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TOWARDS OPTIMIZING (BAPV) AND (BIPV) APPLICATIONS IN EDUCATIONAL BUILSINGS IN EGYPT

[By aid of (IT) applications validated by real (PV) Experimental station]

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ABSTRACT

Environmental threats of: [Climate changes, Green House gasses (GHG) emissions, and Economic crisis] led to paradigm shift towards renewable clean Energy, which becomes a major strategy. Egypt taking steps by raising its potentials of Renewable energies production from (2%) in 2010 aiming to be (53%) of electricity from Renewables by 2035, basically depends on development in Solar Energy. Photovoltaics (PV) applications become a major approach for Solar Energy utilization on: (buildings "Rooftop" and Façades) through two major systems: [Building Applied Photovoltaics (BAPV), and Building Integrated Photovoltaics (BIPV)]. Applications of (PV) in buildings have great double impacts; Active: of Clean Energy production, and Passive: duo to shading, thermal Insulation and time lag effects.

Research aims to Optimize (PV) applications on: ["Rooftop" and Façades] to get visible Efficient Operation according to parameters: [Tilt angel – Orientation – Type of applications], thus to propose a reliable Matrix, that can help: [Architects– (PV) Developers] in decision making of the most Prior of (PV) applications. Depending on Research Methodology, and by aid of reliable (IT) Simulation tools used ("PVSYST" – "Energy +"), then Validated Results by records of Experimental (PV) Station, found that; Optimizing the application of (PV) Panels on standard educational building "Rooftop"; can save more than (37 %) of conventional annual Energy consumptions. Otherwise, optimizing the whole application of (PV) Panels on both:["Rooftop" and (South, East, and West facades respectively)] can save more than (81%) of "Base-Case" Energy consumptions, which approaches to be a Zero Net Energy educational Building (ZNB), by clear energy source.

KEYWORDS: Solar Energy – (PV)"Rooftop"– Building Integrated Photovoltaics (BIPV) – (PV) Simulation – (PV)Optimization –Tilt angel – Orientation – Shading – Thermal insulation –Time Lag

نحو منهج لتحسين تطبيقات الخلايا الشمسية (المضافة و المدمجة) في المباني التعليمية بمصر

[دراسة حالة: باستخدام تطبيقات تكنولوجيا المعلومات وتحقيقها من محطة تجارب خلايا شمسية]

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الملخص

لقد مثلت التهديدات والمخاطر البيئية الراهنة من [التغير المناخي – الاحتباس الحراري – الانبعاثات الغازية الضارة – الازمات المالية /الاقتصادية العالمية] الدافع القوي والرئيسي لتحول المفهوم العالمي نحو الاعتماد علي مصادر الطاقات الجديدة والمتجددة واعتبارها توجه استراتيجي دولي تعقد له المؤتمرات الدورية وتتخذ له القرارت الدولية الملزمة. و قد تحركت مصر مؤخراً في هذا الاتجاه بخطوات واعدة بزيادة الاعتماد علي مصادر الطاقة المتجددة لديها ليرتفع من 2% في عام 2012 لتحقق 22% في عام 23/22 وتسعي جاهدة علي عدة محاور لتصل بمقدار انتاجيتها من الكهرباء النظيفة لنسبة 53% من مصادر متجددة بحلول عام 2035، معتمدة في ذلك علي مصدر الطاقة الشمسية لديها بصورة رئيسية نظراً لموقعها الجعرافي المتميز– وعليه قد أصبح الاعتماد علي نظم الخلايا

الشمسية/الكهروضوئية (المضافة و المدمجة) في تصميم أغلفة المباني (المُحدثة و الجديدة) مصدراً هاماً للبحث العلمي و التطوير المعماري المتلازمين ليس فقط لدور هذه الأنظمة النشط (الفعال) بما يضيفه للشبكات/للمباني من طاقة نظيفة مُنتجة، و لكن أيضاً لدوره الايجابي في توفير الظلال الذاتية والعزل الحراري لغلاف المبني نتيجة (التركيب – الدمج) ومايتبعه من تخلف زمني يساعد علي تحسين خصائص الانتقالية الحرارية للفراغات الداخلية و من ثم تحسين كفاءة الطاقة بخفض استهلاكاتها اليومية.
هذا و يهدف البحث لتطوير (منهج /نموذج/ اطار تقييم) بناء علي تحليل علمي منهجي لتحسين كفاءة تطبيقات نظم الخلايا الشمسية بأغلفة المباني التعليمية بمصر وفق دراسة مجموعة من البدائل التصميمية بكل عنصر(الأسقف – الواجهات) اعتماداً علي أهم العوامل و المتغيرات بهذه النظم :[التوجية – الموقع – زوايا الميل للألواح – مكان التركيب بالغلاف – ....] وذلك قياساً علي دراسة حالة حقيقية لمبني تعليمي قياسي بإحدي الجامعات المصرية- بإقليم القاهرة الكبري، مع الاستعانة بأدوات محاكاة رقمية لها اعتمادية دولية في نمذجة و تحليل نتائج الاختبارات، مع تأكيد صلاحية و تصحيح النتائج بالاستعانة بمحطة تجارب خلايا كهروضوئية حقيقية موجودة بالموقع.

و باعتبار أن الطاقة التي يتم (اكتسابها/خفضها) هي نتاج حاصل جمع [الطاقة النظيفة المُنتجة من النظام والتي يتم ضخها للشبكة + الطاقة التقليدية التي تم توفيرها نظراً للعزل الحراري للغلاف والظلال الذاتية الناتجة عن استخدام النظام مقارنة بالوضع الأساسي]، هذا و توصل البحث للنتائج التالية : انه بنمذجة الاستخدام الأمثل لنظم الخلايا الشمسية بالأسقف فقط للمبني محل الدراسة يمكن خفض استهلاكات الطاقة بمقدار 37%- بينما في الواجهات تصل إلي:[25% في الواجهات الجنوبية – 10% في الواجهات الشرقية – 9% بالواجهات الغربية]، و ذلك لنفس عدد وحدات الألواح الشمسية– لذا يعتبر الاستثمار في نظم الخلايا الكهروضوئية بالأسقف أفضل نسبيا يليه الواجهة الجنوبية ثم الشرقية . كما توصل البحث بأنه في حالة الاعتماد علي النمذجة المثالية المسبقة لتطبيقات نظم الخلايا الشمسية علي غلاف المبني بالكامل (الأسقف + الواجهات الثلاث: الجنوبية - الشرقية - الغربية) قد تصل نسبة الوفر الكلي السنوي للطاقة 81% وربما أكثر، و ذلك مقارنة بالاستهلاك الأساسي ،و مع التحسين المستمر لكفاءة تطبيق نظم/أنواع الخلايا الشمسية قد نصل به ليكون مبني صفري الطاقة.

1. INTRODUCTION

The global paradigm shift towards Renewable / Clean Energy sources, become a major strategic plan for both: advanced and developing countries to more sustainable energy management [2]. The world Environmental threats such as: [Climate changes, Green House gasses (GHG) emissions, Global warming, furthermore the world Economic crisis] become a driving force to a rapid transition from conventional fossil resources to clean/Renewable energy sources to save the rest of our environment.

In Egypt, after three years of instability of Political /Economic conditions followed 2011 Egyptian revolution with shortage of most of all energy sources; especially in Electricity and Fuel supplies. Egypt began a new reform program within a new Integrated Sustainable Strategic development plan; “Egypt Vision 2030” [3]. In2015, the Ministry of Electricity and Renewable Energy (MERE) created an ambitious plan by Integrated Sustainable Energy Strategy (ISES) to year 2035, to ensure the stability and security of the energy supply through two major axis by:

- Raising the national grid Energy Efficiency by: [Construction of new power plants, Enhancement/maintain of existing power plants], and decreasing CO_2 emissions from burning fossil fuels [4].
- Increasing the share of Renewable Energy production from: [(2%) to (20%) by 2022, and reach (42%) of total production by 2035], in addition to first Nuclear energy production from nuclear power plant in “El-Dabaa” with a capacity of (4,800 MW) is completed [1].

