and with 45.5 m^2 area for each class, the illumination level reached to the classroom with a provision of one single lamp is 17.57 lux. To achieve the target level, 22 single lamps should be distributed among the class area regularly. (Note: average 400 lux is the calculated value to keep the illumination level on the safe side even with the impact of LLD and increases as a result of interior surfaces reflections factors [see **Figure 4.4.c**].)

Table 4.3 Suggested LED lighting data for Al-Zahra school

Zone\s	Lighting Info	Value
For all Zones	**Luminaire type**	LED Dimmable
	Installing type	Surface-mount
	Radiant fraction	0.72
	Visible fraction	0.18
Ground Floor (Bio lab, Computer lab, Home eco, Library, Physical lab, Teachers room)	**Lighting Power Density (W/m^2)**	6
Typical Floors (all Classrooms)		5
All Corridors		1
Ground Floor (Admin)		4
Ground Floor (First aid + Kitchen) All Stairs		0.75
Shed + Students Toilets + Guard Room		1

Table 4.3 shows the suggested LED lighting technical data for Al-Zahra school. Other illumination levels for the remaining zones were also calculated based on the last methodology. While **Figure 4.4** shows the suggested LED lamps arrangement in a single

classroom and the simulated illumination contour map (done by ReluxPro 2016 software) on 0.75m height as a target level. Both 0.86 Uniformity and 0.80 Diversity ratios reflect a uniform illumination distribution.



(a) (b)

Height of the reference plane		: 0.75 m
Average illuminance	Eav	: 433 lx
Minimum illuminance	Emin	: 374 lx
Maximum illuminance	Emax	: 466 lx
Uniformity Uo	Emin/Eav	: 1 : 1.16 (0.86)
Diversity Ud	Emin/Emax	: 1 : 1.25 (0.80)

(c)

Figure 4.4 Suggested LED lamps' arrangement in Al-Zahra classrooms, a) Lamps distribution plan, b) 3d view of lamps' arrangement, c) illuminance map above the target plan.

Minimum 377 lux and maximum 466 lux with 433 average lux are the actual indications to justify the selection of the nominated LED category parallel to other efficiency, durability, cost and dimming features. After simulating the expected consumed energy with the modified lighting system in both ideal and existing operation schedules for the whole school, a considerable amount of reduction has been observed.

Figure 4.5 shows a comparative graph of the monthly electricity consumption between LED and T8 fluorescent in both existing and ideal operations for Al-Zahra school. From around 3200 kWh consumption in January for fluorescent ideal operation case to 1538 kWh in LED is the recorded reduction. The same decrease is noticed (reaching 50%) for both luminaries but in the existing operation schedule. The reduction characteristic still behaves constantly during the academic months and each couple of the intended luminaire with both different scenarios meet at the same level during summer vacation months.

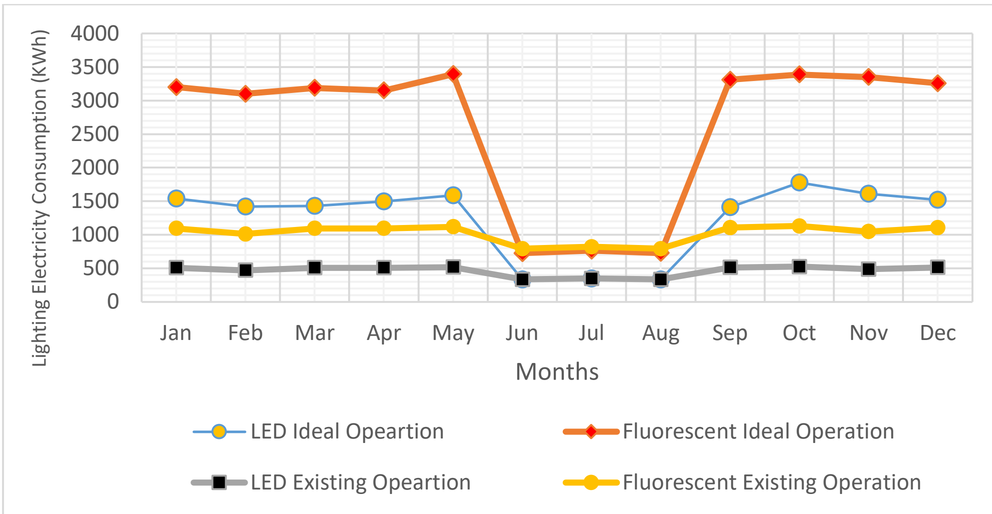


Figure 4.5 Comparison between LED and T8 fluorescent in both of existing and ideal operations for Al-Zahra school

The total annual electrical energy consumptions for the chosen four cases are shown in **Figure 4.6**.

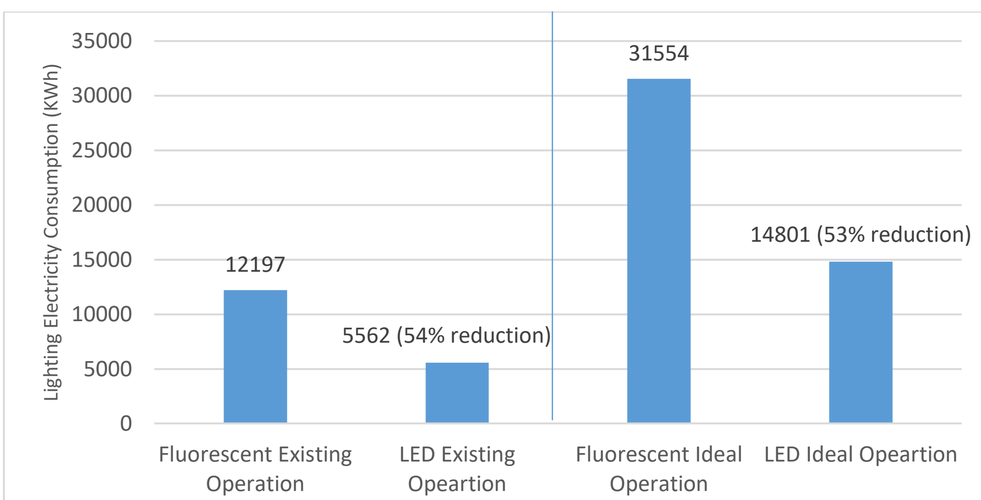


Figure 4.6 Annual electricity consumption for Al-Zahra school at different scenarios

4.2.2 Daylight Harvesting Technology

Modern technology allows us to benefit from daylight and fixes the target level of illumination at the space by balancing between both day and artificial lights. It has several advantages as follows **[74]**:

- Reduces energy consumption by dimming or turning off electric lights based on the natural daylight entering the space;
- Can deliver up to 60% lighting energy savings in some areas;
- Helps maintain the proper light level for a space, so a space is never too dark or too bright;
- Continuously adjusts lights automatically so occupants do not have to manually adjust them as daylight levels change;
- Meets the mandatory requirements set for building construction and renovation;
- Can contribute to obtaining points in several LEED credit categories.

Early morning and late evening are the two critical time zones when such photosensor is provided. Adjusting the operation schedule for a facility is crucial for saving energy especially with a provision of time-switch controller for adjusting the lighting schedule with operation periods automatically.

Figure 4.7 shows the simulated behavior for LUTRON photosensor during a whole working day.

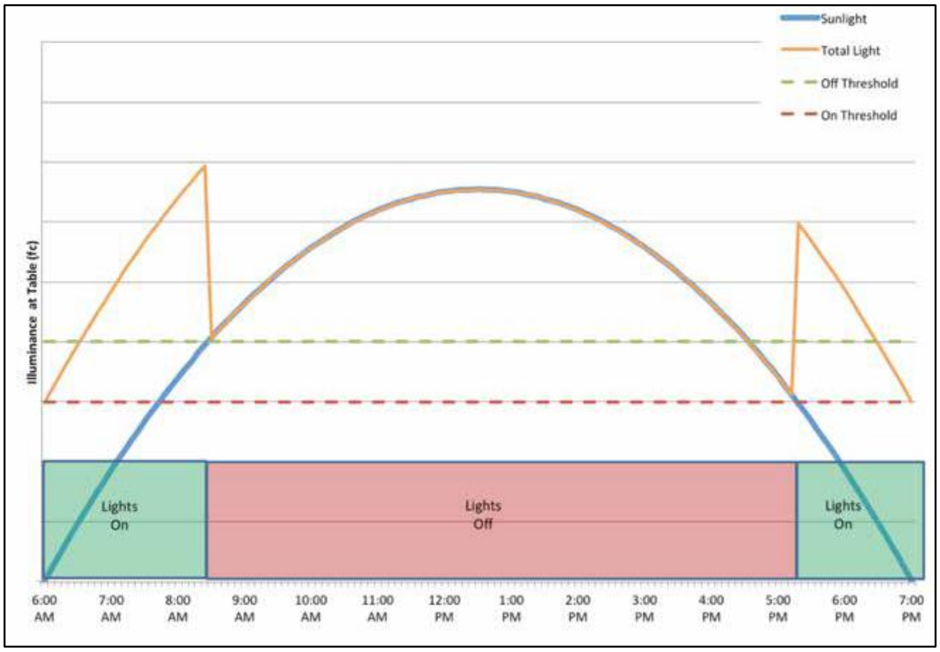


Figure 4.7 Simulated behavior for LUTRON photosensor during a whole working day **[74]**

Determining the proper location of the photosensor is restricted by different technical criteria as follows **[81]** (see **Figure 4.8**):

- The arrow on the daylight sensor points toward the area viewed by the sensor.
- Place the daylight sensor so its viewing area is centered on the nearest window at a distance from the window of between 1-2 times the effective window height, H.
- The effective window height, H, starts at the window sill or 3 feet (91 cm) up from the floor, whichever is higher and ends at the top of the window.
- Ensure that the view of the daylight sensor is not obstructed.
- Do not position the daylight sensor in the well of a skylight or above indirect lighting fixtures.

- For narrow areas where the daylight sensor cannot be placed 1-2 H from windows, place sensor near a window facing into space.
- In general, the dimming hardware is preferred by occupants because the changes are less noticeable.

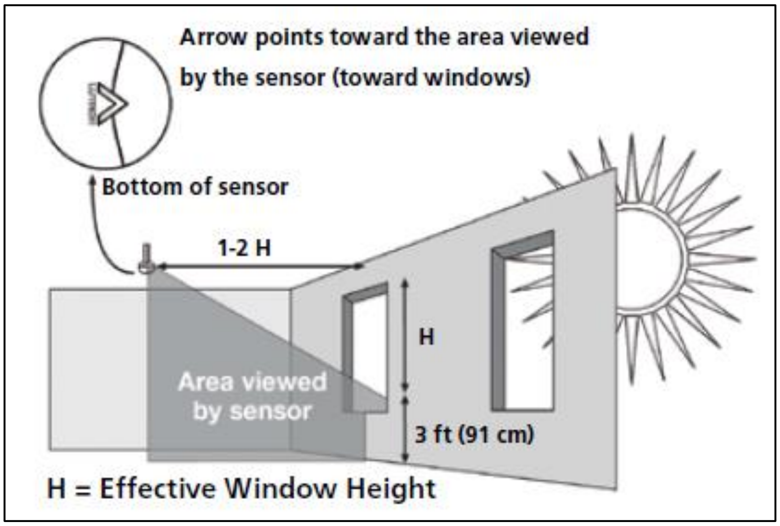


Figure 4.8 Photosensor placement instructions **[81]**

4.2.2.1 Provision of One Photosensor

Only one photosensor was installed at the center of each zone at the ceiling level. The position of the sensor was selected based on the preferred 1-2 H and to avoid the direct sun beam. The type of dimming was linear (to avoid sudden changes and to keep the target illumination at the required level) with 0.10 minimum output and input power fractions. It seems that between the two rows of openings is the ideal placing case when one photosensor is available. Note that based on the daylight map and the uniform distribution of the received illumination (lux), the average of the higher and lower values was in the middle. The sensor in this case is supposed to control all luminaires so they dim at once.

Figure 4.9 shows the noticeable energy reduction with providing a photosensor compared with the absence of a photosensor in a particular zone (Class F2 Admin). Note that the annual electrical energy consumption was reduced by 82% from 540.3 kWh (absence of a photosensor) to 93.85 (provision for one photosensor) under 400 lux target illumination.

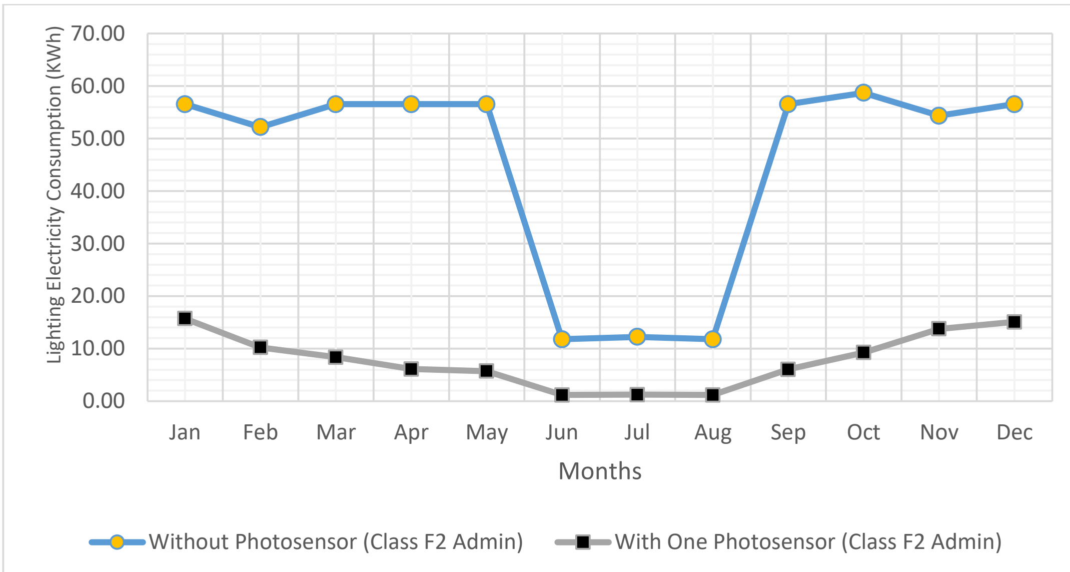


Figure 4.9 Monthly electrical energy consumption for Class F2 Admin when one centralized photosensor is provided and not.

4.2.2.2 Provision of Two Photosensors

To receive a regular and equal illumination level for each pupil in the class, and because of the irregular distribution of the illumination, two photosensors were placed at one-third and two-thirds of the class width and at the center of the 8m side (class length). This methodology was tested to ensure if there was any noticeable difference between one and two photosensors in terms of monthly and annual energy consumption. **Figure 4.10** shows this comparison in two different zones.

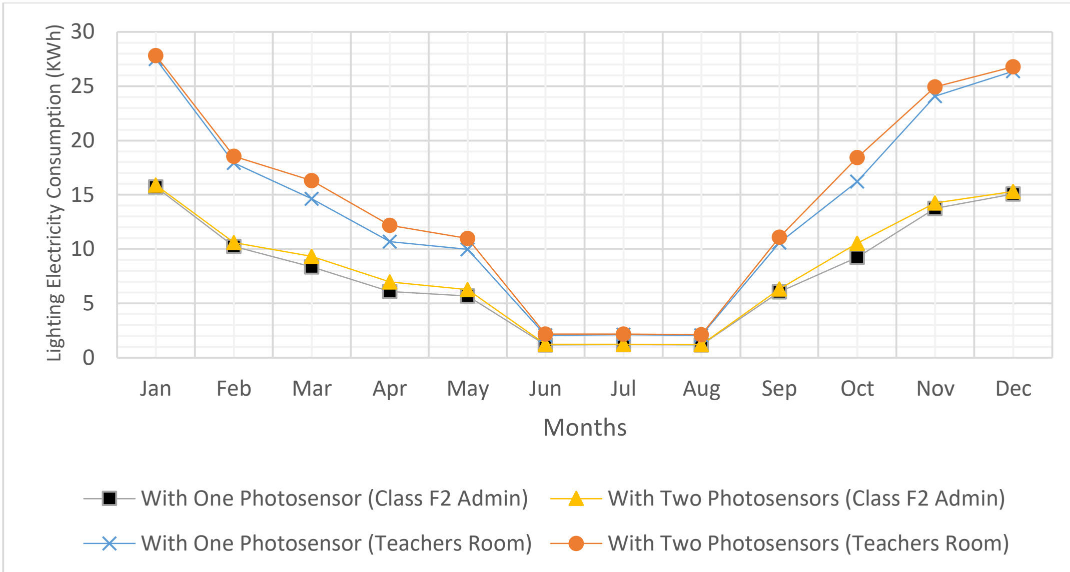


Figure 4.10 Monthly electrical energy consumption for class f2 admin and teachers room when one and two photosensors are provided

The teachers room was selected to be tested because of its location on the ground floor as well as due to the variation in the distribution of the illumination among the zone (see **Appendix C**). From the results, the energy consumption was almost the same in both cases (although different zones). Some minor increasing in two sensors case resulted due to the sensor that installed above the relatively darker half. Hence, the dimming process did not occur at the same time. However, fixed 400 lux is not necessary to be provided at all times, a range from 300-500 lux is also acceptable. Applying this range to both two photosensors was turned the monthly energy consumption same as one photosensor case. Finally, by conducting a simple trade-off study, duplicating the number of the suggested single photosensor as well as the cost of each is not justified.

4.2.2.3 Glare Control (Provision of Blinds)

It is necessary to avoid glare phenomena in each zone in the school. DesignBuilder software has the capability to control the glare index by selecting blinds. More than 19 glare index is not acceptable for classrooms. The software was programmed to automatically close the curtains when the glare index exceeds the target. Note that this automatic process is done manually in real life by the students. Drapes-open weave light blinds with 3mm thickness and 0.7 solar transmittance ratio were installed inside the exterior windows. If any noisy glare is available, the final energy consumption will be affected as the daylight will be obstructed by the closure of the blinds (note that the view angle was selected to face the blackboard as a default). **Figure 4.11** shows a comparison (conducted in two different zones with different orientations with one photosensor) between a case where blinds are provided and controlled by maximum glare index and a case without blinds in terms of monthly lighting electricity consumption.

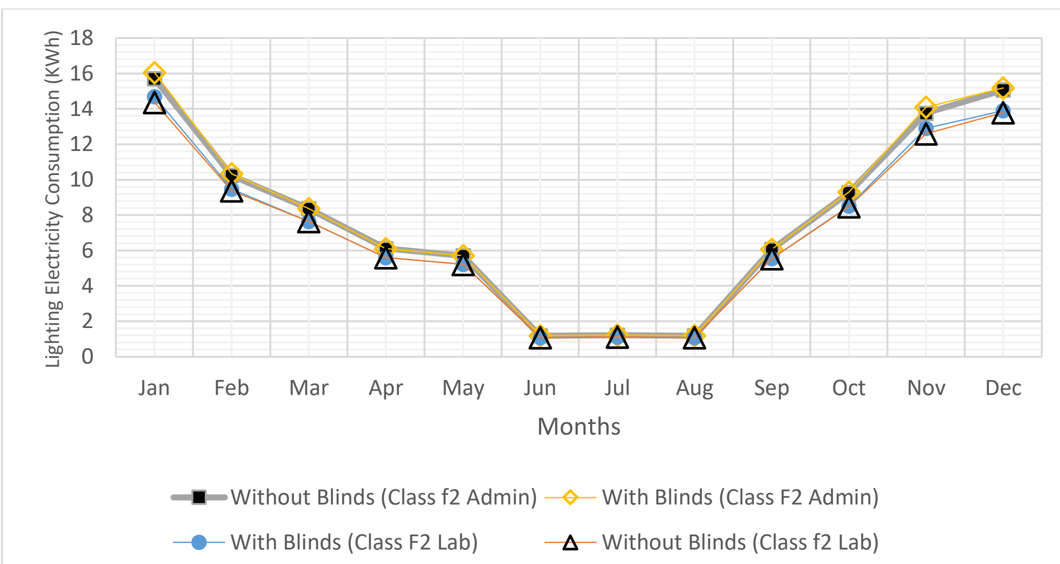


Figure 4.11 Impact of blinds controlled by glare index on electricity consumption for two different zones

From the simulated results, a very slight increase in the “with blinds” case was noticed in both zones. It means that the glare index exceeded its limitation after a few hours along the whole year as shown in **Figure 49**. However, it is not a justification for purchasing and installing blinds, especially as they could obstruct the daylight and air flow during the summer months which causes noticeable impacts on thermal/visual comfort and energy consumption as well.

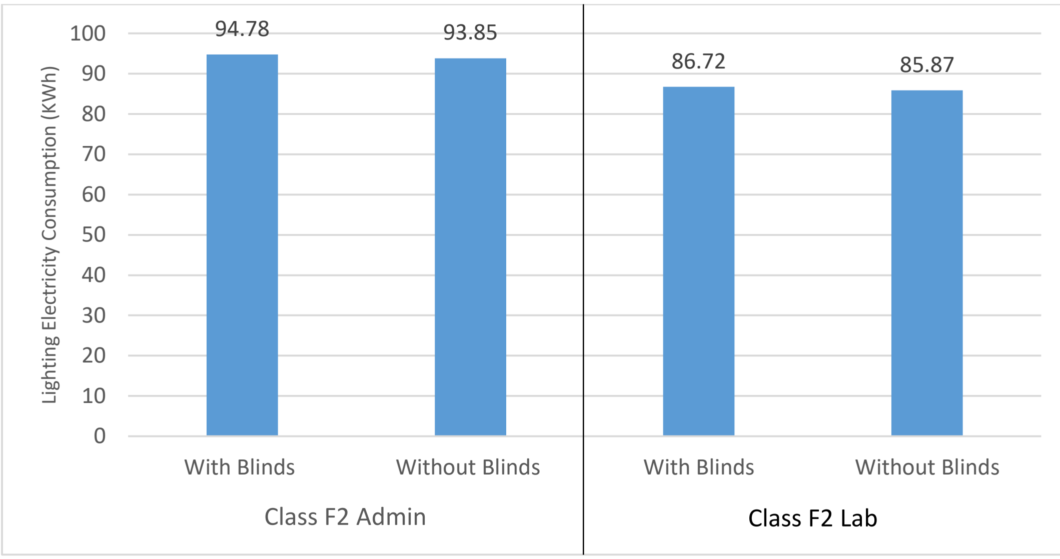


Figure 4.12 Annual energy consumption for both "Class F2 Admin" and "Class F2 Lab" zones with and without provision of blinds.

4.2.3 Building Envelope

Building envelope components have a considerable impact on environmentally controlled buildings in terms of thermal comfort conditions. However, the same alternations on these components do not have the same impact with naturally ventilated buildings. A kind of integration between thermal conditions, visual comfort, and energy consumption is available. The best thermal conditions do not match with the best visual comfort levels. However, trade-off study and optimized solutions should be selected carefully. To prove that, a well-studied methodology for investigating all possible building envelope options was used to optimize the best case in terms of thermal/visual comfort and accumulated energy consumption. The first step is selecting the worst zone in terms of thermal conditions. After that, an attempt to optimize indoor thermal and visual conditions will be checked. Finally, the results for this zone could be validated to be applied to the whole school.

4.2.3.1 Worst-Case Selection

In terms of visual levels, all zones at Al-Zahra are almost the same. This was proved while studying different alternatives for providing photosensors (see **section 4.2.2**). So, regardless of the visual levels for the selected zone, thermal conditions (operative temperatures) are the criterion in which the judgment was based on.

Al-Zahra school consists of three floors; each floor consists of a group of different spaces (zones). The differences in each storey height from the ground causes changes in each indoor environmental aspect. The ground floor is located 2m beside the external fence, hence, it may be fully or partially shaded during the day. This leads to a reduction in indoor operative temperature readings. On the other side, the direct exposure to the solar radiation for the second floor negatively affects the indoor thermal values. **Figure 4.13** shows the operative temperature averages for each floor in Al-Zahra school and illustrates the ACS acceptability limits (see **Table 3.9*)***.

It is noticed that the simulated readings describe the theoretical justifications. During the academic months, September touched the peak value with almost 30 ^{o}C in the second floor zones while the minimum reading was obtained during January on the ground floor.

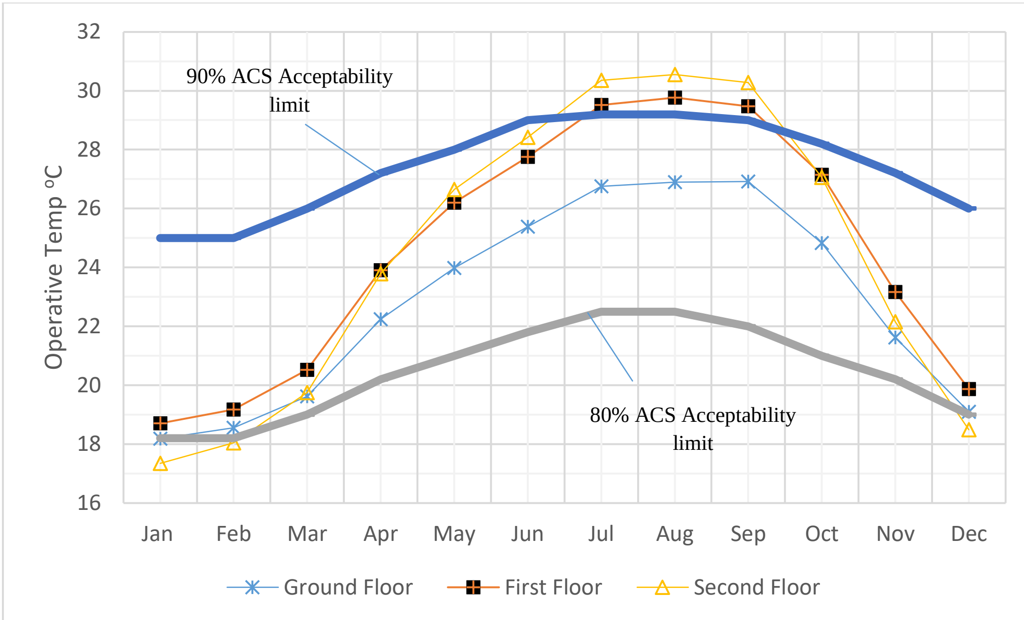
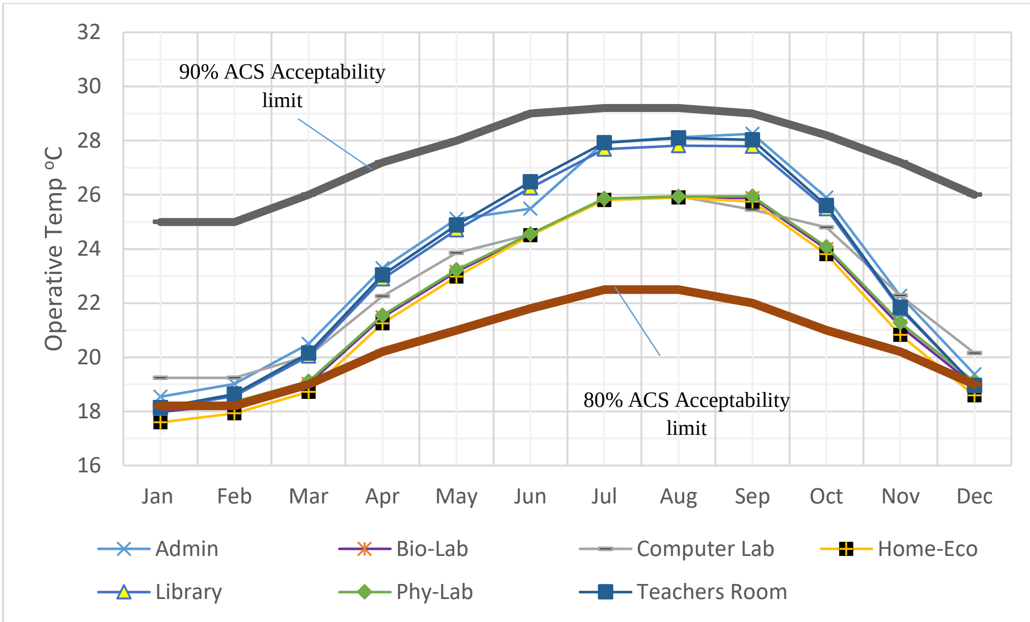
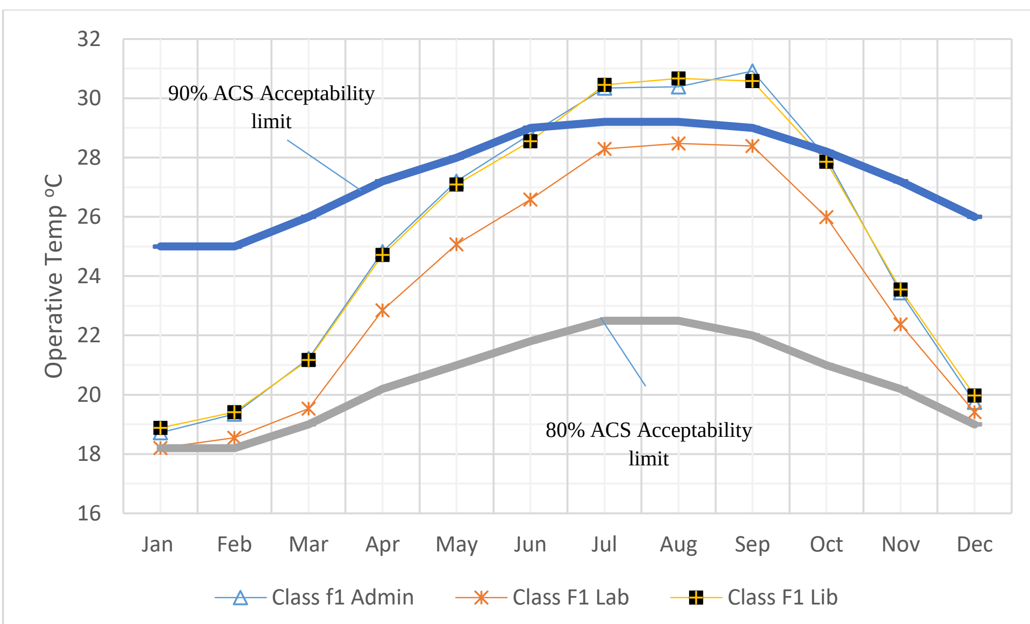


Figure 4.13 Al-Zahra school average operative temperatures for the three floors

Generally, there were noticeable differences between ground floor and first and second floors readings. However, the averages do not always reflect each single value. For this reason, zones with high operative temperatures were examined. This comparison was necessary to give an initial indication about each floor behavior. For more details, each single zone for the whole school was simulated alone and its monthly operative temperature averages were obtained as shown in **Figure 4.14**. "Computer Lab" has the highest temperatures in winter months as the devices contribute to the accumulated thermal conditions. "Admin", "Library," and "Teachers Room" are the zones in which peak temperatures during the summer months were obtained. It is necessary to mention that in **Figure 4.13** the highest average value was almost 26 ^{o}C for all ground floor zones, while 28 ^{o}C was recorded for "Teachers Room" and "Admin" zones as single units. Other zones (Bio-Lab, Phy-Lab and Home-Eco) have lower averages because of their locations (they are located in the northern side and exposed to the direct sun beam from only east and south facades, as well as they are fully shaded afternoon times [west]).



(a)



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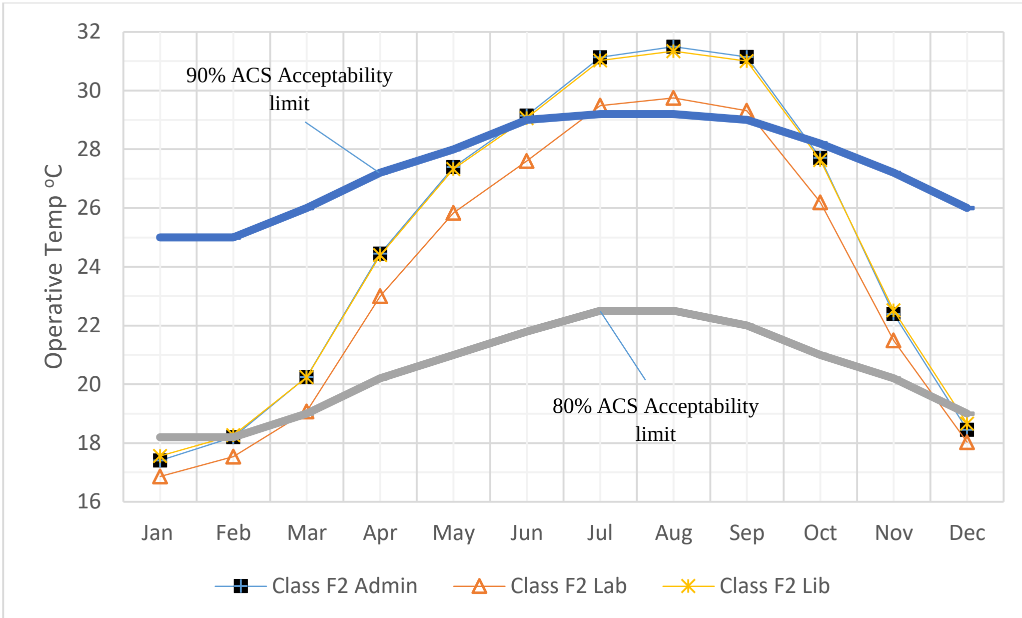


(c)

Figure 4.14 Monthly operative temperature averages for Al Zahra school zones, a) Ground floor zones, b) First floor zones, c) Second floor zones.

For the first floor, "Class F1 Admin" and "Class F1 Lib" have almost typical values, while "Class F1 Lab" is relatively lower.

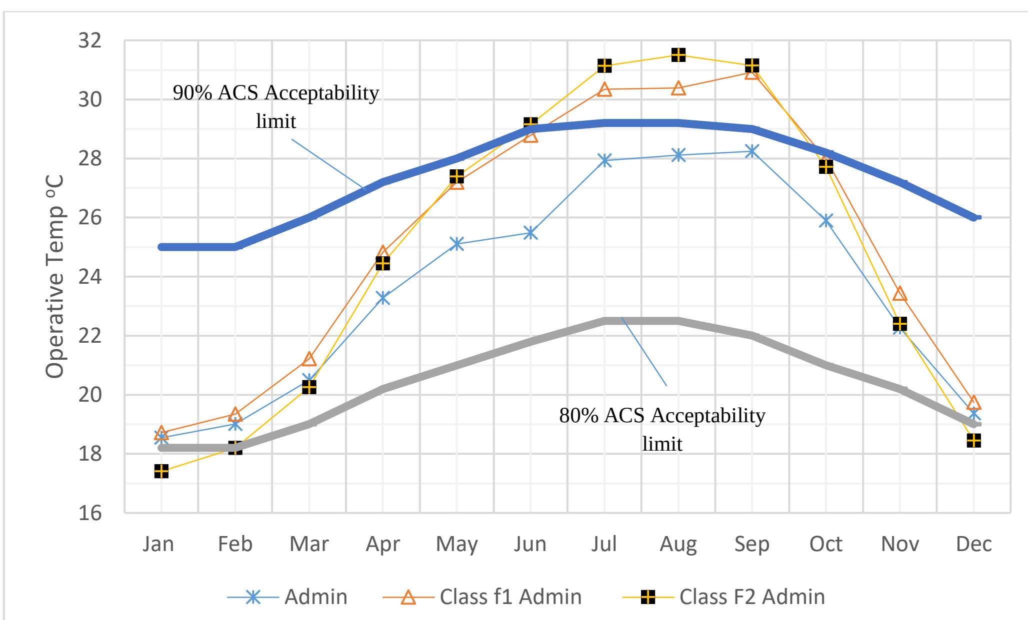


Figure 4.15 Comparison between worst zones for each floor

On the same floor, around 31 °C is the highest recorded average in September, while 17 °C is the lowest in January. The second floor has the highest averages among others. "Class F2 Admin" and "Class F2 Lib" touched the peak with 31 °C. However, "Class F2 Lib" could not represent the whole school because of its unique location. **Figure 4.15** proved that "Class F2 Admin" is the worst case in which the following studies were implemented on.

4.2.3.2 Wall System

Different wall systems affect the thermal comfort conditions. Selection of various wall construction and finishing materials is limited by the availability in the intended place. Such changes could not be applied to the existing schools. The suggested solution (if any) will be only applicable for new constructions. Double and cavity walls are expensive and not preferable in Gaza-Strip.

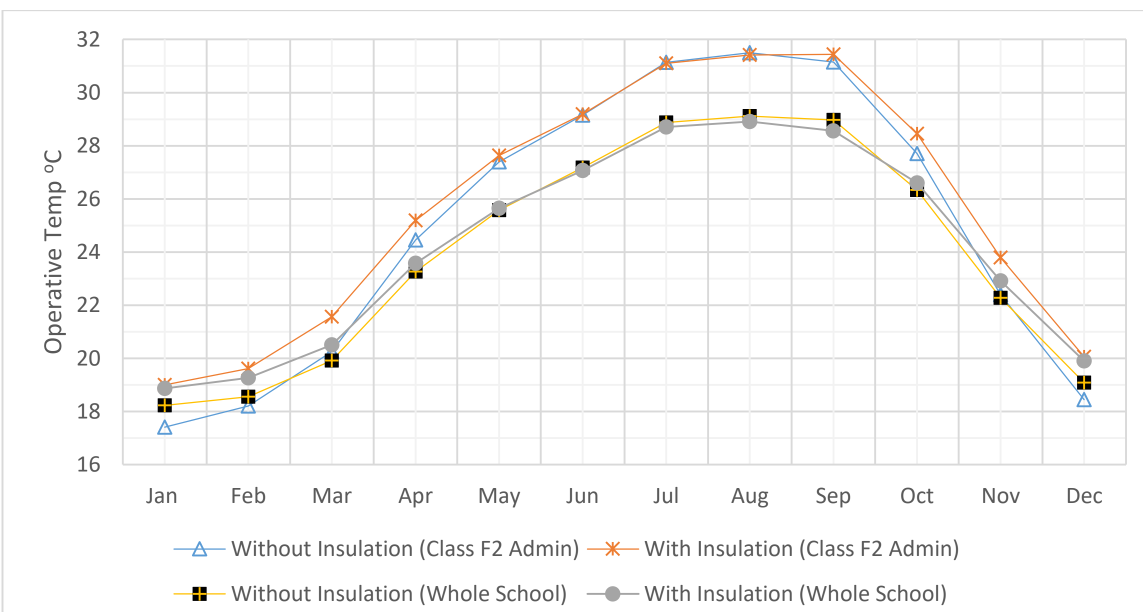


Figure 4.16 Impact of Foam-Polyurethane insulation on monthly operative temperature averages

Only thermal insulations could be installed to achieve more thermal comfort. However, insulations are more adaptable with mechanically ventilated buildings. Polyurethane insulation boards were selected because of their availability, low cost, ease of use, and high efficiency. the insulation with 0.0280 W/m-k conductivity, 30 kg/m3 density and 5 cm thickness has been installed on all exterior walls for the whole school from the inner surface. the results in **Figure 4.16** assured that the provision of thermal insulation is not justified. Almost the same values were obtained during the summer months for with/without cases because of the operable windows. However, the heat is trapped during winter months and causes a slight increase in the indoor temperature while the insulation is installed.

4.2.3.3 Window Glazing Type

Windows have several types of glazing based on construction material, low conductivity values, number of layers, tints, and finishing colors. It is impossible and not viable to test all glazing data sets in terms of their thermal and visual impact. However, a good methodology for sorting them in order to select the credible alternatives that should be available. Out of thousands of glazing types, seven categories were selected carefully to be examined. The criteria for selection were based on solar transmittance/solar heat gain coefficient factor, market availability, and cost. After filtering the DOE-2 Glass Library, ten sorted glazing categories were chosen. **Table 4.4** shows the selected categories and illustrates the thermal and visual performance for each. Although the listed types fulfilled the selection criteria, tribble glazing windows are rarely used in schools even in mechanically ventilated ones. Using three layers of glasses is not justified in terms of the intended function and life cycle cost efficiency.

Table 4.4 Selected glazing categories based on Tvis/SHGC factor

DOE-2 Glass Library, Sorted by Tvis/SHGC	G, U-SI ($W/m^2.K$)	G+F, U-SI ($W/m^2.K$)	SHGC	Tvis	Tvis/SHGC
Double Low-E (e2=.04) Clear	1.34	1.95	0.43	0.7	**1.63**
Triple Low-E Film (66) Clear	1.23	2.08	0.36	0.54	**1.5**
Double Low-E (e2=.04) Tint	1.32	1.87	0.28	0.41	**1.46**
Double Tint Green	2.56	3.41	0.49	0.66	**1.35**
Double Low-E (e2=.1) Clear	1.46	2.11	0.56	0.75	**1.34**
Triple Low-E Film (66) Tint	1.23	2.08	0.25	0.32	**1.28**
Single Tint, Green	6.17	6.72	0.61	0.75	**1.23**
Triple Low-E Film (55) Tint	1.22	2.08	0.22	0.27	**1.23**
Single Low-E Clear (e2=.2)	4.27	4.63	0.72	0.81	**1.13**
Double Clear	3.16	4.24	0.69	0.78	**1.13**

Seven categories out of the listed ten (after eliminating the tribble glazing) were parametrically examined to test their impact on annual operative temperature averages. It is noticed from **Table 4.5** that the annual averages for the nominated categories are almost the same. Slight difference range does not exceed 0.20 ^oC is between the highest 25.07 ^oC for “Double Low-E (e2=.1) Clear” and the lowest 24.87 ^oC for “Single Tint, Green”.

The results could be interpreted by the role of the operable windows at most times of the year. In most naturally ventilated buildings, changing window types is not as much necessary as mechanically ventilated ones. The role of thermal efficient construction materials for insulated windows is affected strongly with the increasing of air infiltration and air exchange amounts. These two values are not controlled in naturally ventilated facilities.

In conclusion, changes in both wall system and glazing type were not experimentally justified. It seems that the existing conditions for the school envelope achieve the optimized solution. It has been proven by conducting complete parametric analysis for the whole school and examining the seven windows categories.

Table 4.5 the impact of the nominated glazing categories on annual T_{op} averages for both "Class F2 Admin" zone and the whole school

Nominated Glazing Categories	Annual T_{op} (°C) "Class F2 Admin"	Nominated Glazing Categories	Annual T_{op} (°C) "Whole School"
Double Low-E (e2=.04) Clear	25.02	**Double Low-E (e2=.04) Clear**	24.05
Double Low-E (e2=.04) Tint	24.85	**Double Low-E (e2=.04) Tint**	24.04
Double Tint Green	24.97	**Double Tint Green**	24.04
Double Low-E (e2=.1) Clear	25.07	**Double Low-E (e2=.1) Clear**	24.05
Single Tint, Green	24.87	**Single Tint, Green**	24.04
Single Low-E Clear (e2=.2)	25.06	**Single Low-E Clear (e2=.2)**	24.06
Double Clear	25.10	**Double Clear**	24.05

4.2.3.4 Window-Wall Ratio

Al-Zahra classrooms have identical architectural and structural designs. Two 0.20m reinforced concrete beams (along with the upper and lower exterior windows sills) wrap the whole class from all directions. Hence the process of changing window-wall ratio is restricted. However, a clear 55 cm height is available above the interior and exterior windows.