According to new Renewable energy law issued in 2014, called “Feed in-Tariff” (FiT), thus regulates Renewable Energy prices by the Egyptian government for the energy injected to national grid from Private sector, Renewable developers and Investors at attractive tariff [5].Solar Energy considers one of the most common and “Eco-friendly” Renewable energies with no-exhausts and harmful emissions, furthermore quick and continuous development of (PV) systems in [Technologies –Types– Components]. Egypt has very good potentials for solar Energy production due to many reasons such as: sunny weather along year with average: (2,000: 3,000 kWh/m^2/year) of direct solar radiation, which considers the second-highest solar energy generator in Africa after South Africa, while it is the thirty-first worldwide according to Solar Atlas, and sun shines (9-11 hours) a day from North to South, with few cloudy days [6].

A solar photovoltaic (PV) system is an electrical installation that converts solar energy into electricity. This system can be Applied/Attached (BAPV) or even mounted on the building envelope: [even integrated into “Rooftop”/Façade structure as (BIPV)] to produce energy, which can provide the building by its own energy consumption requirements, or in certain situations, feedback energy into the electrical grid, furthermore the passive impact of "Rooftop" shading and façades thermal, sound insulation [7].

Energy consumptions by building and construction sector exceeds (45%) of total world energy productions, which considers one of major causes of environmental pollution [8]; So as to, it worth to be adapted to be more energy efficient in consumption, addition to a rapid transition to renewable energy resources not only as a Clear energy dependent, but also as a Clear energy producers - as well as to be Zero Net Energy Buildings (ZNE).

By reviewing many of previous researches and studies of (PV) applications in buildings we can conclude them in three major lines:-

- Most: Devolve/Improve of physical/chemical characteristics of (PV) inner cells and types
- Moderate: Innovate/developed/monitor the impeded (PV) systems within building construction and finishing systems as (BIPV) and its impact.
- Rarely: Optimizing the applications of (PV) from energy efficiency point of view- mostly in residential buildings, but less than in public /commercial/even Industrial ones [13].

So as to, the research hope to be a useful guide-line to Optimize (PV) applications in very important/vital building sector, not only for its Economic impact as a clear energy production, but also for both: Environmental impact of lowering energy consumptions, gas emissions, and important Social impact of conceptual transition towards renewable energies and sustainable applications through young students and new generations.

1.1 Research Problem

Research Problem has many Major/vital roots can be concluded as follows:-

- Environmental: Clean/Renewable Energy become an urgent demand worldwide than fossil fuel with more rising of gas emissions, global warming problems, then rapid rates of climate change.
- Educational buildings (University campuses/Colleges – Schools – Educational centers) nears to (18%) of buildings stock [9], come next to residential and industrial ones and have services labors, which can be adapted in (PV) operation more than small and individual residential buildings; thus can be more passively enhanced, if there is a guide-line strategy/plan to be applied in new and retrofit buildings.
- Economic: Huge and fast demand on Energy by construction and building sector, then rapid jumps in Energy/Electricity prices, that becomes a heavy economic burden on both: (Individual and educational institutions) of our developed country, which can be reduced and adapted depending on Renewable/Clear energy sources [5].
- Social: Support the daily culture/concept of Renewable Energy dependent, by real (PV) building application, thus spreading a (ZNE) culture among students.

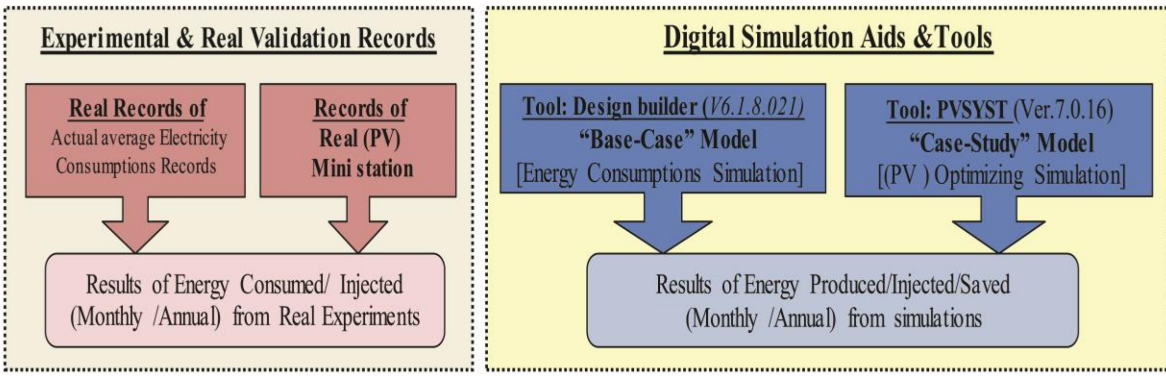
1.2 Research Goals

The main goal of research is to "Optimize the application of (PV) on Educational buildings "Rooftop" and Façades"; to get the most (Adapted/Visible) Clean Energy production/Efficiency, by optimizing (PV) parameters such as: [Tilt angel – Orientation – Type of applications],thus enhance building Energy Efficiency, the next associated goals:-

- Propose a Guide-line/Matrix to support [(PV) Developers/ Manufacturers – Educational establishments' managers – even Researchers] on their decision making about (PV) application in standard Educational buildings.

- Get Prior application of (PV) panels in building Envelope elements: ("Rooftop" – Façade) according to (Benefit–Energy production/saving) analysis in a comparative with conventional/traditional "Base-Case" consumptions.
- Monitoring the recent Egyptian Renewable Energy plan, especially solar one.
- Differentiate between (BAPV) as a retrofit approach, and (BIPV) as a newly construction strategy towards (ZNE) buildings.

1.3 Method and Technical Aids



(Fig.1) – Research Technical Aids used, and Experimental Validation, [Ref., Author].

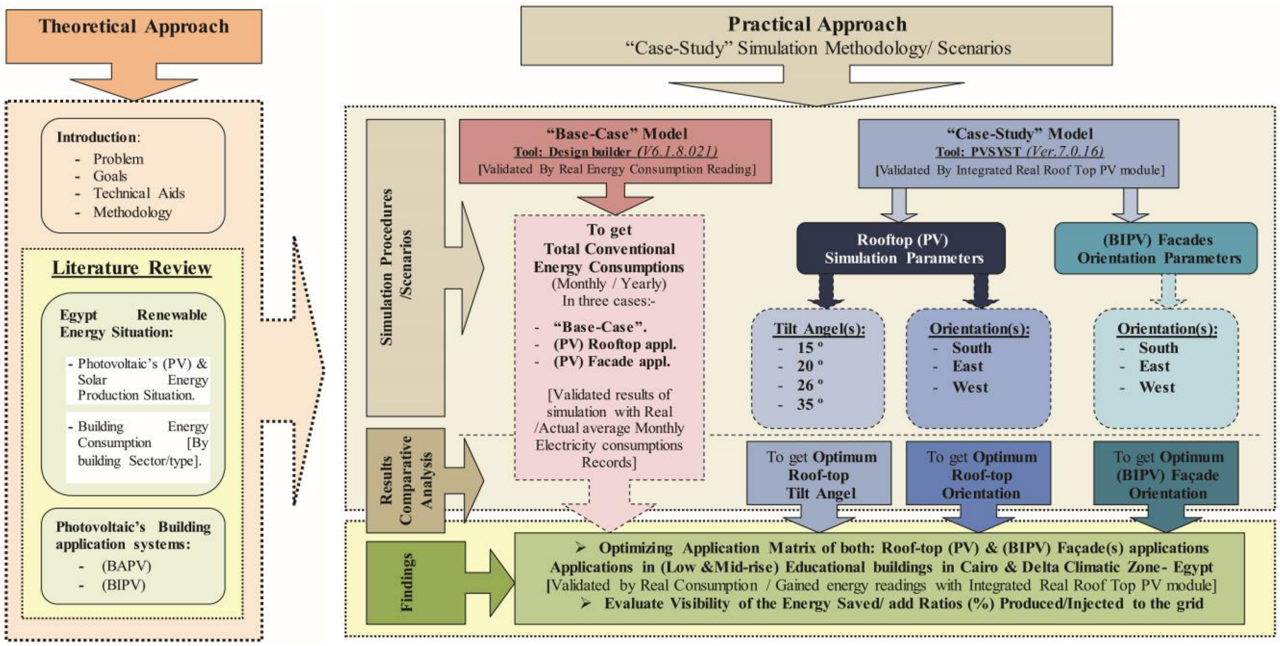
The application approach of the research depends upon two complementary lines, (Fig. 1):-

- Aid of reliable, popular and accurate simulation tools for (PV) application on building envelope as a "Case-study" with (PV.SYST-Ver.7.0.16) to optimize (PV) parameters such as: [Tilt angel – Orientation – Type of applications], and another tool (Design builder-V6.1.8.021) linked to (Energy Plus engine) for building Energy consumptions as a "Base-Case" to be compared.
- Validation of simulation results depending by real Records of existing Experimental (PV) Mini-station in site, and annual Energy produced/ consumed.

1.4 Research Methodology

As shown in (Fig. 2) Research methodology compromises between:-

- Theoretical approach: this covers the literature review of both:
  - Egyptian Renewable Energy current situation and its strategic plan till 2030 focusing on Solar Energy production evolving rates.
  - Main Strategies/approaches of (PV) applications in architecture and building sector such as :(BAPV), (BIPV) systems and their field of applications.
- Application approach: using both credited (IT) tools such as: (PV.SYST) and (Design Builder) on "Case-Study" and "Base-Case" models for a real existing standard educational building; to get optimum parameters of (PV) application on "Rooftop" and Façades.

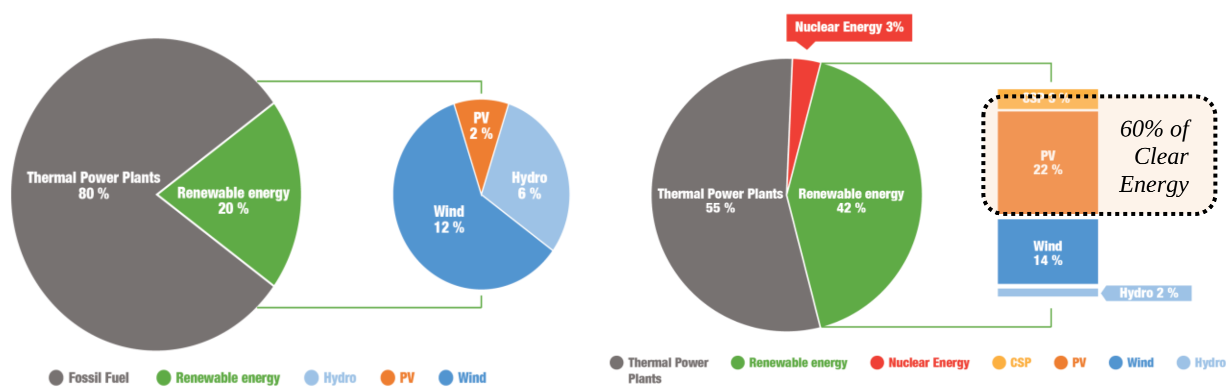


(Fig. 2) – Research Methodology Chart, [Ref., Author].

2. EGYPT'S PLAN TO RENEWABLE ENERGY TRANSITION [CURRENT–VISION]

Egypt considered the second highest renewable energy capacity in Africa after South Africa, with the potential up to (4,813.0 MW) of electricity from renewable Energy sources such as: solar energy, water and wind [5].

In 2015, the Ministry of Electricity and Renewable Energy (MERE) created ambitious plan by Integrated Sustainable Energy Strategy (ISES) to year 2035, compromised with The Sustainable Development Strategy "Egypt Vision 2030" to ensure the stability and security of the energy supply through two major axis - First: raising Energy efficiency of production by maintenance and rehabilitation programs in the power sector, Second: targets to increase the share of renewable energy in the energy mix to (20%) by end of 2022 to reach (42%) of total generating by 2035 with the engagement of all sectors,(Fig.3).In addition to plans on nuclear power generation to contribute to the electricity mix with (3%) by the same target year; from first nuclear power plant in El-Dabaa (with a capacity of 4,800 MW) is completed [3].

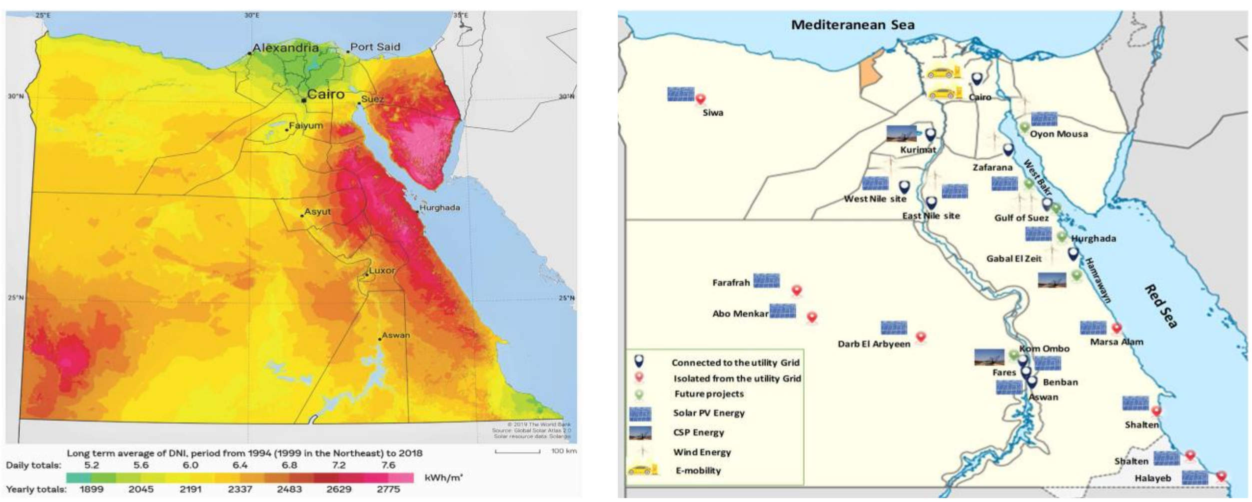


(a) Energy produced 2020 (by source) (b) Estimated Energy to produced 2035 (by source)
(Fig.3) - Energy production by source (a) 2020,(b) Future estimation(2035),[Ref.[5], adapted by Author]

Under these targets, solar energy would feed up (22%) of the total generated electricity, wind (14%) and hydropower (2%). Most of this capacity is expected to be delivered by both: government and private sector. According to the International Renewable Energy Agency (IRENA) predicted that Egypt could supply about (53%) of its electricity using renewable energy by 2030 [1]. All previous international and local statistics, reports and indicators, mentioned that: solar energy will be the major renewable source to be developed now and in the future.