Regarding the 1.35 m height below the exterior windows, it is not possible to utilize this area for safety and educational purposes. Yet, a 0.45 m height below the internal windows is still available to be studied. All possible window-wall ratios are explained in **Figure 4.17**.

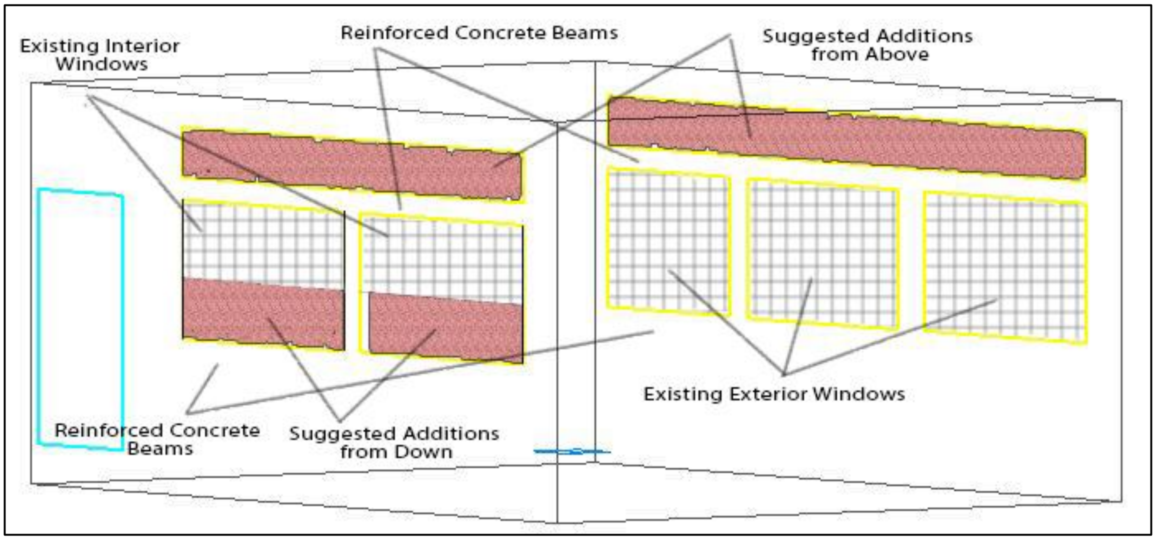


Figure 4.17 Possible window-wall ratios for a single classroom in Al-Zahra school

With reference to **Figure 4.17** and **Table 4.6**, eight suggested window-wall ratio scenarios were studied:

Base. Existing interior + existing exterior window wall ratios.

1. Existing interior + suggested exterior (with additions from above);
2. Suggested interior (with additions from above) + existing exterior;
3. Suggested interior (with additions from above) + suggested exterior (with additions from above);
4. Suggested interior (with additions from down) + existing exterior;
5. Suggested interior (with additions from down) + suggested exterior (with additions from above);
6. Suggested interior (with additions from both sides) + existing exterior;
7. Suggested interior (with additions from both sides) + suggested exterior (with additions from above).

Table 4.6 The Suggested window-wall ratios for both internal and external windows

	Internal Windows			External Windows		
	Existing Ratio%	**Suggested Additional Ratio%**	**Total Window-Wall Ratio%**	**Existing Ratio%**	**Suggested Additional Ratio%**	**Total Window-Wall Ratio%**
B	14.70	-	**14.70**	35.20	-	**35.20**
1	14.70	-	**14.70**	35.20	11.80	**47.00**
2	14.70	7.30	**22.00**	35.20	-	**35.20**
3	14.70	7.30	**22.00**	35.20	11.80	**47.00**
4	14.70	8.30	**23.00**	35.20	-	**35.20**
5	14.70	8.30	**23.00**	35.20	11.80	**47.00**
6	14.70	15.60	**30.30**	35.20	-	**35.20**
7	14.70	15.60	**30.30**	35.20	11.80	**47.00**

Based on monthly/annually simulation results shown in **Figure 4.18 and Figure 4.19**, the eight categories show convergent values in terms of the consumed electrical energy.

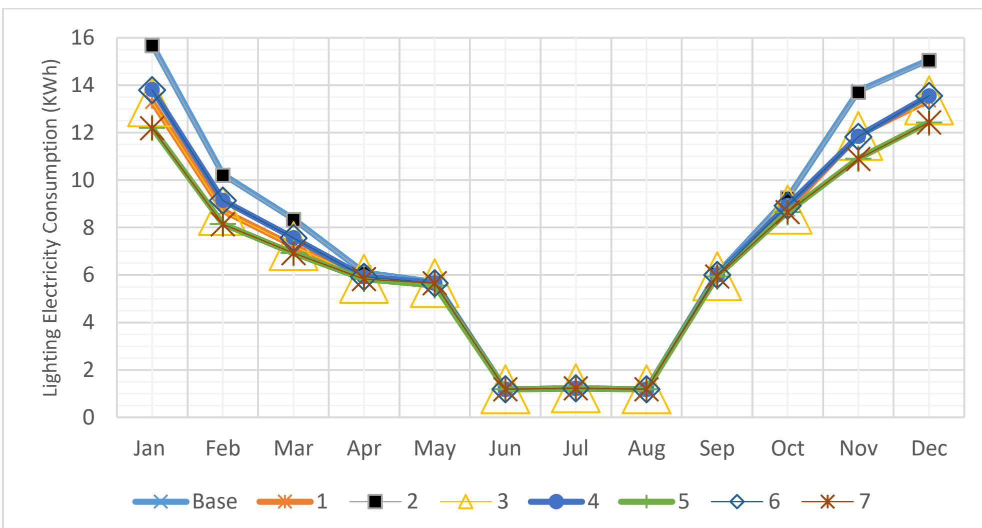


Figure 4.18 Monthly lighting electricity consumption for the selected window-wall ratio cases

Adding some extra openings above the existing internal windows while keeping the external as they are, gives the same results as the base scenario. Little expected reductions resulted by enlarging the external windows from the upper side regardless the conditions of the internal windows. This was approved by the obtained results from both 5, 7 cases. It is noticed that the impact of changing window-wall ratio is almost occurred in winter due to the low sun angles that could hit the sensor directly from the upper external windows.

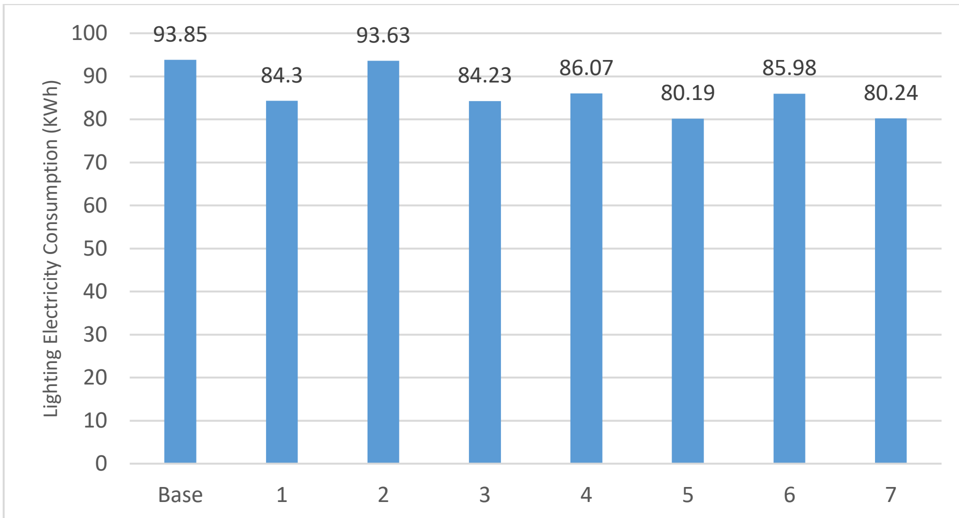


Figure 4.19 Annual lighting electricity consumption for the selected window-wall ratio cases

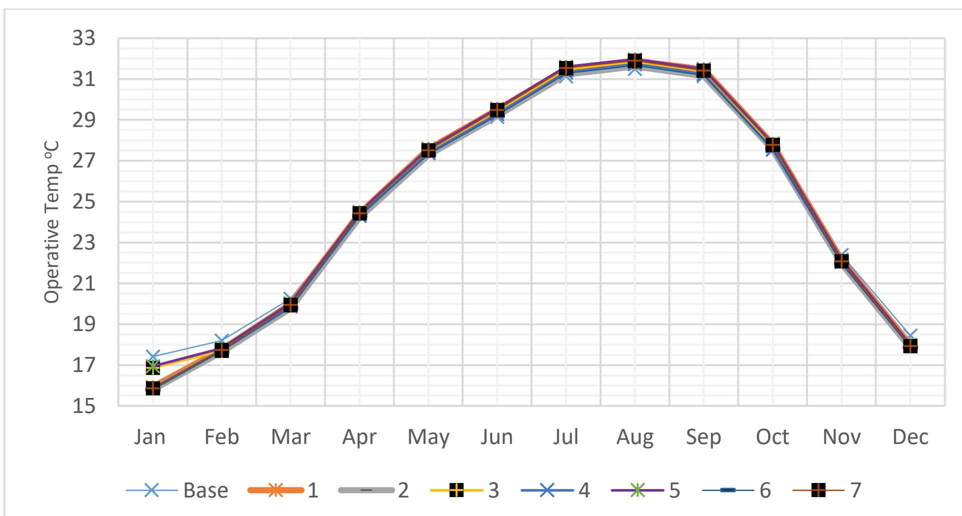


Figure 4.20 Monthly operative temperature for the selected window-wall ratio cases

However, slight annual reductions (almost 13 KWh) are not enough to justify the costs of adding more glazing areas, especially, when the thermal conditions are also considered. **Figure 4.20** shows almost similar thermal conditions for the all last cases.

4.2.4 Ceiling Fans

As indicated in section 3.4.5.2 with regards to section 4.2.3.1, the impact of the provision for ceiling fans parallel to thermal conditions for “Class F2 Admin” has been extracted. It was indicated that even through peak months when the operative temperature reaches almost 30-31 ^{o}C, these values are located between 80% - 90% acceptability ranges for the adaptive ASHRAE .55 ACS. Despite that, the indoor operative temperature is not the only indication for the thermal comfort conditions; both air velocity and relative humidity are also required. For ensuring the comfortability conditions for the nominated worst-case (after that, results could be applied to the whole school), a CFD study was suggested in order to examine the possibility of enhancing the indoor thermal comfort levels. Three months during the year their thermal conditions should be improved: May, September, and October. Increasing air velocity to an acceptable range (see **Table 4.7**. Note: Every 0.076 m/s increase in air movement above a velocity of 0.152 m/s is sensed by the body as a 1° temperature drop **[82]**) increases heat loss by convection between human skin and the surrounding air as well as contributes to evaporating sweat. The last mentioned advantages are responsible for increasing users’ satisfaction in terms of their response to thermal conditions. To practically implementing that, two similar ceiling fans were suggested to be in the middle of class width axis and each distributed by the center of one-third of the longitudinal axis. The technical specifications for the selected ceiling fans are shown in **Table 4.8**. The selection was based on different criteria: efficiency (cfm per watt), warranty, durability, controller, price, availability, and manufacturing quality. To simulate both of them, a CFD study in DesignBuilder was prepared. In order to test the impact of changing motor velocity, two airflow values were analyzed, 7105 cfm (at maximum speed) and 3550 cfm (at the middle speed). This helped in determining the optimum solution for operative temperature, air velocity, and consumed energy. “Class F2 Admin” zone was chosen and highest external/internal boundaries values (31 ^{o}C average operative temperature in 2nd September) were collected automatically from the simulation results.

Table 4.7 Occupant reaction for different air velocities **[82]**

Air Velocity		
fpm	m/s	Occupant Reaction
0 to 10	0 to 0.05	Complaints about stagnation
10 to 50	0.05 to 0.25	Generally favorable (air outlet devices normally designed for 50 fpm in the occupied zone)
50 to 100	0.25 to 0.51	Awareness of air motion, but may be comfortable, depending on moving air temperature and room conditions
100 to 200	0.51 to 1.02	Constant awareness of air motion, but can be acceptable (e.g., in some factories) if air supply is intermittent and if moving air temperature and room conditions are acceptable
200 (about 2 mph) and above	1.02 and above	Complaints about blowing of papers and hair, and other annoyances

Table 4.8 Selected ceiling fan technical specifications

Product Name	Westinghouse	**Model**	7812700 Industrial
Size (inch)	56	**Number of Blades**	Three-Blades
Dimensions (cm)	23.1x21.6x72.9	**Weigh (kg)**	7.65
Airflow (CFM)	7,105	**Power (W)**	63 (at maximum speed)
Efficiency (CFM / W)	113	**Color**	White
Material\Finishing	Metal\Steel	**Controller**	five-speed wall control
Price ($)	59.64	**Warranty**	15-years motor warranty

Air velocity and indoor operative temperature are the two factors that were tested. To achieve smooth and practical results, 7326 cells identified the 3d grid as 22, 37 and 9 cells for x, y and z axes respectively. **Figure 4.21** shows both the indoor operative temperature and air velocity in the existing conditions (without ceiling fans). The results were extracted during the peak annual operative temperature (3rd Sep, 12:00 pm).

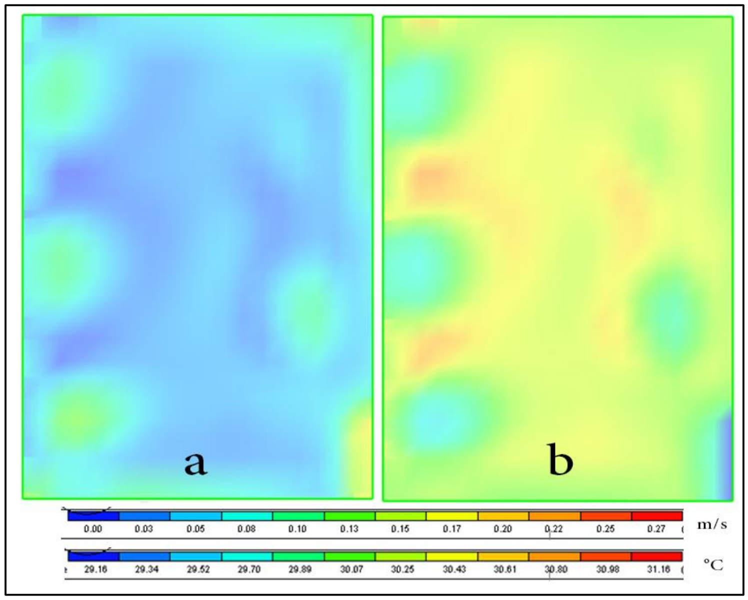


Figure 4.21 CFD contour maps for the existing conditions at the peak operative temperature, a) Air velocity, b) Operative temperature.

Figure 4.22 shows both the indoor operative temperature and air velocity for the first alternative when two similar ceiling fans are operating and have the same maximum airflow (7105 cfm – 63 W).

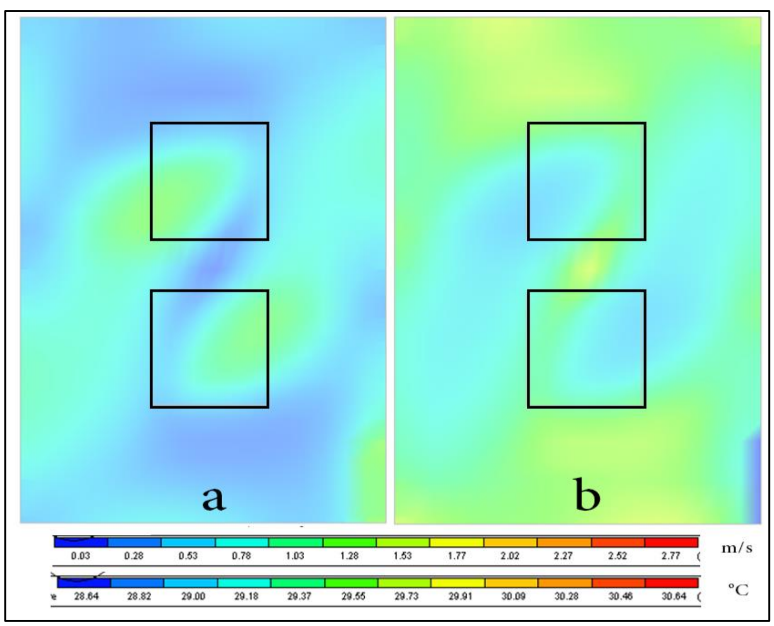


Figure 4.22 CFD contour maps for two ceiling fans operate at maximum 7105 CFM, a) Air velocity, b) Operative temperature

In the first case, the ceiling fans were operated at the same maximum airflow value. Despite the enhancement in decreasing the operative temperature by almost two degrees from 31.16 ^{o}C to 29.5 ^{o}C at most of the working plane (0.80 m from the ground), the air velocity exceeded the generally favorable levels under the two fans (above 0.70 m/s).

Figure 4.23 shows both the indoor operative temperature and air velocity for the first alternative when two similar ceiling fans are operating and have the same maximum airflow (3500 cfm – 63 W).

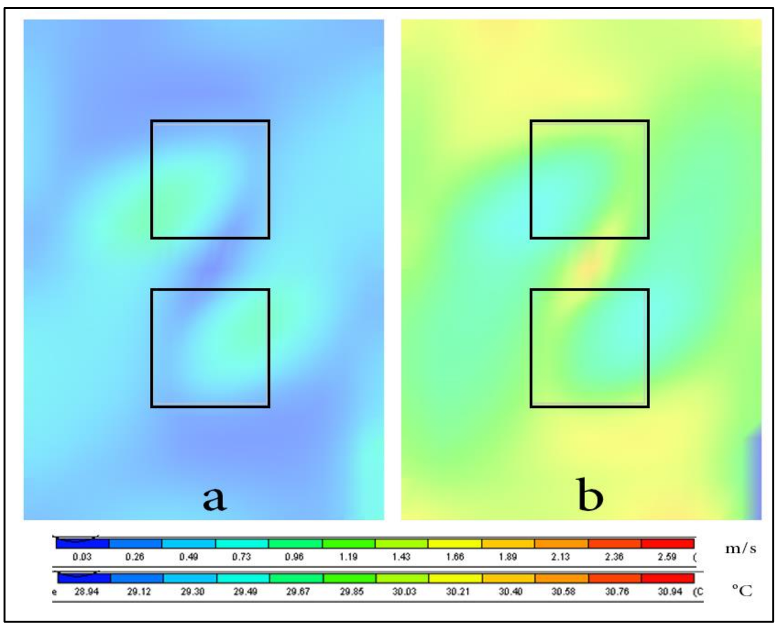


Figure 4.23 CFD contour map for two ceiling fans operate at middle airflow 3500 CFM value, a) Air velocity, b) Operative temperature.

In the second case, the ceiling fans were operated at the same middle airflow values. Indoor operative temperature decreases by almost 1.5 ^{o}C from 31.16 ^{o}C to 29.85 ^{o}C at most of the working plane (0.80 m from the ground). Moreover, air velocity is within the recommended levels (0.25 - 0.70 m/s). This favorable air velocity has the capacity to enhance the occupants' sensation and increase the thermal comfort zone by up to 1 ^{o}C.

It is important to indicate that the reduction in the operative temperature was a result of the decrease in the air temperature while the MRT was taken as a fixed average. Each ceiling fan has the capability to mix and circulate the cooler outdoor air in the zone. This process helps to increase the air exchange between the inside and outside of the classroom.

The first scenario has been eliminated (maximum speed) because of the high generated air velocity and the two fans operating at the maximum power (63 W).

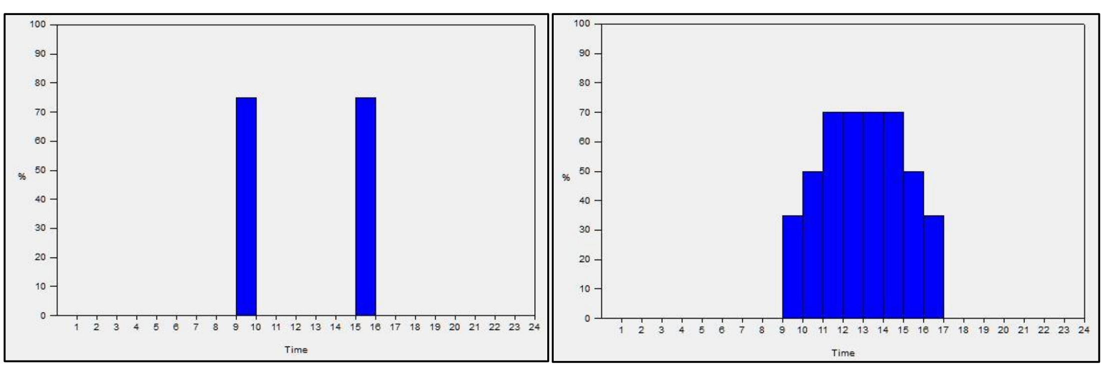
To conclude, ceiling fans which are operated at middle-speed values (3500 cfm) and consume the half energy (30 W) are relatively more practical. The maximum 29.85 ^{o}C resulted by the provision of the ceiling fans assured that all the annual operative temperatures are now within the comfortable zone.

4.3 Conclusion: Selecting the Optimum Model

Different simulations were conducted for several alternatives in order to end up with the optimum school characteristics. In this chapter, a set of conclusions were summarized and optimum solutions for both energy consumption and thermal/visual comfort were extracted. They could be summarized as the following:

- One centralized photosensor for each zone with core function (except stores, stairs, toilets, and corridors) operate under the target illumination;
- LED lighting system in all spaces equipped or not equipped with any photosensor;

- Full lighting operation schedule for both morning and evening shifts;
- Existing window wall ratio for both exterior and interior windows for the school;
- Existing wall system and window glazing type;
- Utilizing of two centralized ceiling fans (see **section 4.3**) operate with middle speeds in the 24 classrooms only (first and second floors). **Figure 4.24 (b)** shows the hourly fans operation schedule during the two shifts. (Note that it was assumed that ceiling fans have 63 W power rating (at maximum speed), hence 70% of hourly operation means that all fans in all classes are operated with 70% of the maximum speed. This assumption suggests +20% safety factor at the peak times. However, with the provision of 35%, the overall mean of operation is almost 50%. Although the same energy is consumed in both constant 50% and average 35%-70% operations, the last assumption is more safe in terms of the peak power calculations (example, in PV array design).
- The computer lab operation was suggested as shown in **Figure 4.24 (a)**. Note that it is highly recommended to avoid operating the computer lab during the most and maximum operating lighting times at early morning and late evening (due to daylight sensors) in order to reduce the accumulated peak power.



(a) (b)

Figure 4.24 Annual operation schedules, a) Computer Lab, b) Ceiling fans

As summarized in **Table 4.9,** before conducting any improvement, the school was consuming around 16,000 kWh annually, therefore, around 5.55 kWh/ m^2 was the average consumption per school building area (16,000 kWh / 2880 school building area); further, 20 kWh was the consumption per capita (16,000 kWh / 800 school occupants). After the improvements, a reduction of 65% was achieved (the school consumes 5609 kWh annually), hence, the consumption could be figured out as 1.95 kWh/m^2 and 7 kWh per capita. **Figure 4.25** shows the optimum monthly energy consumptions for Al-Zahra school.

Table 4.9 Summery Table shows a comparison between both existing school and improved model energy characteristics

	Existing School	**Improved Model**
Annual Consumption (kWh)	16,000	5609
Operation Schedule	Existing	Ideal
Consumption per School Building Area (kWh/m^2)	20	5.55
Consumption per Capita (kWh/Capita)	7	1.95

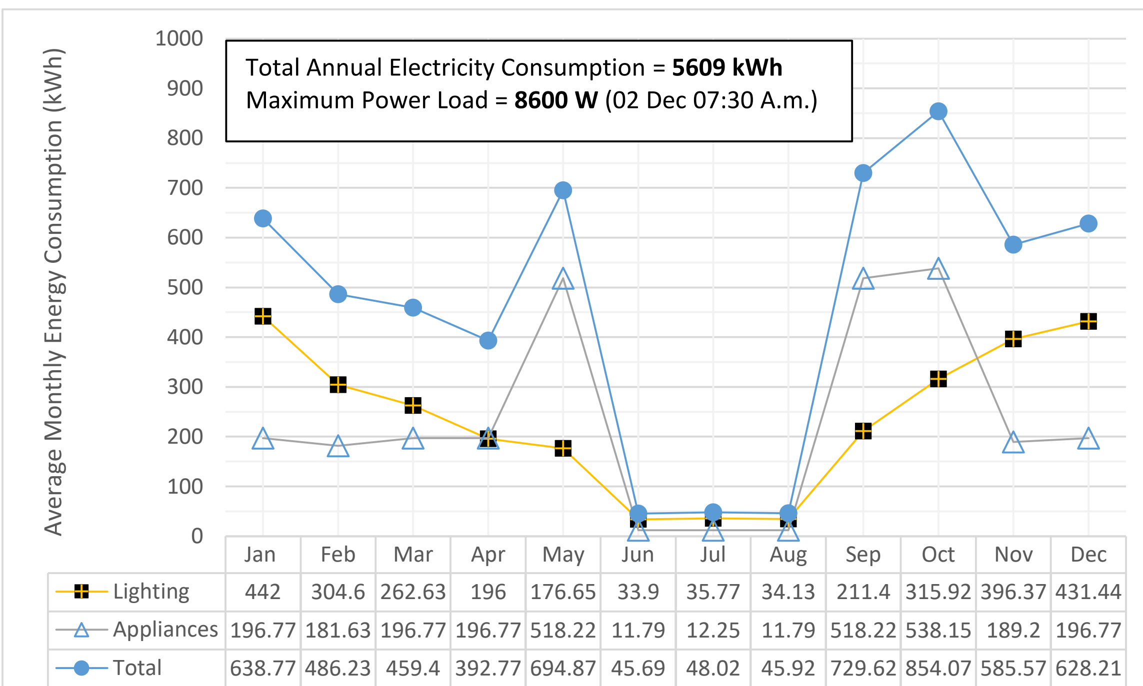


Figure 4.25 Breakdown of optimum monthly energy consumption for Al-Zahra school

CHAPTER 5

APPLYING GREEN ENERGY (PV) ON THE IMPROVED SCHOOL MODEL: TECHNICAL, ENVIRONMENTAL AND FEASIBILITY STUDIES

5.1 Introduction

Gaza-Strip has more than 3000 sun hours annually and it is characterized by high daily solar radiation horizontal averages with 3.04 – 8.44 $kWh/m^2/day$ and 4.11 – 7.81 $kWh/m^2/day$ by the optimum 23^o tilt angle to the south direction. **Figure 5.1** shows both horizontal and tilt daily solar radiation averages collected by NASA Surface Meteorology and Solar Energy **[77]**.

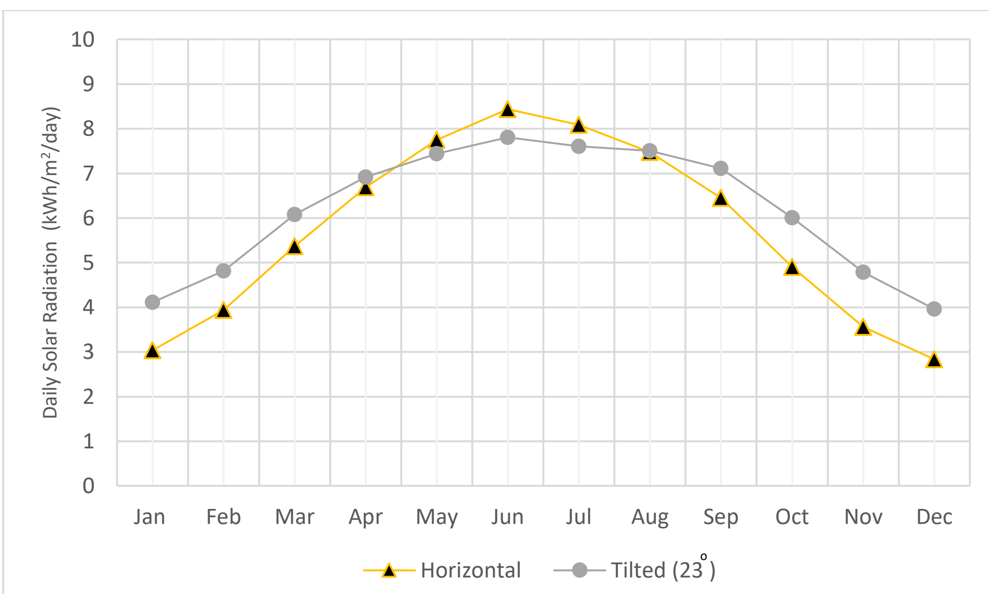


Figure 5.1 Gaza-Strip both horizontal and tilt daily solar radiation averages **[77]**

“RETScreen is a Clean Energy Management Software system for energy efficiency, renewable energy and cogeneration project feasibility analysis as well as ongoing energy performance analysis. RETScreen empowers professionals and decision-makers to rapidly identify, assess and optimize the technical and financial viability of potential clean energy projects. This decision intelligence software platform also allows managers to easily measure and verify the actual performance of their facilities and helps find additional energy savings/production opportunities. The software, provided free-of-charge, can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs). The software (available in multiple languages) also includes product, project, hydrology and climate databases, a detailed user manual, and a case study based college/university-level training course, including an engineering e-textbook. RETScreen International is managed under the leadership and ongoing financial support of the CanmetENERGY research center of Natural Resources Canada's (NRCan). RETScreen is developed by a core team at CanmetENERGY located in Varennes in collaboration with a number of other government and multilateral organizations, and with technical support from a large network of experts from industry, government and academia.

The RETScreen Climate Database includes the meteorological data required in the model. While running the software the user may obtain climate data from ground monitoring stations and/or from NASA's global satellite/analysis data. If climate data is not available from a specific ground monitoring station, data is then provided from NASA's satellite/analysis data.” **[83]**

5.2 PV System design for School Utilization (Phase I)

In this section, PV design process will be limited to cover school's requirements. If available, any remaining area after calculating the required space to install PV arrays will be utilized totally to make extra generations and feed the community.

5.2.1 Base-Case Power System and load characteristics

The design will be a mix of off-grid and grid-tied methodologies. It means that a kind of storage system will be available to store energy from PV array and to feed the school, however, any extra generations will be turned directly to school's central grid to be transferred to the electricity company.

The base-case power system is the utility grid in which feeds the school in the normal situation. The end-user fuel rate is 0.131 $/kWh. A reciprocating diesel-generator is currently provided and it Is frequently used during electricity shutting to supply power to core facilities (e.g. computer lab, copy machines …etc.). Often, the generator does not supply the lighting system as a 5 - 10 kW generator is not able to cover the lighting load. Generator fuel rate is 1.5 – 1.8 $/L, and about 500 $ is the annual expenses for its operation and maintenance.

Regarding the base case maximum load and monthly energy consumption, and according to the obtained results in chapter 4 (see **section 4.4**, **Figure 4.25**), the maximum power load was 8600 W (on 02 Dec at 07:30 A.m.) while 5609 kWh A.C is the annual energy consumption. In order to keep the PV system on the safe side, 10% safety factor was suggested to the maximum load to be 9500 W approximately.

5.2.2 Proposed Case Power System

In this section, all of the basic proposed PV system components (inverters, batteries, PV modules) will be selected and their both technical and financial properties will be discussed.

5.2.2.1 Selected PV Module Technology

To calculate the number of modules, strings and arrays, PV technical specifications should be available. Based on the conducted literature for the common PV materials (see **section 2.4.2.3**), PV production (see **section 2.4.3**) and based on project scale, investment lifetime, cost estimations, module efficiency, module optimum operating voltage (V_{dc}) (to fit other PV components), module's maximum power rating (P_{max}), durability, temperature coefficient, warranty, ease of transportation and maintenance, product trademark …etc. the selection of the PV module was done.

"Suntech develops, manufactures, and delivers the world's most reliable and cost-effective solar energy solutions. Founded in 2001, they have supplied photovoltaic panels to more than a thousand customers in more than 80 countries. they have 22 years of overseas distributed solar project experience. They would be devoted to bringing the green energy to tens of thousands of families. Suntech is recognized worldwide as a best-in-class multinational company. The solar industry's top research institute, EuPD Research, awarded Suntech Top Brand PV, making Suntech the first company in China to win this award. For its contribution to environment protection, Suntech received awards from the

United Nations Climate Change Conference, the United Nations Human Settlements Program, The World Economic Forum and worldwide top media outlets." **[84]**

One of the most offered powerful, efficient and cost-effective mono-crystalline modules is "Suntech STP300S-20/ Wew". The technical specifications of the module are shown in **Table 5.1**. With 18.4% efficiency, this module is suitable to be installed especially in locations with high-radiation levels.

Table 5.1 Selected PV Module technical specifications **[85]**

STP300S-20/Wew	
Maximum Power at STC (P_{max})	300 W
Maximum Power at NOCT (P_{max})	220.9 W
Optimum Operating Voltage (V_{mp})	32.6 V
Optimum Operating Current (I_{mp})	9.21 A
Open Circuit Voltage (V_{oc})	39.9 V
Short Circuit Current (I_{sc})	9.65 A
Module Efficiency	18.40%
Operating Module Temperature	-40 °C to +85 °C
Maximum System Voltage	1000 V_{dc} (IEC)
Maximum Series Fuse Rating	20 A
Power Tolerance	0/+5 W
Length, Width, Weight	1.64 m, 1.00 m, 18.2 kg
Cost per Module	210 $
STC: Irradiance 1000 W/m2, module temperature 25 °C, AM=1.5 NOCT: Irradiance 800 W/m2, ambient temperature 20 °C, AM=1.5, wind speed 1 m/s	

To design a preferable PV output voltage, inverter and battery storage specifications should be identified. However, to identify the required number of modules, maximum load wattage (after calculating all losses) should be determined.

Hence, *Number of modules* = $\frac{Maximum\ load}{P_{max}}$ (5.1)

$$\textit{Number of modules} = \frac{9600}{300} = 32 \text{ Modules}$$

Let assume two strings are available, each string contains 16 modules connected in series, and the two strings are connected in parallel, then:

$$\textit{PV string output voltage} = \textit{Number of modules connected in series} \times V_{mp} \tag{5.2}$$

$$\textit{PV string output Voltage} = 16 \times 32.6 = 521.6 \text{ V}_{dc}$$

$$\textit{PV array output Current} = \textit{Number of Strings connected in Parallel} \times I_{mp} \tag{5.3}$$

$$\textit{PV array output Current} = 2 \times 9.21 = 18.42 \text{ I}_{dc}$$

Hence, Inverter input operating dc voltage and current should fit both PV output V_{dc} and I_{dc}. As the PV array is connected to both storage system and inverter directly, batteries input voltage should be capable to contain the income voltage as well as batteries should have enough capacity to cover the daily consumption. With regards to the following criteria; daily solar radiation (see **Figure 5.1**), 0.40% / ^{o}C temperature coefficient, 96% inverter efficiency, 98% dc\dc converter efficiency and 2% transmission lines to the grid losses as well as 0.131 $ feed in tariff price per each sold kWh, the monthly generations as well as the annual difference between the generation and the consumption are shown in **Table 5.2**. (*Note: About 5% losses were assumed for extra batteries charging. As known, batteries will be charged until a fixed ratio daily to meet the state of charge ratio and any more generations will be transferred to the inverter directly to be shifted to the public grid. Hence, there is no way to control batteries charging to accommodate only the daily required energy, there will be a surplus energy stored in the batteries and will not be transferred to outside the school. As a result, 5% losses were assumed for this kind of stored surplus energy). About 18,710 kWh is the total annual generations out from the system, part of them (6732 kWh) will be stored in the batteries to cover the required energy and the other part (11380 kWh) will be transferred to the grid to be sold. The actual annual required energy is 5610 kWh, however, after system components losses as; batteries (15%), inverter (4%), charge controller (2%) and local network cables (1%), the total losses will be:

$$Total\ system\ losses = Inverter_{efc} \times batteries_{efc} \times charge\ controller_{efc} \times cables_{efc} \quad (5.4)$$

$$Total\ system\ losses = 96\% \times 85\% \times 98\% \times 99\% = 80\%$$

To avoid these ratio of losses, annual required energy should be multiplied by 1.20 %, hence, to consume 5610 kWh, 6732 kWh should be generated.

Table 5.2 Monthly\Annual generation\consumption out from PV system with annual accumulated feed in tariff income

Month	Generations from PV Modules (kWh)	Required energy from PV Modules (kWh)	Extra generation (kWh)	Extra generation (kWh) - (5 %) losses	Monthly feed in tariff income ($)
Jan	1112	756	356	338.2	44.30
Feb	1171	576	595	565.25	74.05
Mar	1605	504	1101	1045.95	137.02
Apr	1736	444	1292	1227.4	160.79
May	1902	840	1062	1008.9	132.17
Jun	1899	60	1839	1747.05	228.86
Jul	1896	60	1836	1744.2	228.49
Aug	1863	60	1803	1712.85	224.38
Sep	1715	888	827	785.65	102.92
Oct	1529	1068	461	437.95	57.37
Nov	1215	720	495	470.25	61.60
Dec	1067	756	311	295.45	38.70
Total	18710	6732	11978	11380	1491

5.2.2.2 Inverter specifications

One of the most critical components of any PV system is the inverter. It is essentially used to convert received PV DC current to AC. It is mandatory to calculate the maximum DC voltage and the received power from each PV string\array. Several manufacturers are available in the market and it is important to select what fits the system. Efficiency, cost, durability, capacity, life degradation …etc. are the criteria in which the selection should be based on. ABB is a pioneering technology leader that is writing the future of industrial digitalization. For more than four decades, they have been at the forefront, innovating digitally connected and enabled industrial equipment and systems. Every day, they drive efficiency, safety and productivity in utilities, industry, transport and infrastructure globally. With a heritage spanning more than 130 years, ABB operates in more than 100 countries and employs around 135,000 people **[86]**.

Based on each string peak operating voltage and PV array output DC current, the capacity of the inverter was selected. From results of (5.2) and (5.3) equations, "ABB PVI-5000-TL-OUTD" inverter is appropriate. **Table 5.3** shows the selected inverter technical information. With 90 – 580 V maximum operating DC input voltage, 36 A maximum DC input current and 5150 W rated DC input power, the inverter is capable of receiving peak DC voltage from each string and PV array output current. However, two inverters should be available, each of both should be linked to each string.

The inverter has dual input section with independent MPP tracking, it allows to perform optimal energy harvesting from two sub-arrays oriented in different directions.

Table 5.3 Selected inverter technical datasheet **[87]**

ABB PVI-5000-TL-OUTD Inverter (1200 $)	
Input Side	
Absolute maximum DC input voltage ($V_{max,abs}$)	600 V
Start-up DC input voltage (V_{start})	200 V (adj. 120 - 350 V)
Operating DC input voltage range (V_{dcmin} - V_{dcmax})	0.7 x V_{start} - 580 V (min 90 V)
Rated DC input voltage (V_{dcr})	360 V
Rated DC input power (P_{dcr})	5150 W
Number of independent MPPT	2
Maximum DC input power for each MPPT ($P_{MPPTmax}$)	4000 W
DC input voltage range with parallel configuration of MPPT at P_{acr}	150 - 530 V
DC power limitation with parallel configuration of MPPT	Linear derating from max to null [530 V≤V_{MPPT}≤580 V]
DC power limitation for each MPPT with independent configuration of MPPT at Pacr, max unbalance example	4000 W [220 V≤V_{MPPT}≤530 V] the other channel: P_{dcr}-4000 W [90 V≤V_{MPPT}≤530 V]
Maximum DC input current (I_{dcmax}) / for each MPPT ($I_{MPPTmax}$)	36.0 A / 18.0 A
Maximum input short circuit current for each MPPT	22.0 A
Number of DC inputs pairs for each MPPT	2
DC connection type	Tool Free PV connector WM / MC4
Input Protection	
Reverse polarity protection	Yes, from limited current source
Input over voltage protection for each MPPT varistor	Yes
Photovoltaic array isolation control	According to local standard
DC switch rating for each MPPT (version with DC switch)	25 A / 600 V
Output Side	
AC grid connection type	Single-phase
Rated AC power (P_{acr} @cosφ=1)	5000 W
Maximum AC output power (P_{acmax} @cosφ=1)	5000 W
Maximum apparent power (S_{max})	5560 VA
Rated AC grid voltage (Vac,r)	230 V
AC voltage range	180 - 264 V
Maximum AC output current ($I_{ac,max}$)	25 A
Rated output frequency (fr)	50 Hz / 60 Hz
AC connection type	Terminal block, cable gland M32

The wide input voltage range makes the inverter suitable for low power installations with reduced string size. Flat efficiency curves ensure high efficiency at all output levels ensuring consistent and stable performance across the entire input voltage and output power range. This outdoor inverter has been designed as a completely sealed unit to withstand the harshest environmental conditions.

5.2.2.3 Storage System

According to **section 2.4.2.4** and **Table 2.10**, Lead-Acid batteries are the most suitable batteries to be used in this small-scale system. Days of autonomy were selected to be only one day, however, decreasing the depth of discharge rate to the almost half, helps in keeping enough stored energy for emergency cases and increases batteries life-cycle.

Figure 5.2 shows the required daily energy for the school during a typical year. Note that about 35 kWh is the maximum daily energy consumption value.

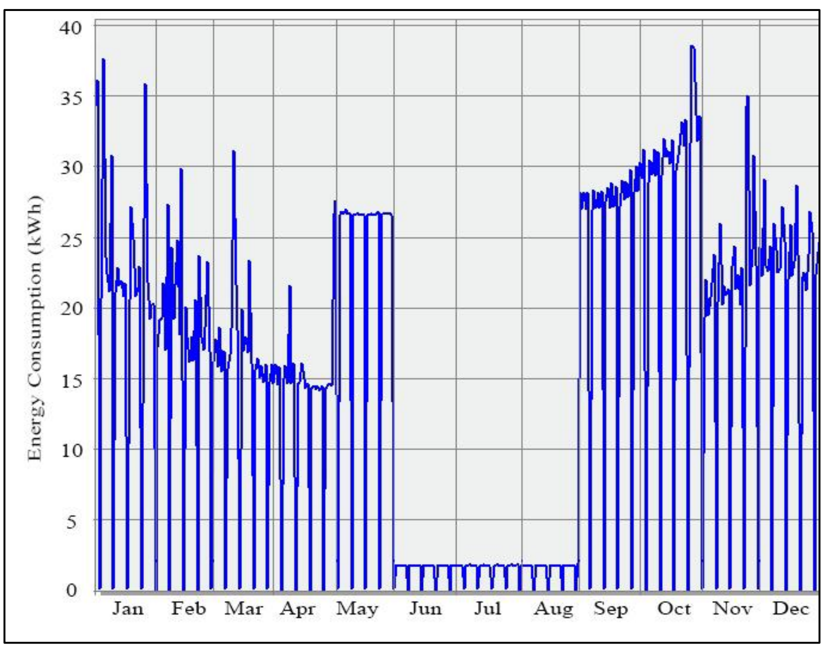


Figure 5.2 Daily energy consumption for all school utilizations

The following equation is used to design batteries capacity:

$$\textit{Batteries Capacity (Ah)} = \frac{\textit{Maximum daily energy (Wh)}}{\textit{Battery Voltage} \times \textit{System efc} \times \textit{DOD} \times \textit{Days of Autonomy}} \quad (5.5)$$

$$\textit{Batteries Capacity (Ah)} = \frac{35{,}000}{24 \times 0.80 \times 0.55 \times 1} = 3314 \text{ Ah}$$

To identify number of required batteries, the following equation is used:

$$\textit{Batteries Quantity} = \frac{\textit{Batteries Capacity (Ah)}}{\textit{Each Battery Capacity (Ah)}} \quad (5.6)$$

$$\textit{Batteries Quantity} = \frac{3314}{150} = 22 \text{ Batteries}$$

With using 24 volt batteries, and connecting the 22 batteries in series, the maximum batteries voltage is: 24 × 22 = Inverter maximum V_{mp} > 528 V_{dc} > String maximum V_{mp}. To conclude, 9.6 kW dual off\tied-grid system was suggested to cover Al-Zahra school energy utilization. **Table 5.4** summarizes system design.