2.1 Photovoltaics (PV) & Solar Energy Production Situation

The converting energy process from sunlight into electricity is called solar energy. It can be done directly by PhotoVoltaics (PV), to feed-up this energy to the electrical national grid it called “Electrify” solar energy through (PV).
According to Egypt Solar Atlas,(Fig.4-a) Egypt has the highest daily typical irradiance values in Northern Africa, averaging from (2000 to 3200 kWh/m2/y) with average sunshine of (9 –11 h/d) and a total sunshine duration of up to (4,000 hours) [6]. According to (MERE), the solar energy generation capacities could be extended further (3500 MW) by 2027.In 2022, solar energy in contributed by (2%) of the produced electricity making Egypt is the second-highest solar energy generator in Africa after South Africa, and the thirty-first worldwide rank [1], and predicted as (ISES 2035 plan) to reach (22:26%) of total energy production and to be the first of renewable energy production.



(a) Egypt Solar Atlas and direct normal radiation details (b) Renewable Energy sites in Egypt (Present/Futuristic)

(Fig.4) – Renewable Energy Potentials in Egypt, Ref.[6]

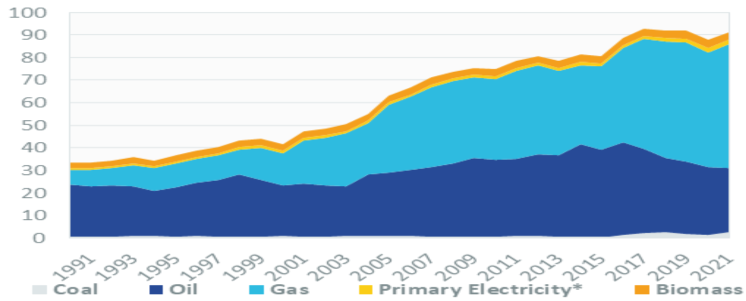
Egypt’s first solar power plant opened in 2011 in “Kureimat” with a total capacity of (140 MW). In 2019, operations started at “Benban” Solar Park, the largest grid-connected solar installation in the world with a total capacity of (1.8 GW.) Located in the Western Desert near Aswan, the overall global capacity of solar energy utilization has reached (177 GW), marking another record year of expansion with (42 GW) of new capacity in 2022, next Renewal Energy map shows the current and future potential of Renewals projects and locations, as in (Fig. 4-b).

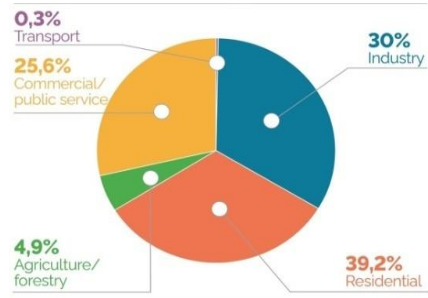
2.2 Building Energy Consumption [By building type/Sector]

According to reports and statistics of (MERE), and International Energy Agency (IEA) for yearly energy consumptions (by building sectors and types), we can note that, both business and industrial buildings consumes more than (55%) of total electricity production [11], as in (Fig. 5).
So as to, these building sectors have a prior by focusing to apply a clear strategy to implement (PV) optimal application in such building types (by retrofitting the existing or by design integration in new ones); for sure will impact a good revenue not only by reduction energy cost paid, but also by reduction

dependent of fossil production and gas emissions then, become a strategic shift plan towards Zero Net Energy Building (ZNE) concept, depending on the following major reasons of such building nature of design and operation:-

- Horizontal building type with extended roof area (suitable for (PV) roof panels' application).
- Availability of cleaning and maintenance of (PV) system, which can be integrated within these building types service plan with-out additional labor cost.





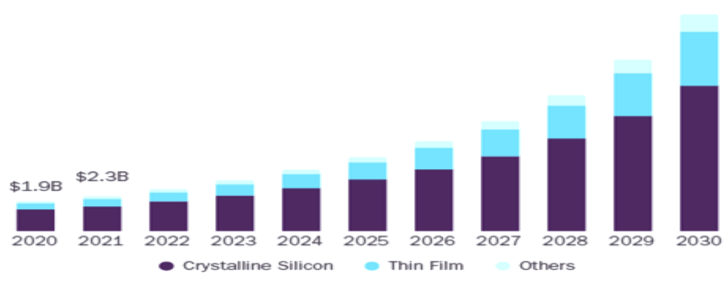
a)- Energy consumption (21/22) (By source types) (b)-Electrical energy consumption (21/22) (By building types)

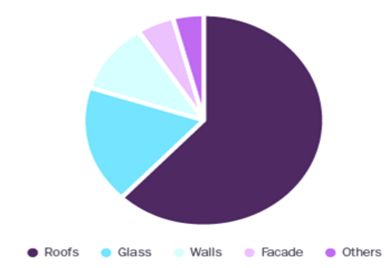
(Fig.5) – Global Electrical Energy consumptions (By source & building types), [Ref.[10], adapted by author]

3. (PV) APPLICATIONS IN ARCHITECTURE/ BUILDINGS [Concept – Classification – Suitability]

As mentioned above Solar Energy considers one of the most ambitious and booming of renewable energies not only for worldwide, but specifically for developed countries which have a very good solar irradiance like Egypt. Thus, transfer of photovoltaics (PV) applications into building design and construction industry become an innovation of design and basics of environmental design strategies. It is much more than an energy-converting solution: it represents a major aspect in architectural design aesthetics and building technology [7].

Many experimental tests, researches have been proceeded to develop (PV) module to improve efficiency, stability and cost reduction of crystalline silicon (SC-i) (PV) module such as both: multi and mono-Crystalline have large market share because of their high efficiency thus, applied widely in "Rooftop" applications (Fig.6.a, b) [13].But, the high efficiency performance usually connected by high cost even, many developed researches has been made for the cost reduction. Although, Other (PV) module like amorphous silicon has low performance and efficiency level, but offer flexibility in usage because of thin (PV) film modules which makes them more suitable, and good architectural attractive appearance for façade applications [14].





(a)-Current/Expected (PV)Building application investment (Investment By (PV) Type and Technology)

(b)-Global view of Building (PV) application (Market Share % By envelope applications)

(Fig.6 a, b) – Global market potentials of (PV) application in Building, [Ref.[18].

A solar photovoltaic (PV) system application in buildings can be implemented in pre-design and building construction systems or post-applied/attached to existing buildings to improve their energy efficiency and sustainable performance by many strategies/techniques, then fed back electricity into the local electrical grid. Generally, most of researches and studies classified (PV) applications on buildings as: Existing and new buildings according to the way of (PV) installation and construction in the building (Fig. 7), then (PV) application is categorized into two main systems (BAPV) and (BIPV) [7], as follows:-

(Fig. 7) ,

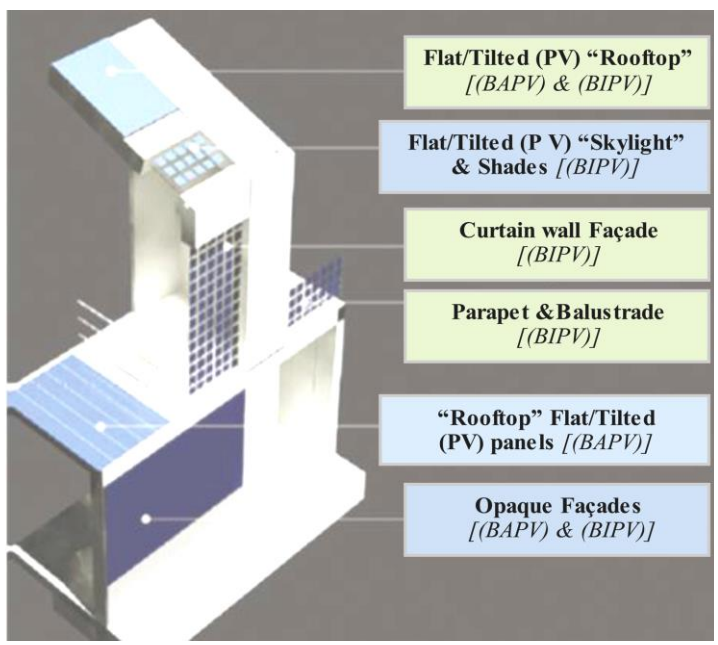
Classification Concept of (PV) application in Building, as (BAPV & BIPV)

[Ref. [19], Adapted by author].