Table 5.4 Al-Zahra School PV System Summery (Phase I)

Maximum Load	8600 W	Inverter Output Ac Power Rating	5000 W
Maximum Design Load	9600 W	Inverter Output Voltage	230 V
Load Safety Coefficient	10%	Inverter Amplitude Modulation Index	0.92
Number of Arrays	1	Number of Inverters per Array	2
Strings Per Array	2	Number of Batteries (All Series)	22
Modules Per String	16	Battery Capacity	150 Ah
Module Rated Power	300 W	Battery Voltage	24
Modules-Connection/String	Series	Maximum Batteries Input Voltage	528 V_{dc}
Strings-Connection	Parallel	Batteries Capacity in kWh	79.2 kWh
String Voltage	521.6 V_{dc}	Days of Autonomy	1
Inverter Maximum Input Voltage	580 V_{dcmax}	Depth of Discharge	55%

5.2.3 Emission Analysis

One of the several photovoltaic advantages is the reduced amount of emitted GHG compared to fuel types. Environmentally, PV could save the eco-system annually from tons of polluting gasses.

As most of the electricity is imported from IEC, about 0.689 tCO_2/MWh is generated by mixed national fuel types, hence, 12.90 tCO_2 are the annual saving by PV. In details, **Table 5.5** shows the annual total GHG reductions from PV system in opposite to using different national fuel types for generating electricity as the default case.

Table 5.5 GHG reduction based on replacing PV with IEC different default fuels

	Oil	Coal	Natural Gas	All Types
GHG Emission Factor (tCO_2/MWh)	0.857	0.840	0.442	0.689
Net Annual GHG Emission Reduction (tCO_2)	16	15.70	8.30	12.90

5.2.4 Feasibility Study

PV system could be considered as a long-term investment. In order to examine the feasibility and estimate the cash flow characteristic, both system's components life-cycle costs and system's boundaries should be determined (see **sections 2.4.4.5** and **2.4.4.6**).

PV modules could serve (as average) until 25 years, this duration was suggested to be system's life-cycle. Major system's components initial costs were collected, as well as each life duration was determined. Lately, Palestine average inflation rate is 2% **[88]** (see **Appendix D)**. **Table 5.6** shows major system components quantities, prices and life duration (Phase I).

Table 5.6 PV system life-cycle costs (Phase I)

	Modules	**Inverters**	**Batteries**	**Others**
Price per Item ($)	250	1000	180	Based on **Figure 2.14**, and with adding batteries to the system, modules represent 35% from the total costs (8000 / 0.35 = **23,000 $** is the estimated system initial costs), inverters 8%, Batteries 20%, and other components (Installation, Structure, Wiring, Conduit, Junction Box, Shipping, Data Acquisition, Miscellanies) **37 %** + **50$** annual maintenance
Quantity	32	2	22	
Total Initial Costs ($)	**8000**	**2000**	**4000**	
	14,000 + Others			
Life Duration (years)	25 - 30	15 - 20	7 - 8	
Annual Maintenance Costs ($)	100	50	50	
Life-Cycle Maintenance Costs	**2500**	**1250**	**1250**	
Number of life cycle replacements	0	1	2	
Costs of Each Replacement ($)	**0**	**1000**	**2500**	
Total Life-Cycle Costs ($)	**10,500**	**4250**	**10.250**	**(0.37 × 23000) + (50 × 25) = 9750**
	25,000			**9750**

Equity payback duration is estimated to be after 8.8 years, it means that after this moment the system will yield profits. After the system passing the equity payback point reaching the end of its life cycle, the estimated gains will be 55,000 $ as shown in **Figure 5.3**.

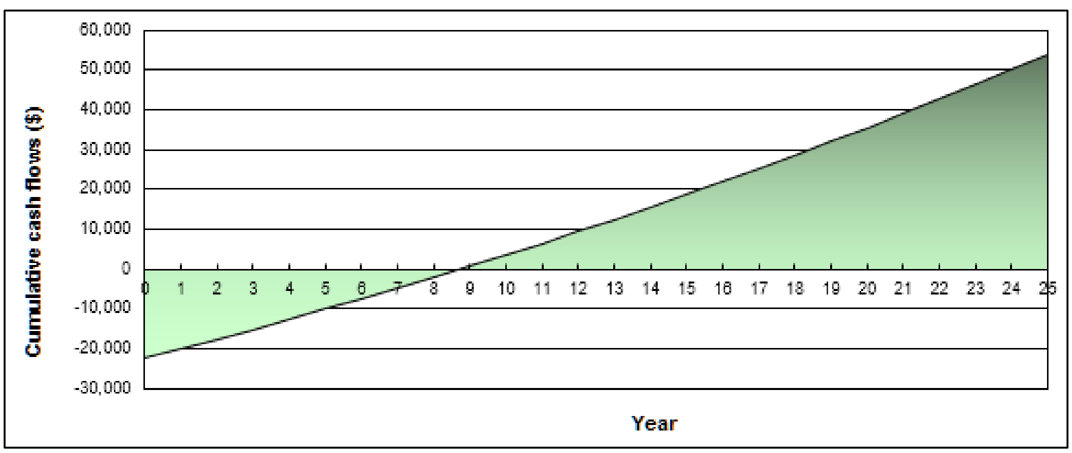


Figure 5.3 "Phase I" PV cash flow diagram

Table 5.7 Summarizes the feasibility study during PV system life-cycle.

Table 5.7 Summary of PV system feasibility (Phase I)

Inflation Rate	2%	**Annual Fuel Base-Case Savings ($)**	1235
Total Initial Costs ($)	23,000	**Annual Feed-in-Tariff Income ($)**	1490
Annual Maintenance and Replacement Costs ($) (Average)	390	**Total Annual Income ($)**	2725
Simple Payback (years)	9.6	**Equity Payback (years)**	8.8

5.3 PV System for Community Utilizations (Phase II)

At **section 5.2**, the PV system was designed to withstand the required daily energy consumption for the school, however, school's roof has enough free space to include more modules. A new plan was suggested to calculate the maximum roof capacity in order to know how much it could accommodate modules. This methodology has been raised in order to generate extra energy to feed the community as well as to find an opportunity for a valuable investment. What makes schools distinguished is the availability of enough area for PV mounting purposes, while external free lands to install such centralized PV systems rarely available and cost more. In order to ensure the feasibility for this phase, all of the usable free roof areas, PV modules optimum layout and orientation, shaded areas and finally system configuration should be carefully identified.

5.3.1 System Size Determination and Modules Layout

Modules should be directed at 0^o azimuth (facing the south) and tilted 23^o. These values ensure the maximum energy generation (see **Figure 5.1**). Selected modules have 1.60 m length × 0.98 m width dimensions and it is important to select in which the modules are either in portrait or landscape orientation. It is not only the free area is controlling modules orientation, however, modules that oriented in landscape way have less shadow length.

Modules spacing is a critical issue that should be determined precisely. It depends on how modules could avoid their shadows. As known, partially or entirely shaded module affects strongly its efficiency and durability. If even a small portion of a PV module is shaded (e.g. shadows from self-shading or high construction), it leads to a very significant drop in power output. This is because a PV module cells are connected in series with one another. The current output from the whole panel is limited to that passing through the weakest link cell. If one cell (e.g. out of 36 in a panel) is completely shaded, the power output from the panel will fall to zero. If one cell is 50% shaded, then the power output from the whole panel will fall by 50%, it means a very significant drop for such a small area of shading.

In addition to a loss of power output, the shade can have much more serious effects on PV modules, hot-spot damage to cells in which a shaded cell or cells overheat and potentially burn out. The obvious solution is to prevent PV modules to be shaded during the peak sunlight hours. However, Bypass diodes can be connected between panels in a system, and also between groups of cells in a panel so that the only power loss is from the shaded portion. When a panel is partially shaded, the current from the unshaded part of the panel passes through a diode which bypasses the shaded group\s of cells. While some power is lost as heat in the diode due to the voltage drop, the overall power generation of the partially shaded panel is better than it would be without the diodes, and the diodes also protect the panel from damage. However, there are cost implications in adding bypass diodes both in time and money.

In order to calculate modules row spacing, Sun-path chart with specific location's latitude and longitude should be available. Gaza-Strip is located between 31.5^{o} N - 34.45^{o} E with

+02.00 GMT at winter and + 03.00 GMT at summer time zones. **Figure 5.4** shows Gaza-Strip sun-path chart.

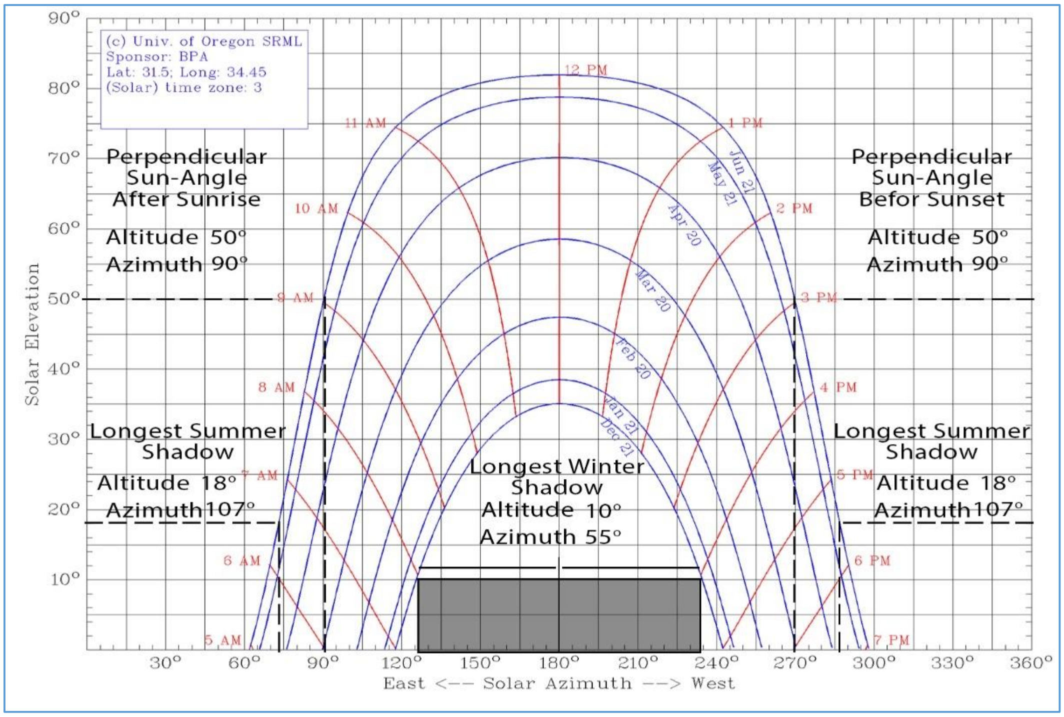


Figure 5.4 Gaza-Strip sun-path chart **[89]**

The longest shadow falls on Dec 21, however, few solar altitude angles (0^o – 10^o) are giving very long shadows during the first sunrise minutes, so it is not logic to be selected, as the modules row spacing will be very large. School classes start at 08:00 A.m. (07:00 A.m. after moving the time one hour backward in winter (Oct 29 in Palestine) which it is the suggested PV starting time), the Altitude at this time is 10^o while the Azimuth angle is 55^o in both east and west. However, the widest Azimuth angle occurs During Summer (Jun 21) in which it may affect the shadows calculations, especially, when a high obstacle is existing. After the Azimuth angle exceeds the 90^o (after passing the perpendicular case), the shadow starts moving in the opposite direction. Hence, it is necessary to calculate it to avoid shadows in all angles and directions. Summer's Altitude angle should be determined depending on the classes starting time. All classes start at 07:00 A.m., and with looking to **Figure 5.4** the altitude angle is 24^o. Sun rises during the same semester at 05:00 A.m. before two hours from classes beginning. However, the sun changes its Altitude angle quickly with time passing. For this reason, it is not logic to consider the lowest altitude angle as the shadow during this time will shrink quickly. However, moving the PV operating time half hour backward from the design time will give one extra hour to the total operating time. Hence, 06:30 A.m. with both 18^o, 107^o Altitude and Azimuth angles will be the selected data. Finally, in order to identify and draw the complete sun path, shadows with another point and different time should be calculated. Shadows in both 90^o in summer and 0^o in winter Azimuth angles were calculated (Note: 0^o Azimuth angle in summer was not selected because shadows at this time are very short, as well as 90^o Azimuth angle in winter is not reachable).

To calculate Modules Row Width, the following equation should be used:

$$\textit{Modules Row Spacing (Tilted Spacing)} = \frac{\textit{Height Difference}}{\tan\theta} \qquad (5.7)$$

While;

Height Difference*: The clear difference between first and second objects height;*

$\boldsymbol{\theta}$*: Solar Altitude angle.*

Figure 5.5 illustrates basic terms used in modules row spacing calculations. However, the calculated result out from equation (5.7) is for the tilted shadow length as shown in **Figure 5.6**. Hence, the minimum perpendicular modules row spacing should consider the impact of Azimuth angle and it could be calculated from the following equation:

$$\textit{Minimum (Actual) Modules Row Spacing} = \cos\psi \times \textit{Tilted Row Spacing} \qquad (5.8)$$

While;

ψ: *Solar Azimuth angle.*

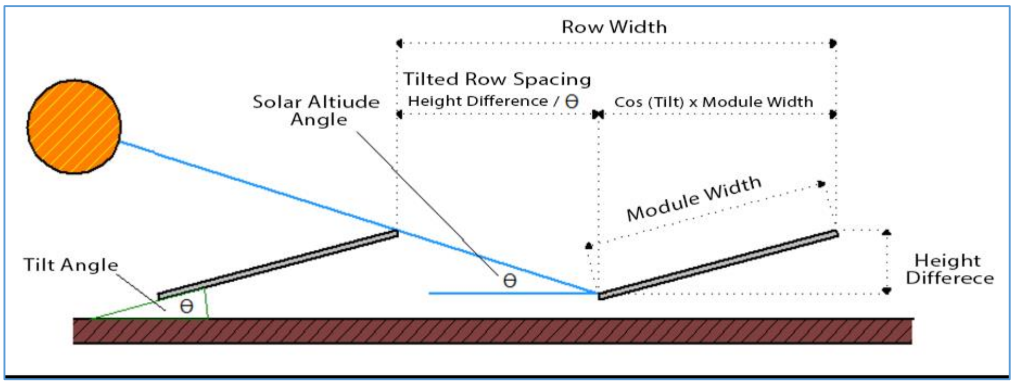


Figure 5.5 Basic terms used in modules row spacing calculations

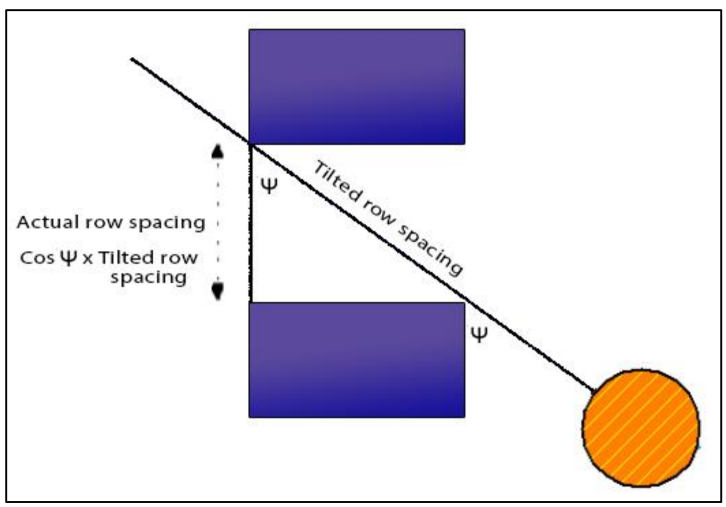


Figure 5.6 Minimum (Actual) modules row spacing

Hence to calculate the modules row spacing, both (5.7) and (5.8) equations should be used. It was assumed that all modules were installed in landscape orientation to ensure fewer shadows length and to increase the number of rows.

Modules height difference is 0.40 m (with 23^o tilt angle), therefore, modules row spacing could be calculated as the following:

$$\textit{Tilted Modules Row Spacing} = \frac{0.40}{\tan 10} = 2.27 \text{ m}$$

$$\textit{Actual Modules Row Spacing} = \textit{Cos } 55 \times 2.27 = 1.30 \text{ m}$$

With using the same modules height (0.80 m) and 1.30 m row spacing, the number of maximum rows installed perpendicularly in school's width (northern side) will be as the following:

$$\textit{School Roof Width} = (Y \times (\cos(\textit{tilt}) \times \textit{Module Width})) + (\textit{Actual Modules Row Spacing} \times (Y - 1)) \quad (5.9)$$

While;

Y: *Maximum Number of Rows (Integer).*

$$8.2 = (Y \times (\cos(23) \times 0.98)) + (1.3 \times (Y - 1))$$

$$Y = 4.52 = \mathbf{4} \textit{ Maximum Number of Rows}$$

Decreasing modules height difference helps in increasing of number of rows as the modules row spacing will be also decreased. However, it is not logic to have a completely tilted (23^o) surface to install all modules (even number of modules will be increased) because the maximum row height will reach 3.48 m above the roof (maximum row height = tan $23^o \times$ 8.20 = 3.48 m with school parapet level) and it will cost doubles for PV mounting purposes and disturb school's external look. Nevertheless, rows could be reached until 5 rows (adding one extra row) with having logical maximum height.

To have 5 rows, equation (5.8) should be used firstly to get actual modules row spacing, after that, modules clear height difference could be determined as the following:

$$8.2 = (5 \times (\cos(23) \times 0.98)) + (\text{Actual Modules Row Spacing} \times (5 - 1))$$

$$\text{Actual Modules Row Spacing} = 0.90 \text{ m}$$

Hence, clear height difference could be extracted from both (5.7), (5.8) equations:

$$\text{Modules Height Difference} = \text{Tilted Modules Row Spacing} \times \tan 10$$

$$0.90 = \cos 55 \times \text{Tilted Row Spacing}$$

$$\text{Therefore, Modules Height Difference} = 0.28 \text{ m}$$

From the result, the second row (from south to north) will be elevated +0.12 m more than the first row height (0.40 m), hence the clear height difference from each row to the next one will be 0.28 m (the same for each row and the row after). Hence, maximum rows height will be 0.88 m above the lowest modules level (0.40 + (4 × 0.12) = 0.88 m plus school parapet).

The another school side was suggested to have the same modules height difference (0.40 m). This because the roof at this side has enough length to install more rows, while if the modules were elevated as the other side, the maximum rows height will be large and not practical. The another obstacle faces modules location design is stairwells. With 3.85 m height (from roof ground to school peak level), stairwells drop shadows to the roof and these shadows should be avoided carefully during the whole year.

With considering maximum summer and winter Azimuth angles, the three stairwells' (A, B and C) shadows lengths could be determined. With applying (5.7), (5.8) equations, and after avoiding the shaded zones, the maximum number of modules that could be mounted on the school's roof is 159 as shown in **Figure 5.7**.

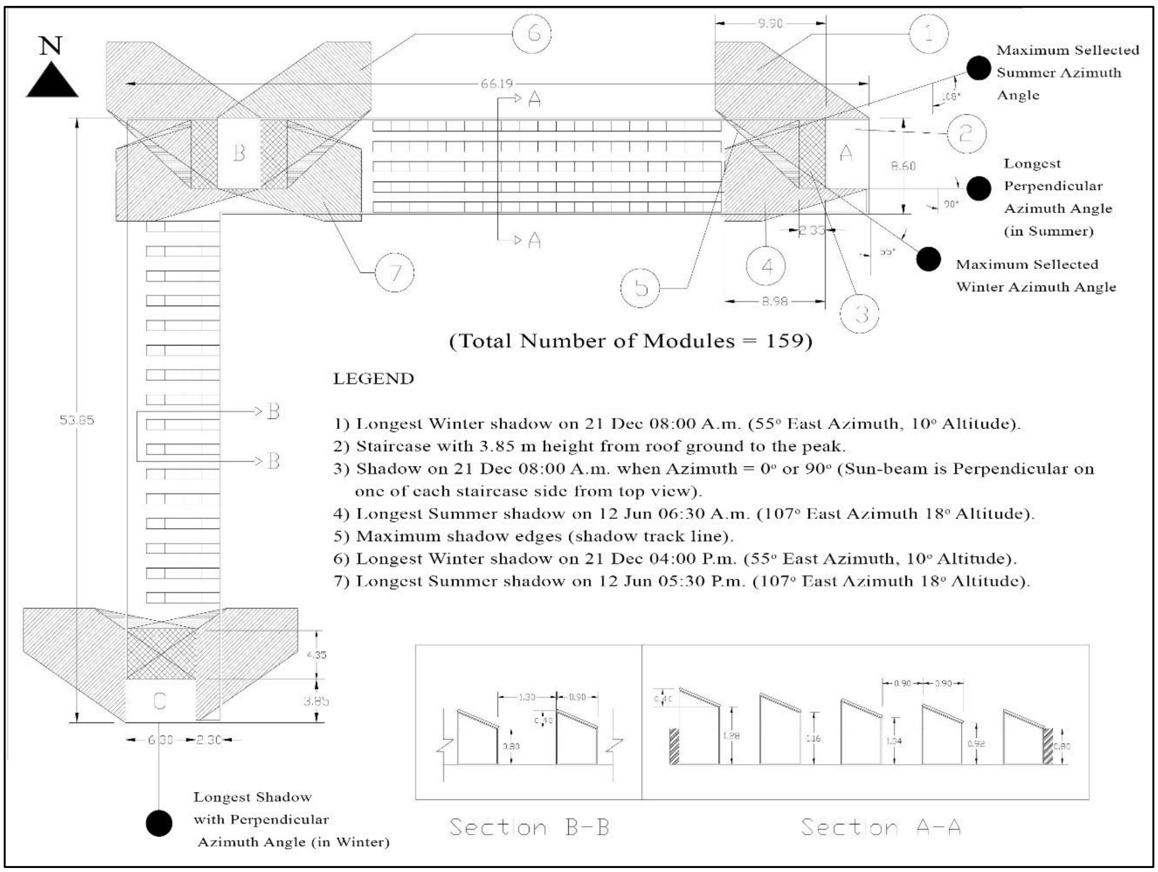


Figure 5.7 Maximum number of modules that could be mounted on school's roof

However, demolishing the stairwells elevated covers and replacing them with simple openings (2.5 m × 3.2 m) leveled with the roof's ground allows to install extra modules. the maximum number of modules reached 256 as shown in **Figure 5.8**.

This option will be selected because it increases roof capacity up to 61% compared to the first case (with the provision of stairwells covers).

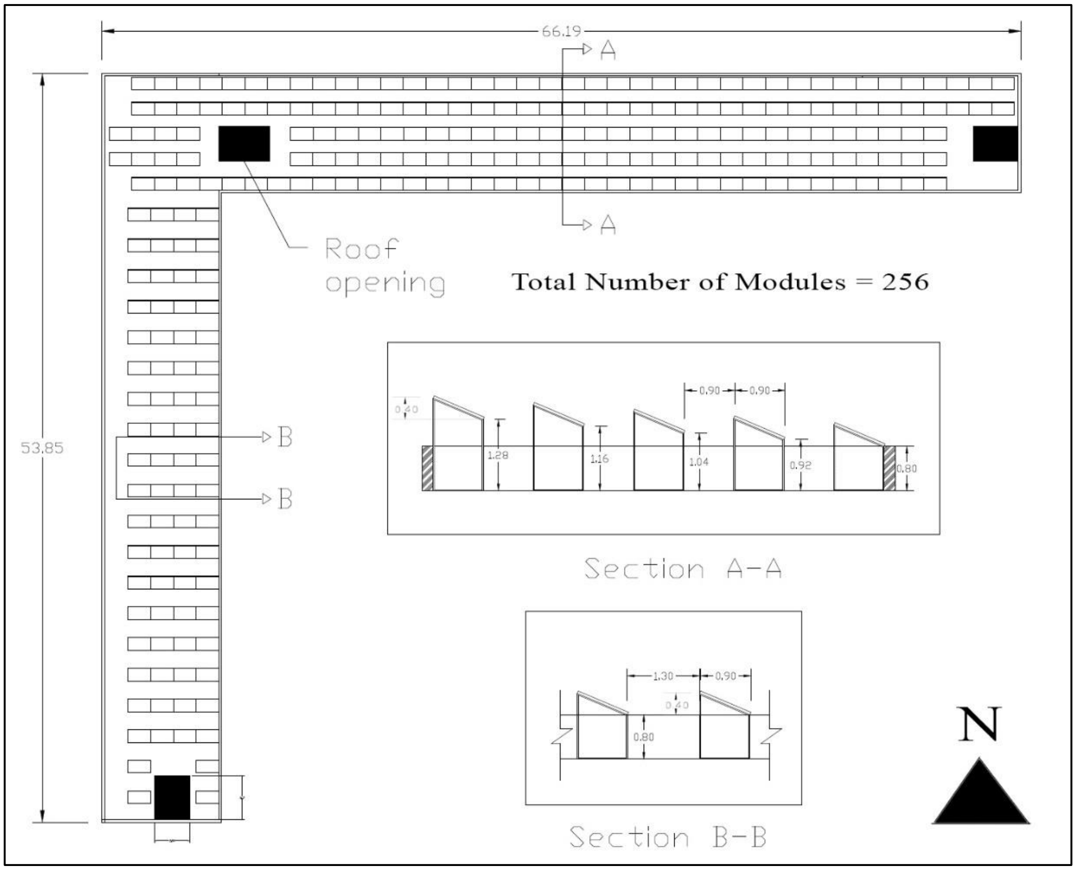


Figure 5.8 Maximum number of modules that could be mounted on school's roof after demolishing stairwells covers

5.3.2 System Configuration

At the first phase (see **section 5.2**), 32 modules were enough to feed the whole school with power. As the maximum roof capacity was able to carry 256 modules, 224 modules are remaining for feeding the community. The PV system at this phase will be grid-tied, so, there is no need for any storage system, hence, number of inverters only should be determined in order to limit all system's components quantities for feasibility study purposes. An appropriate inverter with sufficient capacity and suitable input DC voltage should be selected carefully. For that, "ABB TRIO-27.6-TL-OUTD \ S2X Version" inverter was chosen with 950 V_{dcmax} operating DC input voltage, 64.0 A maximum DC input current and 28.60 kW input rated power **[90]**. The PV system will be unidirectional and will feed the grid with three-phase line (400 V, 45 A, 27.60 kW).

With 96% and 98% both inverter and distribution cables efficiencies, Table shows the annual amount of produced electrical energy out from the system with presenting the expected annual feed in tariff income.

Table 5.8 PV system annual generations and income

Month	Monthly generations from PV Modules (kWh)	Monthly feed in tariff income ($)
Jan	7682	1006.34
Feb	8084	1059.00
Mar	11087	1452.40
Apr	11991	1570.82
May	13133	1720.42
Jun	13118	1718.46
Jul	13095	1715.45
Aug	12869	1685.84
Sep	11846	1551.83
Oct	10560	1383.36
Nov	8394	1099.61
Dec	7367	965.08
Total	129226	16928.61

With assuming two arrays (112 modules per array), each array contains 4 strings connected in parallel and each string contains 28 modules connected in series (the same modules in **Table 5.1**), the maximum V_{dc} output from each array is:

$$Array\ V_{dc}\ output = 28 \times 32.6 = \mathbf{913}\ \mathrm{V_{dc}} < 950\ \mathrm{V_{dcmax}}$$

the maximum I_{dc} output from each array is:

$$Array\ I_{dc}\ output = 4 \times 9.21 = \mathbf{36.84}\ \mathrm{I_{dc}} < 64\ \mathrm{A}\ \mathrm{I_{dcmax}}$$

Hence two inverters are enough for the all the system, each is connected with one Array.

5.3.3 Emission Analysis

Table shows the annual amount of GHG emissions reductions with same of "**section 5.2.2**" specifications.

Table 5.9 GHG reduction based on replacing PV with IEC different default fuel

	Oil	Coal	Natural Gas	All Types
GHG Emission Factor (tCO_2/MWh)	0.857	0.840	0.442	0.689
Net Annual GHG Emission Reduction (tCO_2)	111	109	57.20	89

5.3.4 Feasibility Study

Major system's components initial costs were collected, as well as each life duration was determined. With taking into consideration "**section 5.2.3**" PV life cycle properties, **Table 5.10** shows major system components quantities, prices and life duration.

Equity payback duration is estimated to be after 7 years, it means that after this moment the system will yield profits. After the system passing the equity payback point reaching the end of its life cycle, the estimated gains will be 400,000 $ as shown in **Figure 5.9**. **Table 5.11** Summarizes the feasibility study during PV system life-cycle (Phase II).

Table 5.10 PV system life-cycle costs (Phase II)

	Modules	Inverters	Others
Price per Item ($)	250	4600	Based on **Figure 2.14**, modules and inverters represent 55% from the total costs (65,200 / 0.55 = **118,550 $** is the estimated system initial costs), and 45% for other components (Installation, Structure, Wiring, Conduit, Junction Box, Shipping, Data Acquisition, Miscellanies) + **200$** annual maintenance
Quantity	224	2	
Total Initial Costs ($)	**56,000**	**9200**	
	65,200 + Others		
Life Duration (years)	25 - 30	15 - 20	
Annual Maintenance Costs ($)	700	100	
Life-Cycle Maintenance Costs	**17,500**	**2500**	
Number of life cycle replacements	0	1	
Costs of Each Replacement ($)	**0**	**4600**	
Total Life-Cycle Costs ($)	**73,500**	**16,300**	**(0.45 × 118,550) + (200 × 25) = 58,350**
	89,800		**58,350**

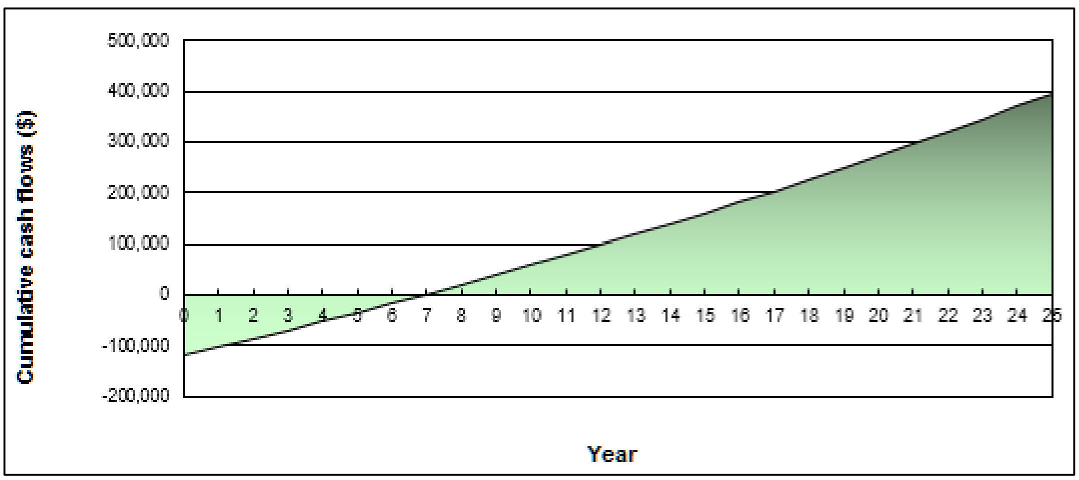


Figure 5.9 "Phase II" PV cash flow diagram

Table 5.11 Summary of PV system feasibility (Phase II)

Inflation Rate	2%	**Annual Feed-in-Tariff Income ($)**	16929
Total Initial Costs ($)	118,550	**Total Annual Income ($)**	16929
Annual Maintenance and Replacement Costs ($) (Average)	1184	**Equity Payback (years)**	7
		Simple Payback (years)	7.5

5.4 Conclusion

A complete PV system with detailed technical, environmental and feasibility studies was suggested and investigated. A mix of off-grid and grid-tied systems with 32 modules out of maximum school's roof capacity (256 modules) was allocated to feed the building with its daily requirements "Phase I". However, another suggestion was made to investigate the feasibility of utilizing the full roof's capacity with PV modules (Phase II). Both of "Phase I" and "Phase II" proved that PV system is rather than being environmental-friendly, but also financially feasible. With gathering both phases and dealing with them as one unit, and in spite of high project's initial cost (141,550 $) as shown in **Table 5.12**, money could be retrieved back after the first seven years of project life-cycle and turns into profits reaching to 450,000 $ with the end of system's life cycle as shown in **Figure 5.10**.

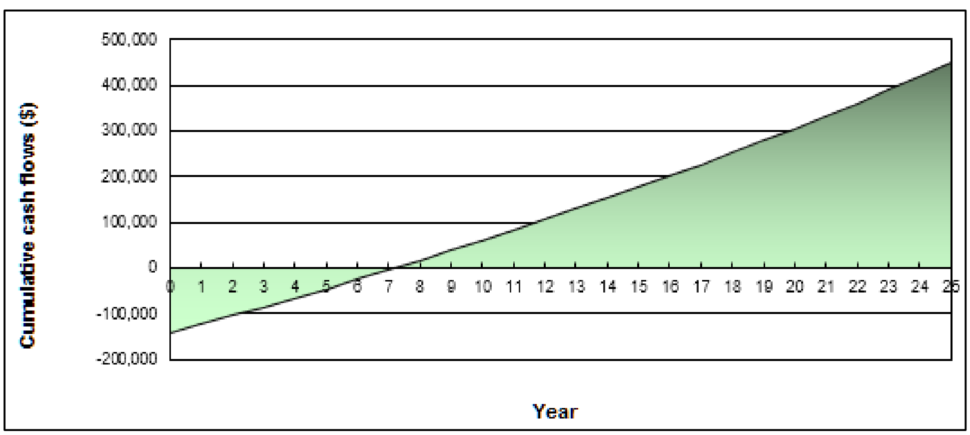


Figure 5.10 Cash flow diagram for whole Al-Zahra PV system

Table 5.12 Summary of whole PV system feasibility

Inflation Rate	2%	**Total Annual Income ($)**	19,654
Total Initial Costs ($)	141,550	**Equity Payback (years)**	7.2
Annual Maintenance and Replacement Costs ($) (Average)	1574	**Simple Payback (years)**	7.8

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary and Conclusions

- **Background**

This study has been carried out in several phases to achieve its objectives. An extensive literature review was undertaken in the fields of international and local energy characteristics, energy conservation strategies, visual and thermal comfort standards, and photovoltaic technology.

Gaza-Strip suffers from a lack of energy sources and is not in control of its energy sources. For the last ten years, electricity has been an unstable characteristic which has strongly affected the operation of schools. However, little efforts were exerted for depending on local and renewable energy sources but they do not reach the required level. More than 7% is the annual increasing in the energy demand due to the rapid population expanding. Therefore, it is necessary to find out other possible ways to cover this increase.

A Gaza-Strip school was selected for this research. Schools were selected due to their essential function; consequently, they should run smoothly. Moreover, schools have the opportunity to educate the community positively if such suitable energy conservation strategies and renewables are implemented. With the provision of enough free area - especially on the roof, the chance to install centralized PV system is more suitable and cost-effective.

The energy crisis is not the only matter in which this study was based on; however, IEQ conditions within Gaza Strip schools were investigated and improved. Standardized visual and thermal comfort levels help in enhancing students' health and performance. As indicated, Gaza Strip schools are naturally ventilated and it is important to deal carefully with these kinds of facilities.

- **IEQ and Energy Conservation Strategies**

A typical school with approved design was chosen in order to investigate the suggested improvement opportunities. It consists of three floors (L-Shape), basic laboratories, library, administration, services, and 24 classes distributed on the first and second floors. The school's constructional drawings as well as related utility bills since 2000 were collected to help correctly model the school.

A detailed description and assessment for Al-Zahra school was carried out. The model was described carefully in terms of basic activity, construction, openings and lighting, energy performance, and both visual and thermal comfort. Al-Zahra's simulated energy consumption (16,239 kWh) was almost the average of both AVR6 (15,229 kWh) and AVR8 (16793 kWh) actual data. A set of daylight maps were analyzed in order to understand the behavior of the illumination inside different school zones at different times and weather conditions. The results for "Class F2 Admin" zone elaborated that the illumination was almost distributed regularly and reached more than 1000 lux at the edges beside the exterior windows and started dimming down until less than 200 lux at the opposite corners during sunny clear conditions. However, different scenarios proved that if the sensor is installed at the ceiling level, almost similar lux distribution occurs.

For assessing the thermal conditions, the Tel-Al-Rabie weather database was evaluated after ensuring the consistency with Gaza Strip climatic conditions. The results assured a clear matching between the simulation thermal data and the actual readings, as well as proved that the school's monthly operative temperature averages were located within the adaptive ASHREA ACS acceptability thermal comfort limits except for May, September, and October.

After modeling the school and validating the results, a group of simulations were conducted for several alternatives in order to improve the current model and optimize its energy and IEQ characteristics. The school was studied under the ideal operation case in which the electricity is provided during the whole day.

After assessing different lighting types in terms of product efficiency, LLS and LLD factors, cost and durability, a suggested LED category was evaluated and selected (CREE A19 LED). After distributing 22 single lamps to each classroom, the minimum 377 lux and maximum 466 lux with 433 lux as an average and 0.86 uniformity ratio index are good enough to ensure standardized visual levels.

The values of 12,197 kWh, 5562 kWh, 31,554 kWh, 14801 kWh were the consumed energy for fluorescent existing operation, LED existing operation, fluorescent ideal operation, and LED ideal operation, respectively. A reduction of around 82% occurred when a single centralized photosensor was installed in each classroom under fixed 400 lux target illumination level. Neither utilizing two photosensors nor installing blinds were justified to be selected, because both energy consumption and the glare index values were not improved or affected.

After nominating the worst-case for the all zones in terms of operative temperature values ("Class F2 Admin" zone was selected), an attempt to study the impact of installing an insulating layer (Foam-Polyurethane) within the classroom envelope on the thermal comfort conditions was undertaken. The results showed that installing such an insulating layer is not effective.

Maximizing/minimizing the existing window wall ratio for both the exterior (35.20 %) and interior windows (14.70 %) for the school was not effective as an energy conservation strategy.

Two centralized ceiling fans operating during the peak months with middle speeds (3500 cfm) were suggested for the 24 classrooms as the optimized solution for the thermal comfort.

The computer lab operation schedule was suggested to avoid early morning and late evening periods to prevent any sudden increase in the school power load.

Before conducting any improvement, the school was consuming around 16,000 kWh annually, therefore, around 5.55 kWh/ m^2 was the average consumption per school building area (16,000 kWh / 2880 school building area), as well as 20 kWh was the consumption per capita (5609 kWh / 800 school occupants). After the improvements, a reduction of 65% was achieved (the school consumes 5609 kWh annually), hence, the consumption could be figured out as 1.95 kWh/m^2 and 7 kWh per capita.

- **Green Energy (PV)**

After conducting the improvements, a complete PV system with detailed technical, environmental and feasibility studies was suggested and investigated.

A mix of off-grid and grid-tied systems with 32 “Suntech STP300S-20/ Wew” modules out of maximum school’s roof capacity (256 modules) was allocated to feed the building with its daily requirements “Phase I”.

About 18,710 kWh will be the total annual generations, 6732 kWh will be stored in 22 batteries (24 V, 150 Ah) to meet school’s requirements, and 11380 kWh will be transferred to the grid to be sold.

The actual annual required energy was 5610 kWh, however, after considering the system components losses as; batteries (15%), inverter (4%), charge controller (2%) and local network cables (1%), the total required energy was (5610 × 120% = 6732 kWh).

The annual reduced amount of GHG emissions was 12.9 tCO_2 as the average of all IEC different fuels. Total system life cycle (25 years) cost is 34,750 $.

However, another scenario has been suggested to investigate the feasibility of utilizing the full roof’s capacity after avoiding shadows with PV modules (Phase II). The first attempt was with keeping the three stairwells covers and avoid their shadows. After calculating the maximum shadows length during the year by getting the Gaza-Strip sun-path chart, 159 modules filled the maximum roof capacity. Another attempt has been done for demolishing the covers and letting more modules to be installed. An extra 97 modules were able to be mounted, hence the maximum number of modules was 256. The last option was selected and approved.

Both of “Phase I” and “Phase II” proved that PV system is rather than being environmental-friendly, but also financially feasible. With gathering both phases and dealing with them as one unit, and in spite of high project’s initial cost (141,550 $), money could be retrieved back after the first seven years of project life-cycle and turns into profits reaching to 450,000 $ with the end of system’s life cycle.

6.2 Recommendations

Based on the analysis of the results, the following recommendations guidelines are recommended in order to utilize the suitable PV system with optimized energy conservation strategies and improved visual and thermal comfort level:

1. Replacing all the existing Fluorescent T8 lamps with high-efficient LEDs as the selected category (CREE A19 LED).
2. Fixed the target illumination level for the different school zones to fit the standardized visual comfort levels. An illumination level of 400 lux is suitable to be fixed in all classrooms, while 500 lux should be provided within the labs and the library.
3. Number of LED lamps should be 22 distributed geometrically in each classroom.
4. Among all photosensor’s installing options, one centralized sensor achieved the optimum energy conservation results.

5. The electricity should run during the whole academic day in both morning and evening periods. The selected school ideal operation schedule should be worked out to feed the building with stable source of energy.
6. School's existing window glazing type (clear 3-4 mm) is the optimum choice in terms of thermal\visual factors out of other categories.
7. School's existing window wall ratio (35.20%, 14.70% for the exterior and interior windows respectively) is the optimum choice out of other larger or smaller percentages.
8. School's existing building envelope (see **Table 3.5)** is the optimum out of other options containing such insulation layer.
9. In order to enhance the thermal comfort conditions for peak months (May, September, and October), two ceiling fans should be installed in the middle of class width axis (6 m) and each distributed by the center of one-third of the longitudinal axis (8 m). the optimum results for each ceiling fan in which provides optimum operative temperature reduction with comfortable air velocity could be achieved when they are operated partially to give 3500 cfm for each out of 7105 cfm airflow and consume around 60 W together.
10. The computer lab's hourly operation schedule should be avoided to meet early morning and late evening periods to prevent any sudden increasing in the peak school's power load.
11. in order to cover the school's electrical load, 32 "Suntech STP300S-20/ Wew" should be mounted on the roof, each 16 modules are connected in series as one string. Each from both strings is connected with "ABB PVI-5000-TL-OUTD"

inverter. The system should be equipped with 22 batteries (24 V, 150Ah, 55% depth of discharge) in order to keep the supply away from any sudden fluctuations caused by changing in modules received irradiance. For getting detailed system's technical data, see **Table 5.4**.