3.1 BAPV System (Concept– Advantages – Negatives)

Building Applied/Attached Photovoltaics (BAPV), where the (PV) Panels/modules are attached directly to the existing building envelope using an additional mounting / adaptable structure [15]. Thus, the (PV) modules are installed at specific tilt angle and orientation either on Rooftop or Façade as: [(BAPV) wall in horizontal/vertical arrangement or (BAPV) flat/curved/ slopped roof], (Fig.8), [16] .The architect/designer should to consider the local weather conditions/of the context. One of the most positives of this system it is the most strategic/suitable approach for Retrofitting of the existing building from environmental and Energy Efficiency upgrading point of view with little modifications, the negatives of this system can conclude as follows:-

- Additional loads on "Rooftop" and Façade must be calculated/ notable before application.
- Need Architectural redesign (Especially in Façade) to be architecturally accepted addition.
- Study of ventilation system for air-gap between (PV) modules and building envelope.
- Need a pre-study of clean and maintenance procedures to the system to be applied.
- Local macro / micro climate/weather should be studied and simulated specifically before (PV) system installation.



(Fig. 8) – (PV) applications in building Envelope elements, Classified as (BAPV) & (BIPV), [Ref. [19] Adapted by author].

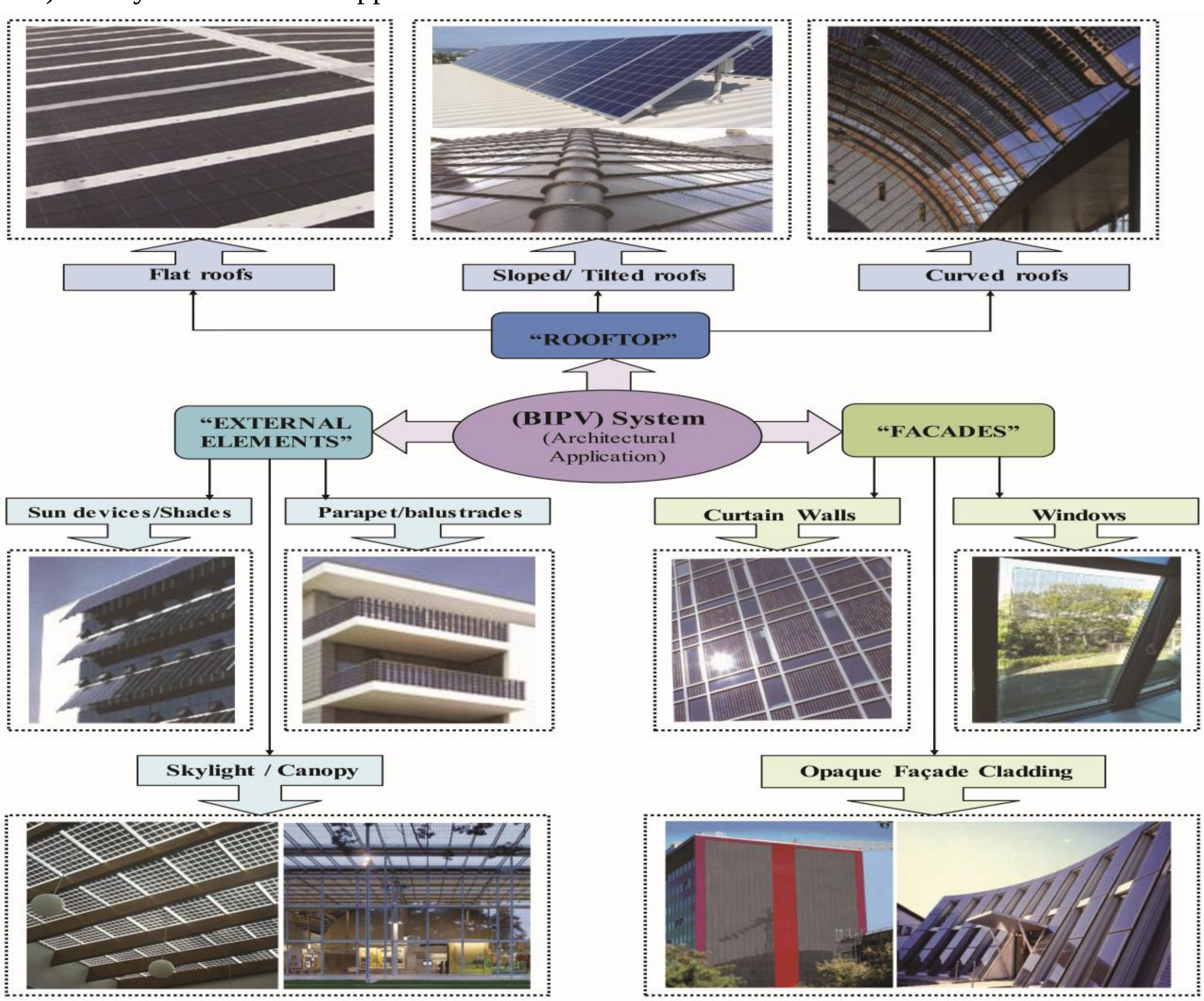
3.2 BIPV System (Types – Advantages – Negatives)

Building Integrated Photovoltaics (BIPV), here (PV) modules are integrated and implemented within the building envelope structures and can be applied on (Roof – Façade –Fenestration– Shading devices – balustrades– …), Such integrations can be referred to as (BIPV facades, BIPV-Rooftop, BIPV window- …etc.) [15] , as shown in (Fig. 9).

Hence, the (PV) modules will replace/implement within the conventional construction building materials used for (the roof/atriums - walls - windows -...) by (BIPV) products/materials. This includes the (PV) modules in the form of transparent/semi-transparent glass. Thus, in (BIPV) system applications the architect/designer must consider the following assumptions in his earlier design stages to get the maximum and optimum benefits of (BIPV) application in his building:-

- Environmental / Solar passive design calculations.
- Local weather/site conditions and site context.
- Architectural Design language, compromises with (BIPV) systems / materials available.

There for, (BIPV) application is most suitable/cost benefit for both: New “Eco-friendly” or “Sustainable Urban and building design. Generally, (BIPV) or (BAPV) systems generate electricity which is relatively free from greenhouse gas emission during the operational phase with no additional land spaces requirements. Hence, the optimizing of (PV) application for buildings as (BAPV) or/and (BIPV) is very recommended approach.