12. in order to take the advantage as much as possible from the school's roof area, a suggestion to demolish the three stairwells covers in order to avoid shadow's impacts. Hence, 256 modules could be mounted with suitable row spacing. The extra 224 modules (after excepting the 32 modules for "Phase I") should be separated into two strings, each string (112 modules) is connected with "ABB TRIO-27.6-TL-OUTD \ S2X Version" inverter. The PV system should be unidirectional and should feed the grid with three-phase line (400 V, 45 A)
13. Finally, it is highly recommended to initiate a clear policy for the feed-in-tariff price in order to totally benefit from the investment. It was suggested to be 0.131 % for each sold kWh and could be increased. Another suggestion is to provide a process called "net-metering", it is very effective especially during cloudy days when the system is not producing enough to power the school, hence, an ability of drawing power back from the grid is provided.

6.3 Suggestions for Future Research

The school was assessed based on energy consumption and both visual\thermal comfort conditions. However, such IAQ could be also assessed and may affect the optimized results. Another suggestion is to select other advanced types of PV modules such as; BIPV, Amorphous, Organic … etc. after their efficiencies have been developed. Another suggestion is to take other facilities such as; hospitals, hotels, shopping centers …etc. and apply the same procedure in order to reduce the energy consumption parallel to improving IEQ standards. Further study could be implemented for the same school if such HVAC system would be installed.

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APPENDIX A: PALESTINIAN SCHOOLS STATISTICS

Table A. 1 Number of schools and kindergartens by region, academic year and stage

Region and Scholastic Year	Stage		المرحلة	رياض أطفال Kindergartens	المنطقة والعام الدراسي
	مجموع Total	ثانوية Secondary	أساسية Basic		
Palestine					**فلسطين**
2009/2010	**2,577**	880	1,697	..	2010/2009
2010/2011	**2,652**	905	1,747	..	2011/2010
2011/2012	**2,707**	915	1,792	..	2012/2011
2012/2013	**2,753**	931	1,822	1,323	2013/2012
West Bank					**الضفة الغربية**
2009/2010	**1,917**	736	1,181	731	2010/2009
2010/2011	**1,975**	760	1,215	782	2011/2010
2011/2012	**2,019**	770	1,249	862	2012/2011
2012/2013	**2,059**	780	1,279	965	2013/2012
Gaza Strip					**قطاع غزة**
2009/2010	**660**	144	516	..	2010/2009
2010/2011	**677**	145	532	..	2011/2010
2011/2012	**688**	145	543	..	2012/2011
2012/2013	**694**	151	543	358	2013/2012

Table A. 2 Number of schools and kindergartens by region, supervising authority and stage

Region and Supervising Authority	Stage		المرحلة	رياض أطفال Kindergartens	المنطقة والجهة المشرفة
	مجموع Total	ثانوية Secondary	أساسية Basic		
Palestine	**2,753**	**931**	**1,822**	**1,323**	**فلسطين**
Governmental	**2,038**	831	1,207	**2**	حكومية
UNRWA	**344**	-	344	-	وكالة الغوث
Private	**371**	100	271	**1,321**	خاصة
West Bank	**2,059**	**780**	**1,279**	**965**	**الضفة الغربية**
Governmental	1,639	691	948	2	حكومية
UNRWA	99	-	99	-	وكالة الغوث
Private	321	89	232	963	خاصة
Gaza Strip	**694**	**151**	**543**	**358**	**قطاع غزة**
Governmental	399	140	259	-	حكومية
UNRWA	245	-	245	-	وكالة الغوث
Private	50	11	39	358	خاصة

Table A. 3 Number of students in schools and kindergartens in Palestine by academic level

Region and Scholastic Year	Stage		المرحلة	رياض أطفال Kindergartens	المنطقة والعام الدراسي
	مجموع Total	ثانوية Secondary	أساسية Basic		
Palestine					**فلسطين**
2009/2010	**1,113,802**	152,135	961,654	..	2010/2009
2010/2011	**1,116,991**	149,691	967,300	..	2011/2010
2011/2012	**1,129,538**	149,325	980,213	..	2012/2011
2012/2013	**1,136,739**	146,495	990,244	111,457	2013/2012
West Bank					**الضفة الغربية**
2009/2010	**660,565**	88,962	571,603	56,728	2010/2009
2010/2011	**666,737**	90,162	576,575	60,134	2011/2010
2011/2012	**668,754**	88,051	580,703	63,007	2012/2011
2012/2013	**673,172**	86,825	586,347	69,588	2013/2012
Gaza Strip					**قطاع غزة**
2009/2010	**453,237**	63,186	390,051	..	2010/2009
2010/2011	**450,254**	59,529	390,725	..	2011/2010
2011/2012	**460,784**	61,274	399,510	..	2012/2011
2012/2013	**463,567**	59,670	403,897	41,869	2013/2012

Table A. 4 Number of students in schools and kindergartens in Palestine by supervising authority, academic year and level

Supervising Authority and Scholastic Year	Stage المرحلة			رياض أطفال Kindergartens	الجهة المشرفة والعام الدراسي
	مجموع Total	ثانوية Secondary	أساسية Basic		
Governmental					**حكومية**
2009/2010*	**771,864**	139,095	632,769	115	*2010/2009
2010/2011	**766,234**	143,510	622,724	121	2011/2010
2011/2012	**761,691**	142,502	619,189	124	2012/2011
2012/2013	**762,499**	139,712	622,787	122	2013/2012
UNRWA					**وكالة الغوث**
2009/2010	**255,186**	-	255,186	..	2010/2009
2010/2011	**261,520**	-	261,520	..	2011/2010
2011/2012	**270,791**	-	270,791	..	2012/2011
2012/2013	**273,616**	-	273,616	..	2013/2012
Private					**خاصة**
2009/2010*	**82,076**	6,040	76,036	51,895	*2010/2009
2010/2011	**89,237**	6,181	83,056	60,013	2011/2010
2011/2012	**97,056**	6,823	90,233	62,883	2012/2011
2012/2013	**100,624**	6,783	93,841	111,335	2013/2012

Table A. 5 Percentage distribution of students in schools and kindergartens in Palestine by region, gender and stage

Region and Sex	Stage المرحلة			رياض أطفال Kindergartens	المنطقة والجنس
	المجموع Total	ثانوية Secondary	أساسية Basic		
Palestine					**فلسطين**
Both Sexes	**100**	**100**	**100**	**100**	**كلا الجنسين**
Males	**49.7**	45.1	50.2	51.3	ذكور
Females	**50.3**	54.9	49.8	48.7	إناث
West Bank					**الضفة الغربية**
Both Sexes	**100**	**100**	**100**	**100**	**كلا الجنسين**
Males	**49.6**	44.3	50.2	51.3	ذكور
Females	**50.4**	55.7	49.8	48.7	إناث
Gaza Strip					**قطاع غزة**
Both Sexes	**100**	**100**	**100**	**100**	**كلا الجنسين**
Males	**49.9**	46.2	50.2	51.4	ذكور
Females	**50.1**	53.8	49.8	48.6	إناث

Table A. 6 Students per class in the Palestine schools by stage, academic year and supervising authority

Stage and Scholastic Year	Supervising Authority الجهة المشرفة			المعدل العام Grand Average	المرحلة والعام الدراسي
	خاصة Private	وكالة الغوث UNRWA	حكومة Government		
Kindergartens					**رياض الأطفال**
2009/2010	..	-	..	**..**	2010/2009
2010/2011	..	-	..	**..**	2011/2010
2011/2012	22.2	-	20.7	**22.2**	2012/2011
2012/2013	23.8	-	20.3	**23.8**	2013/2012
Basic					**الأساسية**
2009/2010*	24.4	34.8	29.7	**29.3**	*2010/2009
2010/2011	23.7	36.0	30.8	**31.2**	2011/2010
2011/2012	23.4	35.9	30.5	**30.9**	2012/2011
2012/2013	23.4	36.7	30.2	**30.9**	2013/2012
Secondary					**الثانوية**
2009/2010*	19.1	-	25.6	**25.1**	*2010/2009
2010/2011	18.7	-	28.6	**28.0**	2011/2010
2011/2012	18.2	-	28.3	**27.6**	2012/2011
2012/2013	17.8	-	27.5	**26.8**	2013/2012

Table A. 7 Number of teachers in schools and kindergartens in Palestine by supervising authority, academic Year and Sex

Supervising Authority and Scholastic Year	Schools مدارس إناث Females	ذكور Males	كلا الجنسين Both Sexes	Kindergartens رياض أطفال إناث Females	ذكور Males	كلا الجنسين Both Sexes	الجهة المشرفة والعام الدراسي
Governmental							**حكومية**
2009/2010*	12,731	10,221	**22,952**	11	..	**11**	*2010/2009
2010/2011	18,298	14,971	**33,269**	..	..	..	2011/2010
2011/2012	20,332	16,221	**36,553**	..	..	..	2012/2011
2012/2013	20,433	16,331	**36,764**	6	-	**6**	2013/2012
UNRWA							**وكالة الغوث**
2009/2010*	1,286	791	**2,077**	-	-	-	*2010/2009
2010/2011	5,451	3,575	**9,026**	-	-	-	2011/2010
2011/2012	6,279	3,627	**9,906**	-	-	-	2012/2011
2012/2013	6,214	3,546	**9,760**	-	-	-	2013/2012
Private							**خاصة**
2009/2010*	3,211	1,150	**4,361**	3,040	14	**3,054**	*2010/2009
2010/2011	3,981	1,377	**5,358**	..	..	..	2011/2010
2011/2012	4,394	1,478	**5,872**	..	..	..	2012/2011
2012/2013	4,635	1,531	**6,166**	4,763	-	**4,763**	2013/2012

Table A. 8 Percentage distribution of Palestinian population (one years and above) by educational attainment, region and gender, 2012

Educational Attainment	Region المنطقة: قطاع غزة Gaza Strip			الضفة الغربية West Bank			فلسطين Palestine			الحالة التعليمية
	إناث Females	ذكور Males	كلا الجنسين Both Sexes	إناث Females	ذكور Males	كلا الجنسين Both Sexes	إناث Females	ذكور Males	كلا الجنسين Both Sexes	
Illiterate	5.5	1.7	**3.6**	6.9	1.9	**4.4**	**6.4**	**1.8**	**4.1**	أمي
Can Read and Write	3.9	5.8	**4.9**	6.9	6.1	**6.4**	**5.8**	**6.0**	**5.9**	ملم
Elementary	10.6	14.1	**12.3**	14.5	17.2	**15.9**	**13.1**	**16.1**	**14.6**	ابتدائي
Preparatory	35.7	35.0	**35.4**	35.4	39.7	**37.5**	**35.5**	**38.0**	**36.8**	إعدادي
Secondary	26.5	22.6	**24.5**	20.7	19.6	**20.2**	**22.8**	**20.7**	**21.7**	ثانوي
Associate Diploma	5.8	5.9	**5.9**	4.7	4.8	**4.8**	**5.1**	**5.2**	**5.2**	دبلوم متوسط
Bachelor and Above	12.0	14.8	**13.4**	10.9	10.7	**10.8**	**11.3**	**12.2**	**11.7**	بكالوريوس فأعلى
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	المجموع

APPENDIX B: TYPICAL PALESTINIAN SCHOOLS CONSTRUCTIONAL SCHEMES

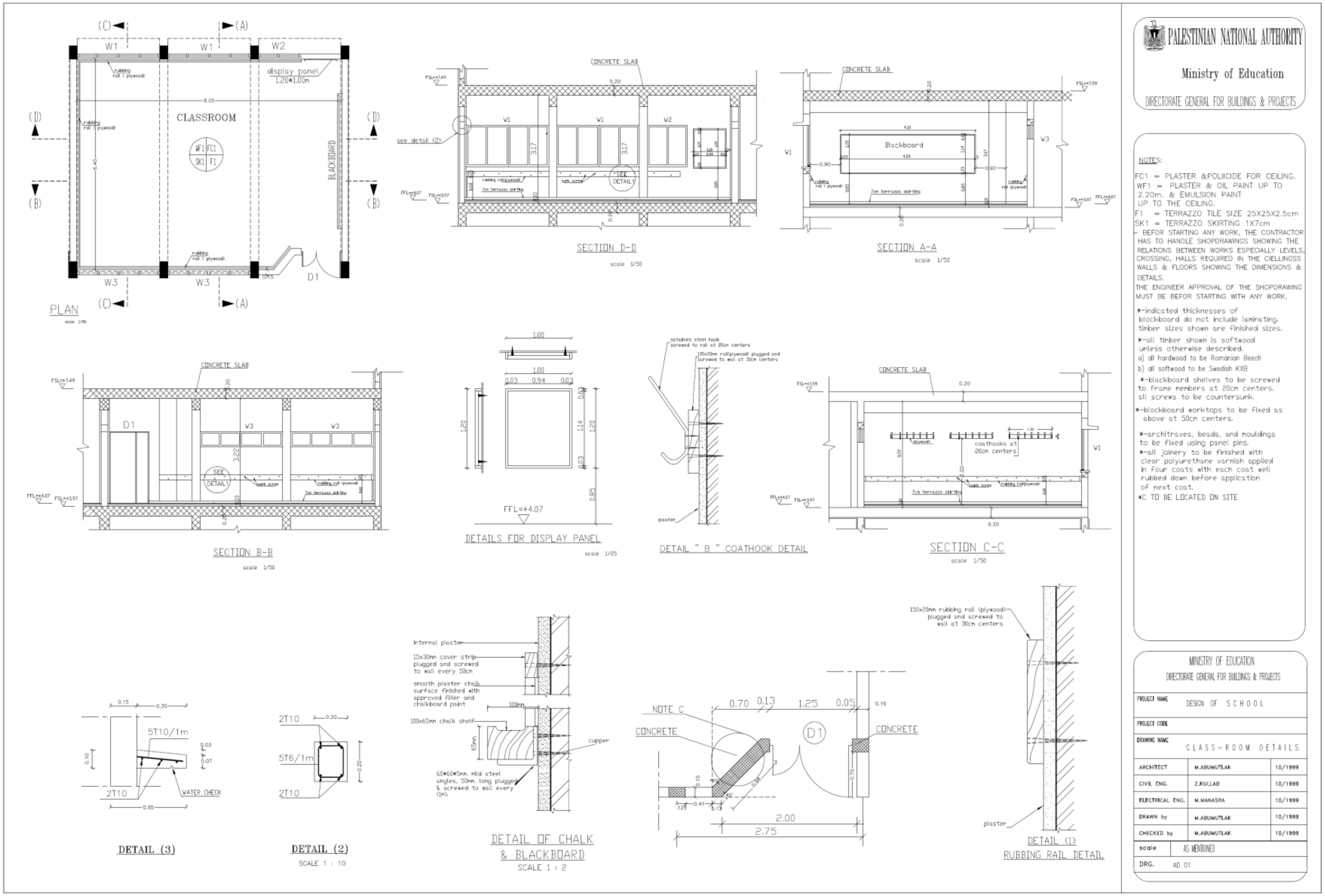


Figure B. 1 Typical Gaza-Strip classrooms design details

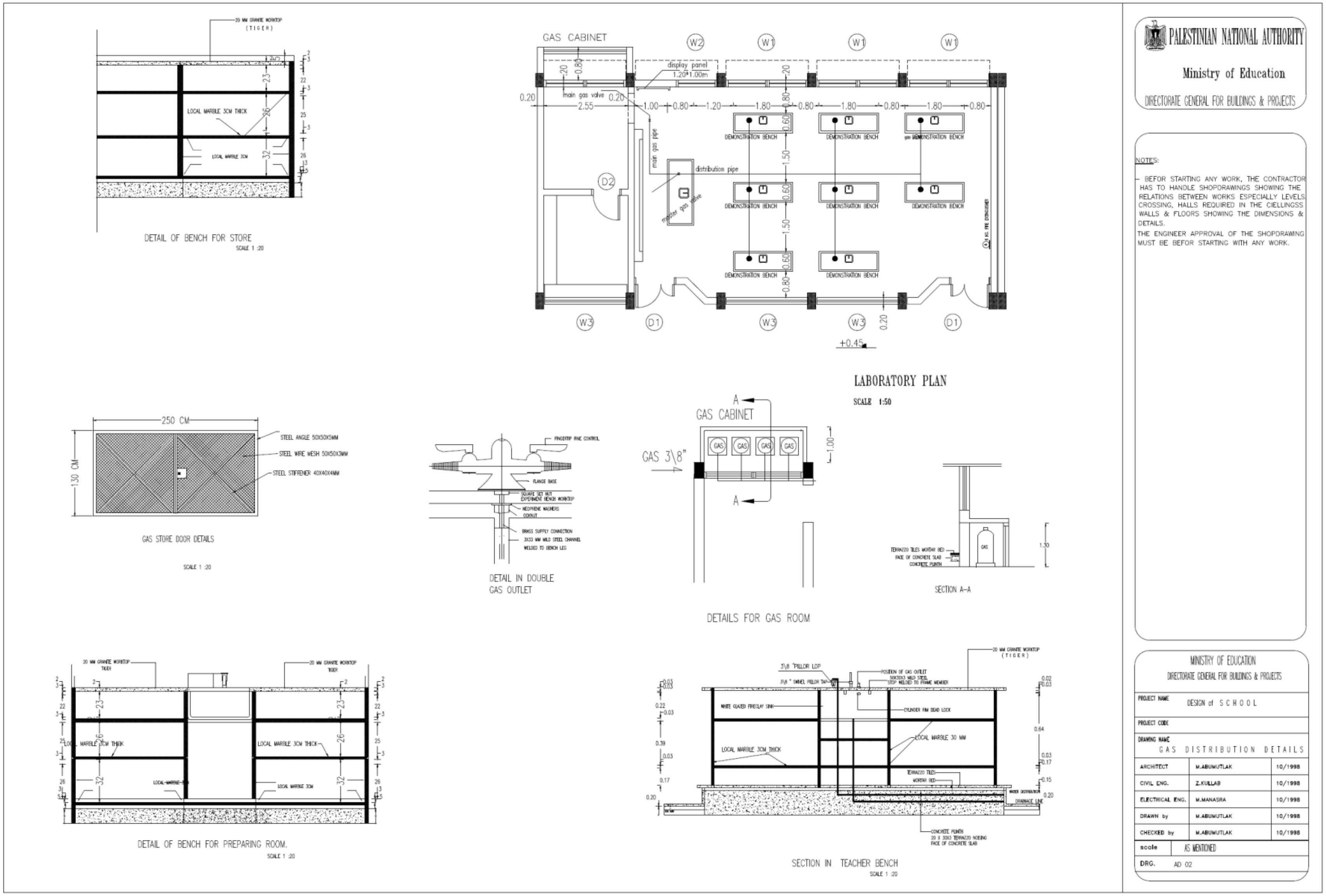


Figure B. 2 Typical Gaza-Strip Labs design details

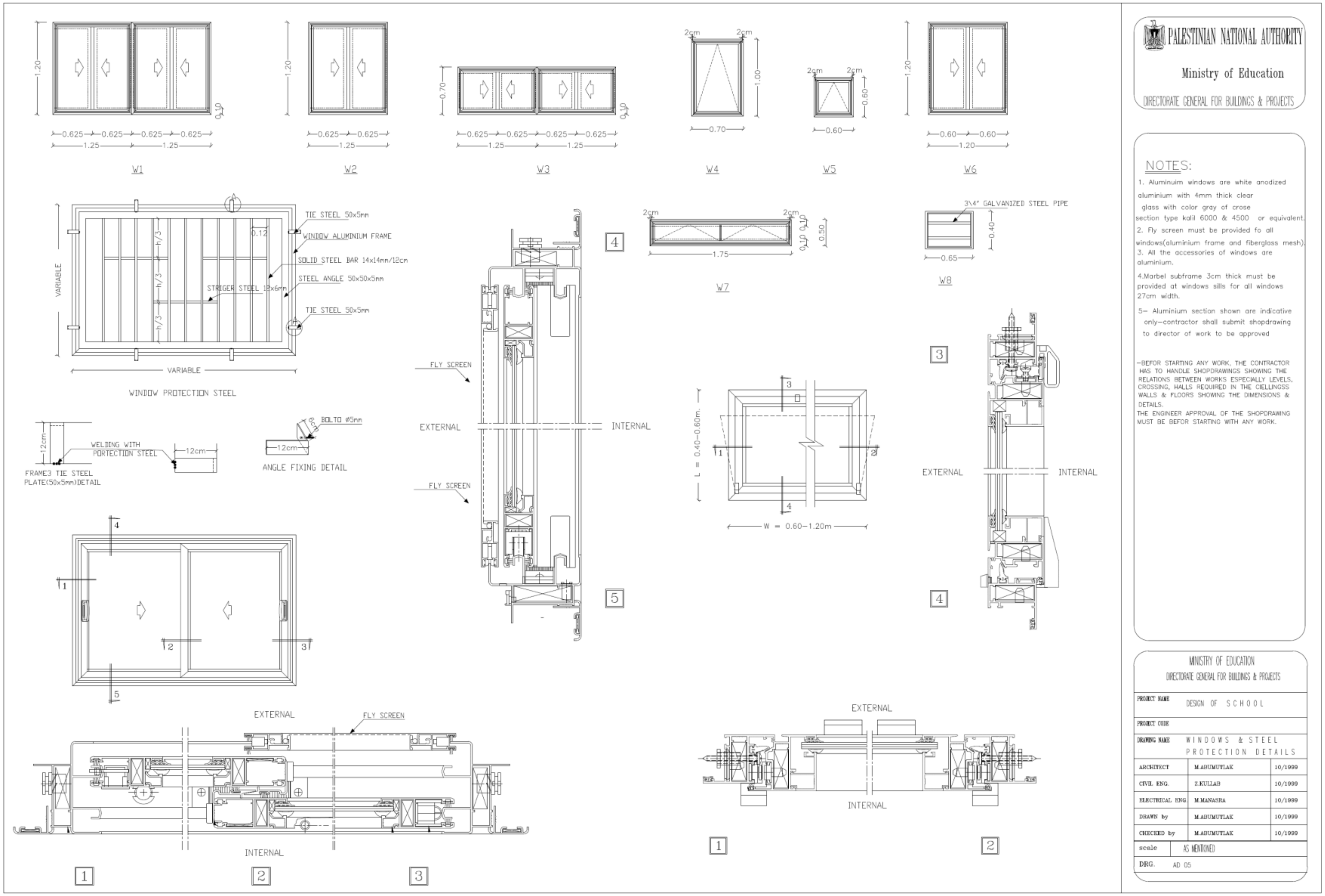
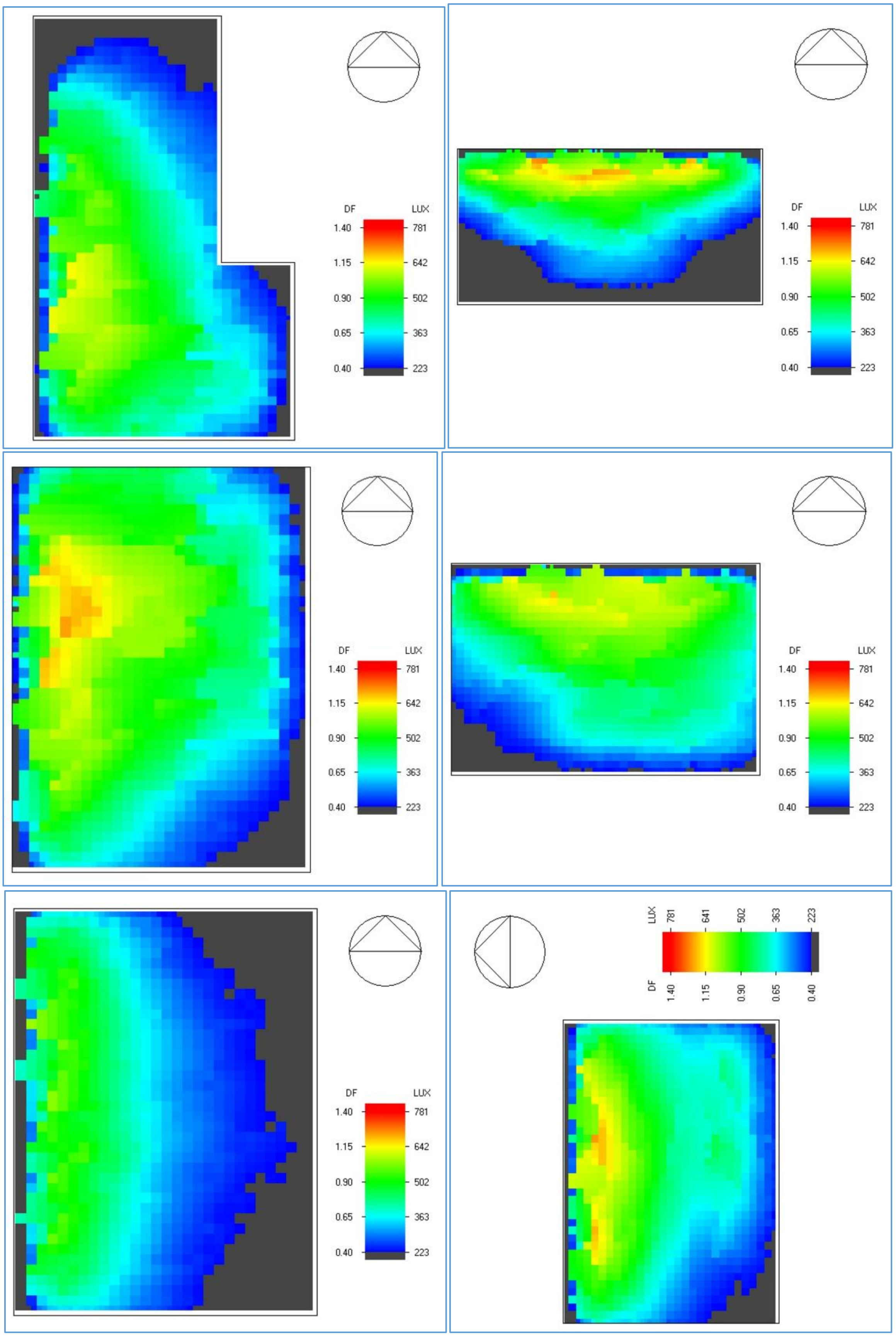
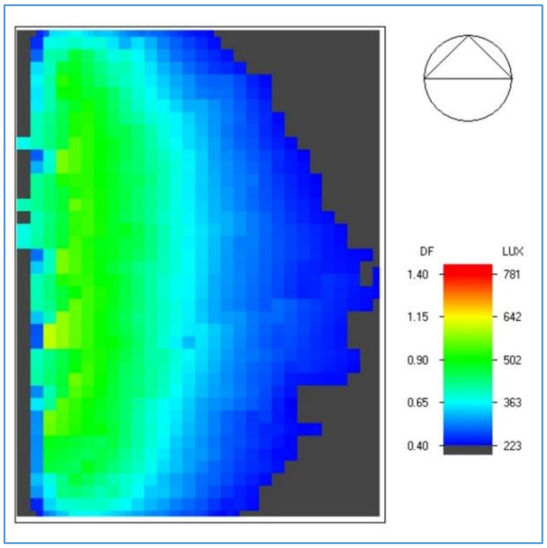
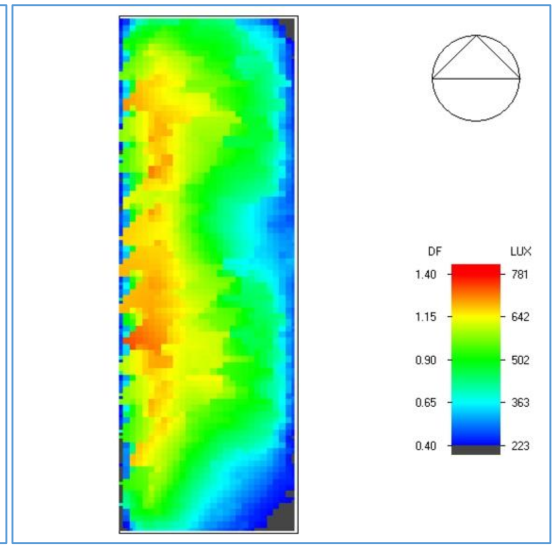


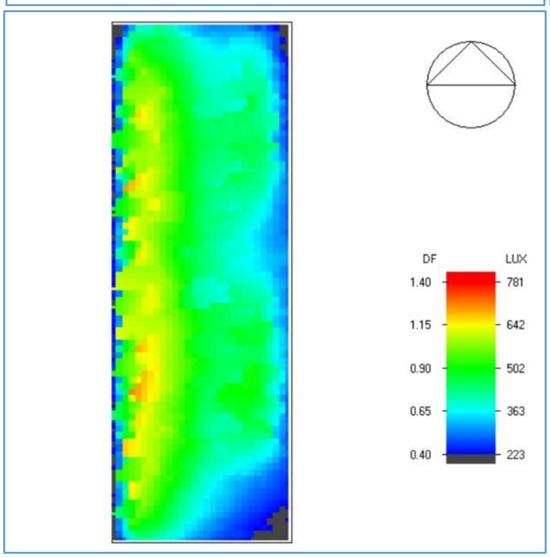
Figure B. 3 Typical Gaza-Strip windows design details

APPENDIX C: DAYLIGHTING MAPS FOR DIFFERENT AL-ZAHRA SCHOOL ZONES


DF
LUX
1.40
781
1.15
642
0.90
502
0.65
363
0.40
223


DF
LUX
1.40
781
1.15
642
0.90
502
0.65
363
0.40
223


DF
LUX
1.40
781
1.15
642
0.90
502
0.65
363
0.40
223


DF
LUX
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502
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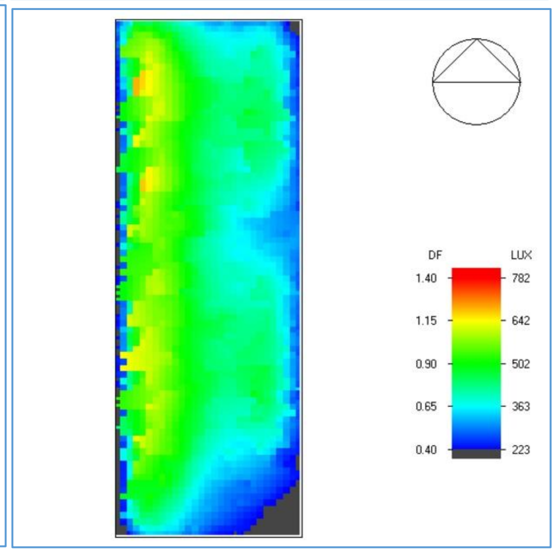
0.40
223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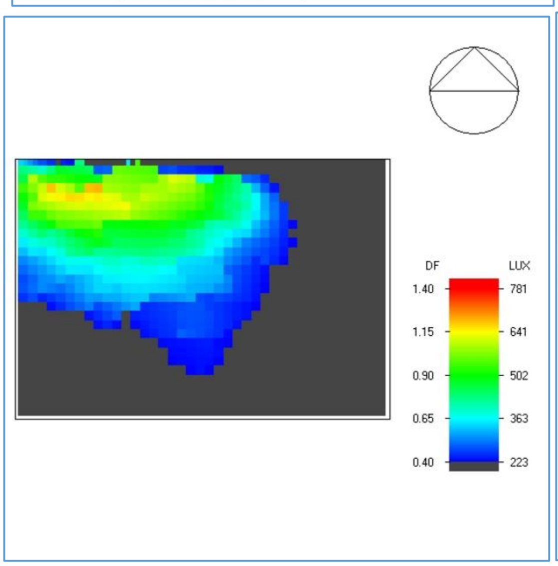
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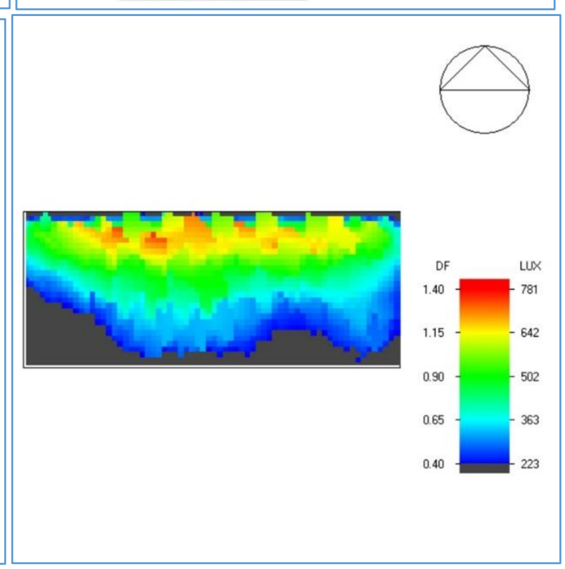
223


DF
LUX
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781
1.15
642
0.90
502
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363
0.40
223

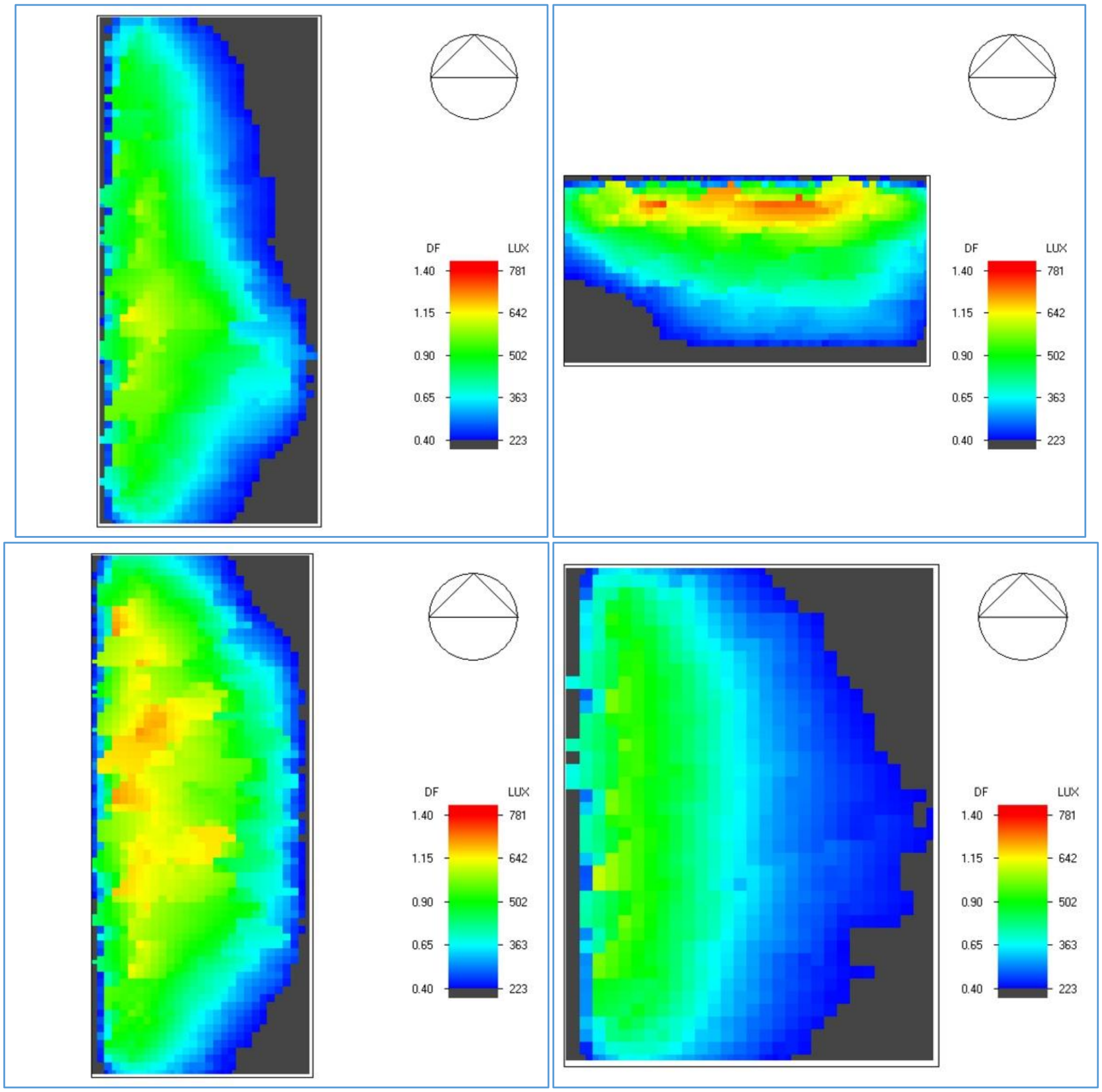

Figure C Daylighting maps for the different school zones (09:00 A.m. 21 Sep, Sunny Clear)

APPENDIX D: TYPICAL PALESTINIAN SCHOOLS CONSTRUCTIONAL SCHEMES

Figure D Palestine inflation rate averages for the last ten years

Vitae

Name	:**Mohammed A. R. Qannan**
Nationality	:Palestinian
Date of Birth	:2/26/1990
Email	:mar_q_9@hotmail.com
Address	:Palestine\Gaza-Strip
Academic Background	:Architectural Engineering
Mobile	:00966532982979

Education

- 2/12/2016 M.Sc. degree in ARCHITECTURAL ENGINEERING (Environmental Control Design) –GPA 3.875- from the college of environmental design from King Fahd University of petroleum and mineral, KSA. Thesis Topic: "The Utilization of Green Energy in Gaza-Strip Schools for Improved IEQ".

- 03/01/ 2012, B.Sc. Degree in ARCHITECTURAL ENGINEERING –GPA 83.7%- from the Faculty of ENGINEERING from the Islamic University of Gaza.

- General Examination Board (96.2%), Al-Salah Secondary School, Dair El-Balah, Gaza strip, Palestine.

Scope of Work:

- Energy Modeling and Simulation in buildings;
- Solar Photovoltaic Systems in Buildings;
- International Building Sustainability Rating Systems;
- Indoor Environmental Quality in buildings (Thermal and Visual Comfort);
- Architectural and landscaping designs;
- Site and Supervisor Engineer;
- Interior design;

- Fire safety systems in buildings;
- Post occupancy evaluation for buildings;
- Architectural drawings: Rendering and visualization;
- 2D and 3D printing technologies;
- Ventilation and indoor air quality strategies (CFD);
- Quality of Life Systems;
- Principles of facility management;
- Principles of building science.

Academic Experience:

- 2016, Lecturer for ARE department in King Fahd University of Petroleum and Minerals for "Architectural design 1 (ARE 202) course"
- 2016, Courses Trainer in ARE department, KFUPM, KSA.
- 2016, Instructor Assistant for "Architectural design 2 (ARE 301) course", ARE department, KFUPM, KSA.
- 2015, Member in ARE Department Club KFUPM, KSA.
- 2015, Working as a Lecturer in "The 2015 Saudi Aramco iExcel Gifted Program"
- 2014, Member in a national project for establishing "sustainability rating system for KSA". KFUPM, KSA.
- 2014, Member in a national project for establishing "Quality of life program in KSA cities". KFUPM, KSA.
- 2014, Member in "ABET Accreditation" team in ARE department. KFUPM, KSA.
- 2014, Instructor assistant for "Architectural design 1 (ARE 202) course", ARE department, KFUPM, KSA.
- 2014, Instructor assistant for "Computer Applications in ARE (ARE 222) course", ARE department, KFUPM, KSA.
- 2014, Instructor assistant for "Architectural design 2 (ARE 301) course", ARE department, KFUPM, KSA.

Architecture and Construction Engineering Management Experience

- 2016, Designer and site engineer for designing "Radisson BLU Resort external landscape and fence\gate" Half-moon, Dammam, KSA.
- 2016, Graphical Designer for Saudi ARAMCO for King Abdul-Aziz Center for World Culture, (i-Read, AAM and Dubai-Days Exhibitions) Dammam, KSA.
- 2013, Working as an architectural engineer in "ENFRA consultant office" in several projects, Gaza, Palestine. (Ex: Design Al-Aqsa University auditorium, Schools, hotels, interior designs, residential buildings).
- 2013, working as supervisor engineer in "Renovating Al-Aqsa Channel Studio" Gaza, Palestine.
- 2012, working as architectural and site engineer in "ARKAN consultant office" in several projects, Gaza, Palestine.
- 2012, participation in "engineering senior projects exhibition" sponsored by UNDP, Japanese government. Gaza, Palestine.

- 2011, Planning Engineer in “Dair El-balah municipality –Department of urban planning-“. Gaza, Palestine.
- 2010, Designer and supervisor for “central public landscape for Al-Buraij municipality”. Gaza, Palestine.
- 2010, Designer and supervisor for “Badri & Haneya mixed commercial and office building”. Gaza, Palestine.
- 2010, Designer and supervisor for “Al-Taawon sport club”. Gaza, Palestine.

Conferences, Seminars and Certificates:

- 2016, Participating as a Lecturer in “The 2016 SABIC Summer Gifted Program”.
- 2016, Participating as a Lecturer in “The 2016 Saudi Aramco iExcel Gifted Program”.
- 2016, Seminar in Efficient Windows Systems prepared by international “GUARDIAN” company, KFUPM, KSA.
- 2016, Seminar in Ferrocement structural technology given by “Dr. Sudhakumar Nair”. KFUPM, KSA.
- 2016, Participating in Entrepreneurial Emerging Leaders Program (EELP) in Entrepreneurship Institute (EI), KFUPM, KSA.
- 2015, Participating as a Lecturer in “The 2015 Saudi Aramco iExcel Gifted Program”.
- 2015, Participating in the “Sixth Scientific Conference (SSC6) for KSA graduate students” in “Strategies for Sustainable Urban Design Using GIS” research, KFUPM, KSA.
- 2015, Certificate in (Ecotect) software, ARE Club, KFUPM, KSA.
- 2015, Seminar in “Building Energy Modeling in Modern Architecture” by: Prof. Godfried Augenbroe, Georgia Tech. school of architecture, USA. In KFUPM, KSA.
- 2014, training course in “Design Builder energy modeling software” KFUPM, KSA.
- 2012, 1st rank for “Design Al-Aqsa university auditorium” Gaza, Palestine
- 2012, participation in “engineering senior projects exhibition” sponsored by UNDP, Japanese government. Gaza, Palestine.
- 2011, three months training in “Dair Elbalah municipality –Department of urban planning”. Gaza, Palestine.
- 2010, a training course in “3d max software” from community service, continues learning, Islamic university, Gaza, Palestine.
- 2010, 1st rank for “Design and plan central public landscape for Al-Buraij municipality” competition. Gaza, Palestine.
- 2010, participating in “Design Badri & Haneya mixed commercial and office building” competition. Gaza, Palestine.
- 2010, participating in “Design and plan Al-Taawon sport club” competition. Gaza, Palestine.
- 2008, a training course in “CAD, Google SketchUp, Photoshop” from community service, continues learning, Islamic university, Gaza, Palestine.
- 2006, training course in “Modern Civil culture” from Hamline University, USA. Gaza, Palestine.

Software:

- DesignBuilder Energy Simulation Software;
- DesignBuilder CFD;
- RetScreen Expert PV Design Software;
- DIALux Pro;
- 3ds Max;
- Autocad;
- Architectural Revit;
- Google SketchUp;
- Lumion;
- Photoshop;
- Inkscape;
- 123D Design;
- MS Project;
- MS Office;
- Video Montage Software (Adobe Premiere, After Effects);
- Sound Montage Software (FL Studio, Samplitude).