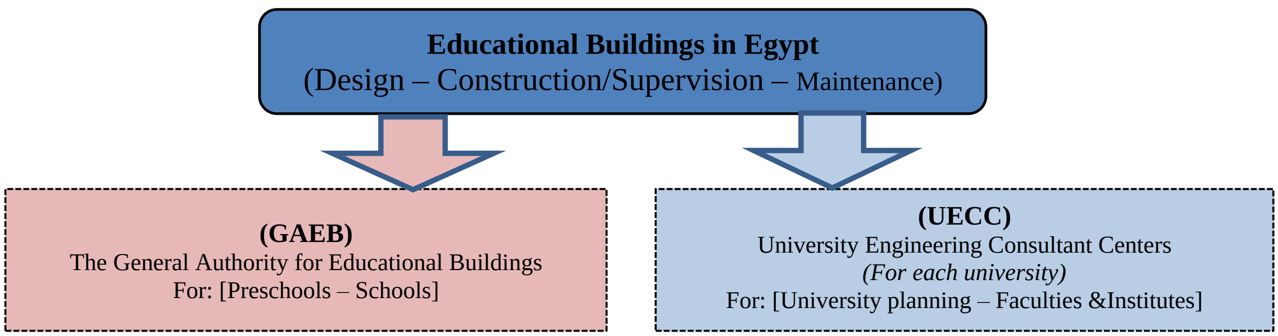
(Fig. 9) – (BIPV) System (By building Envelope Elements), [Ref. adapted by author]

4. EDUCATIONAL BUILDINGS IN EGYPT: AT A GLANCE

As mentioned above in section (2. 2), Public and commercial buildings consumes more than (28%) of Energy/Electricity produced next to residential ones (more 40%), of this sector - Educational buildings [University campuses/Colleges – Schools – Educational centers –….] nears to (18%) of all buildings stock [9], thus deserve to be discussed as suitable/visible field of (PV) architectural applications, due to many strategic reason such as:-

- **Repetition all over country**: with variant climatic zones.
- **Rapid increasing yearly:** considers a growing positive clear energy field as a function of population.
- **Social Impact:** as a real application of Renewable energy which spreads a sustainable and solar energy culture in its urban community through daily public use.

Responsibility for formal governmental Educational buildings in Egypt can be classified into two major authorities according to both educational degrees as follows, (Fig. 10):-



(Fig. 10) – Responsibility for (Design – Construction – Maintenance) for Educational buildings in Egypt,*[By Author]*

- [GAEB]: The General Authority for Educational Buildings, which established on 1988, to be responsible for (design- construction – maintenance) of all governmental schools in Egypt with all degrees and types [20].

(GAEB) stated some basic and necessary goals in developing school buildings, which encompasses all elements necessary for the educational operation, such as:(athletic- entertaining - cultural activities), taking in consideration application of the functional and environmental criteria resulting from the urban and characteristics climatic zones; by divided Egypt into eight climatic zones, to be considered in design, even private sector (National /Language/International) school designs must be approved from(GAEB), which released a comprehensive design guide lines/standards and invited architects in several architectural competitions to develop proper/contemporary design proposals.

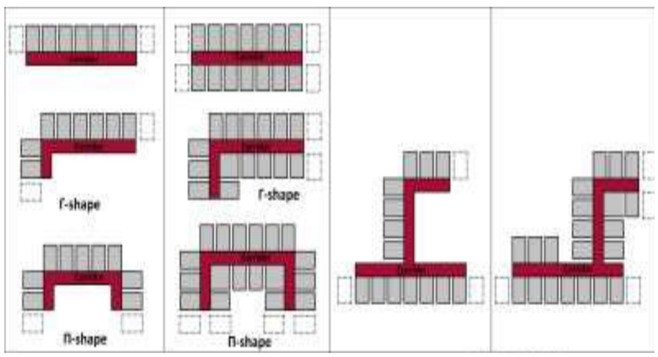
- [UECC]: University Engineering Consulting Centers, depending on experiences of staff of faculty of engineering in each university, as a comprehensive consultancy house, to be responsible for (design– supervision – maintenance) of all university& academic buildings.

Educational buildings haven't only a vital role in supporting Renewable and Clear energy transition process, but also have a social responsibility towards sustainable development integration with-in their building's operations (new and retrofitted ones) [12], then Solar energy through (PV) building applications have a good approach and prior for many reasons such as:-

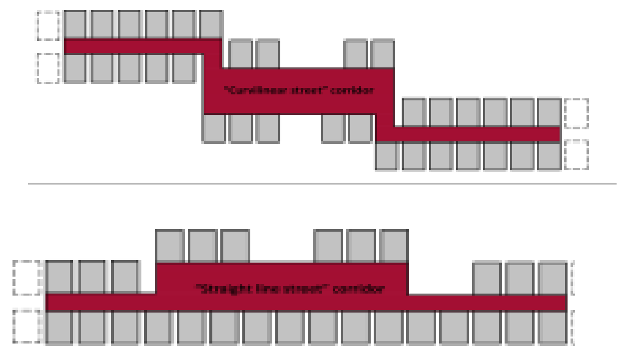
- ***Standard educational building North orientation***: [Pre-oriented with (North +/- 25° east /west inclination), Thus long facades oriented for North natural lighting requirements].
- ***Mid-rise building (3:5) typical floors:*** which suitable ratio of floors number vs floor area).

- ***Modulated facades:*** repeated openings and opaque walls (classes, Labs. & lecture halls (which can be adapted with (PV) wall panels modules with façade design).
- ***Standard and suitable roof area:*** educational plan ratio of (1 Width: 2~2.5 Length).
- ***Existing service labors:*** for continuous maintenance cleaning (PV) panels array (already existing technical /clean labors as regular in building).

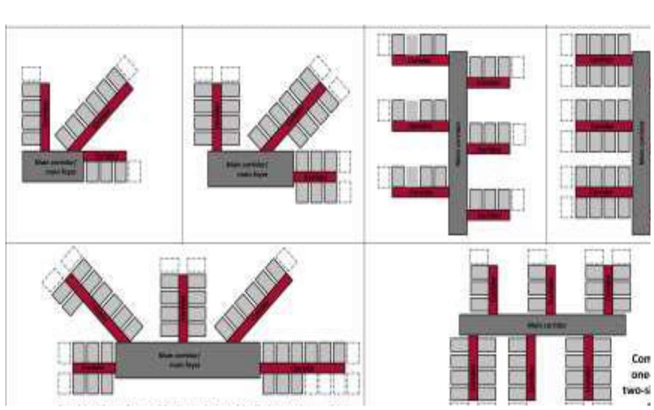
The two main streams for educational buildings in Egypt developed and produced multiple design models/configurations according to (Site planning – North orientation – Building articulations– Functional usage –…), which can be classified, [21] as shown (Fig.11, a: f).



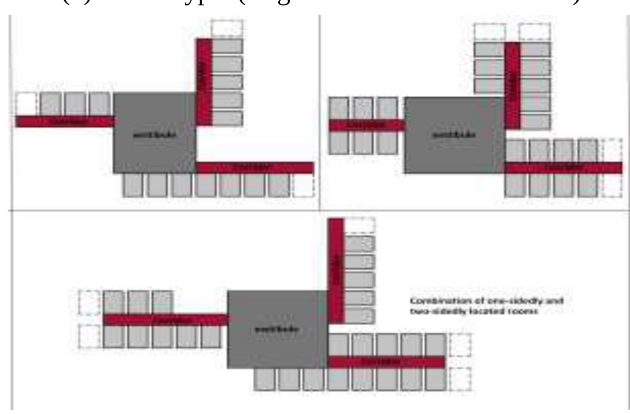
(a) Liner Types: (single /Double loaded corridor)



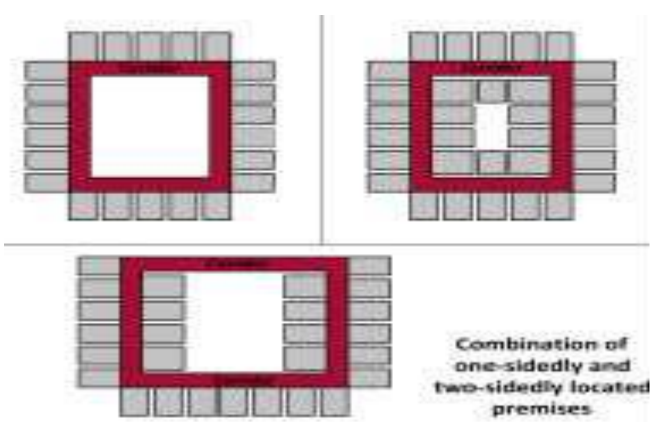
(b) Street Type: (single /Double loaded corridor)



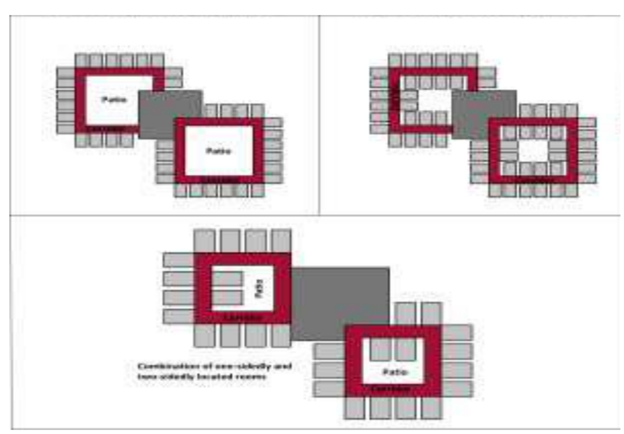
(c) Finger Type: (single /Double loaded corridor)



(d) Central /Radial Type: (single /Double loaded corridor)



(e) Court Type: (single /Double loaded corridor)



(f) Compacted Type: (single /Double loaded corridor)

(Fig. 11:a, b, c, d, e & f) ─ Educational Buildings: Site Combination Prototypes/Models, [Ref.[21] adapted by author.

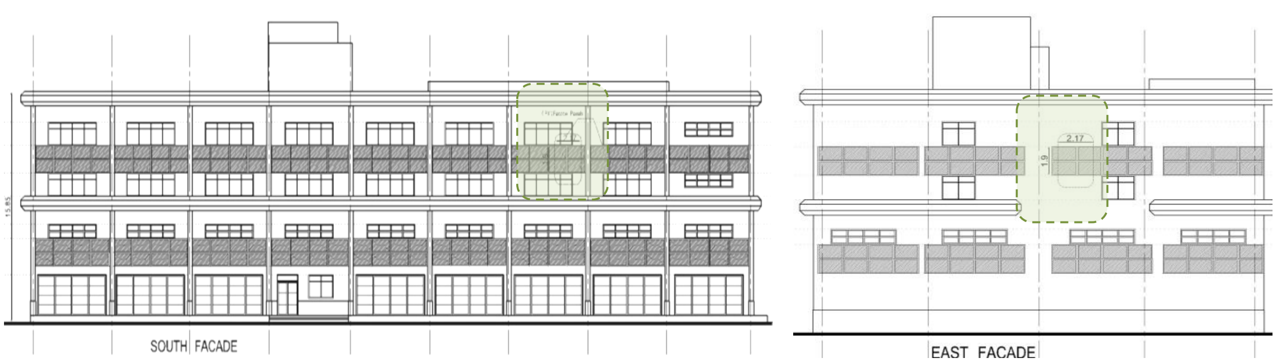
5. "CASE STUDY" AND SIMULAION MODEL(S)

According to previous studies and state-of- the-art of (BAPV & BIPV) building type's priority of application, research applies the "Case-study" on educational building for many reasons such as:-

- Standard and suitable roof area: educational plan ratio of (1 Width: 2~2.5 Length).
- Mid-rise building: (3:5 typical floors).
- Modulated facades: repeated openings and opaque walls: classes, Labs. & lecture halls.
- Standard educational building orientation: with (North/South) Long facades oriented.
- Existing service labors for continuous maintenance cleaning (PV) panels array.
- Real application of Renewable energy & spreading a (ZNE) culture among students.

(Fig. 12 (a) – "Case-Study" Building: (South Façade, Ground and 2nd. Floor plans), [Shoots &Drawings by Author]

Research selects "a case-study" of an educational building located in "Benha - faculty of engineering" campus - Benah University, Benha- Greater Cairo region-Egypt, which composes of simple standard rectangular "Linear plan" with (60.0m L x26.0m W) consists of: [a ground floor (workshops and storages) + Three upper floor levels (Lecture/Drawing halls, Laboratories, Class rooms and offices) + Flat concrete rooftop (with total height 16.0m)],(Figs.12 a, b).



(Fig. 10 (b) – "Case-Study": (PV) Panels module application on (South & East) Façades , [Drawings by Author]

5.1 Validation of (PV.SYST) by Experimental Solar (PV) Station in same site

Firstly, the research Validated simulation results of (PVSYST) simulation tool used to be reliable by compare the actual records of an existing small (PV) station lies-in another small building Rooftop suited nearby to the "Case-Study" building (Figs.13), and then get the produced energy records injected to grid (Monthly and annually), then divided by (PV) panel unit area - to get the Actual /real equivalent amount of energy produced per panel for the roof as follows:-

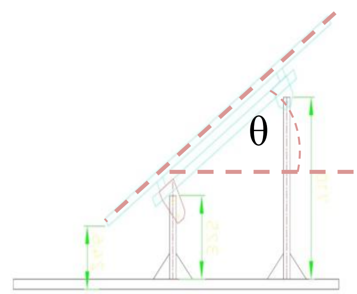
- Simulation of virtual (PV) Station on the rooftop of "Case-Study" building.
- Simulation parameters as same Real conditions such as: [PV type: "Mono-Crystalline" – Tilt Angel – Panels orientation – Building Height – Climate conditions].
- Compare the simulated Results by Actual Records to get the factor of simulation accuracy
- Precede simulations scenarios to get optimizing Matrix of (PV) applications in educational buildings.

(PV) Panels Modules on Sided/ nearby building Roof

(PV) Panels Position Consedring shading angels

"Case-Study" building Roof

(PV) Grid Inverter Readings



Panels Tilt angel (θ) controler

(Fig.13) – Site observation & (PV) Station Lab. Actual Readings Records,[All real Shoots & Records taken by Author]

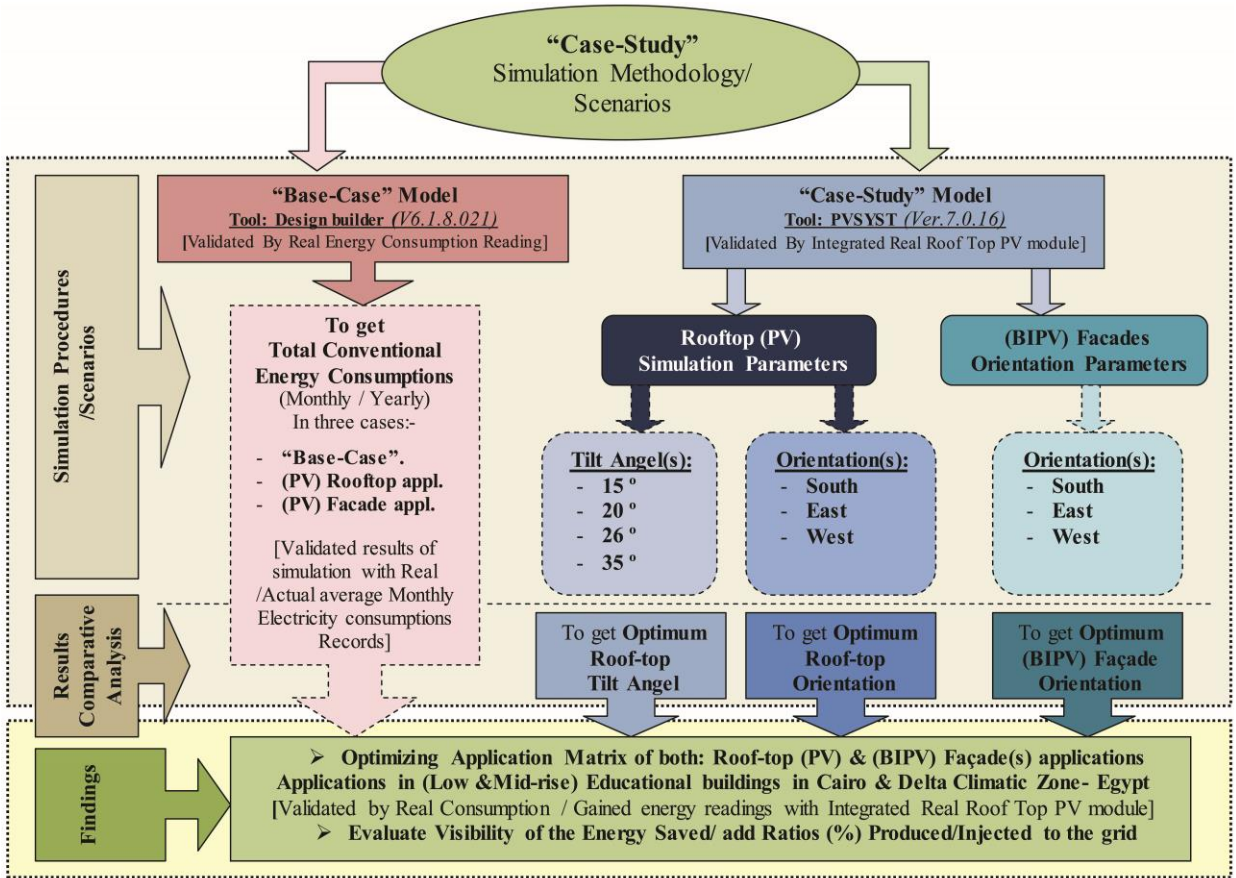
5.2 Simulation Methodology of the "Case-study"

Simulation Methodology of a "Case-study" shown in (Fig.14) depends on three major scenarios:-

- Optimizing the application of (PV) Roof-top orientation: [South – East– West].
- Optimizing the application of (PV) Roof-top Tilt angel: [15 º – 20 º – 26 º – 30º – 35º].
- Optimizing the application of (PV) Facade orientation: [South – East– West].

By these sub-sequent procedures:

- Compute the Energy Consumption of "Base-Case" building Model by "Design Builder" simulation tool and validated by real annual Energy Consumption.
- Test Validation of used simulation tool (PVSYST) by Real/Actual existing partial (PV) Roof-top modules (Comparative analysis of Monthly /Annual) Results.
- Comparative Analysis of each simulation scenario results in optimum applications.
- Optimizing Application Matrix of both: Roof-top (PV) & (BIPV) Façade(s) applications.
- Evaluate Visibility of the Energy add Ratios (%) Produced/Injected to the grid.



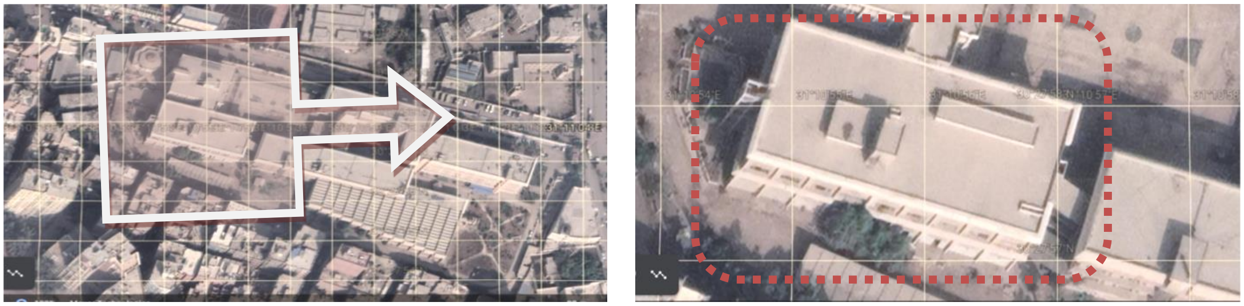
(Fig.14) – Methodology of ["Base-Case" and "Case-study]" Simulation scenarios, [Ref. Author]

5.3 Building Location & Climatic Zone [For both Simulation Tools]

The climatic zone of study location is in Benha city- Elqalyubia Governorate, Egypt which lays within Greater Cairo & Delta climatic zone with (Latitude 30.1° North and 31.4° East Longitudes, (Figs.15a, b), The climatic conditions of simulation models for both: "Base-case" model, and "Case-Study" model, will follow the Egyptian Energy Code for public buildings, 2009,as in (Table: 1) was established by parametric study of thermal and ventilation performance.

(Table:1) – Climatic Conditions for 'Cairo & Delta climate zone', [Ref., Egyptian Energy Code for Public buildings, part: I, EECB- 2009]

City	Location			Winter							Summer			
				Out-door climatic conditions					In-door climatic conditions		Out-door climatic conditions		In-door climatic conditions	
				Dry temperature design values			Moisture temperature design values							
	Longitudes (East)	Latitude (North)	Height (m.)	1%	2.5%	5%	99.6%	99%	Degree (C°)	Relative Humidity (%)	Degree (C°)	Relative Humidity (%)	Degree (C°)	Relative Humidity (%)
Benha	31.4	30.1	74.0	42.1	38	37	26	27	24	50	13.3	70	21	40



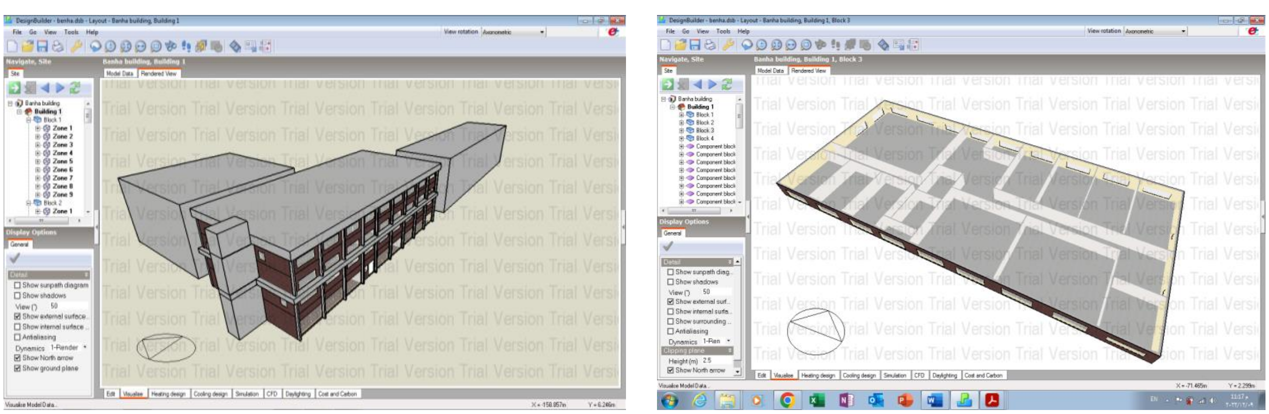
(Fig. 15a, b) – Macro site & Building Location in faculty campus, [Google Earth, adopted by Author]

5.4 Building Architectural Data [For Base-Case& "Design Builder" Simulation-V6.1.8.021]

Secondly, research simulated a whole building as a "Base-Case" study by construction of Exterior and Interior simulated model on "Design Builder-(V6.1.8.021)"software based on (Energy Plus) as a simulation engine - to get a whole building Energy Consumptions, which is considered one of most, reliable, popular and accurate simulation engine, as in (Figs.16 a, b).

(Table: 2) – "Case-Study" Educational building Data entry, [Ref. Author]

General Data		Architectural Data	
- Building Type	Isolated Educational building within Faculty of Engineering Campus / Fully finished & Occupied spaces.	**- Roof Type / Layers**	Flat Concrete roof- covered with roofing layers: [22cm R.Conc.+3 cm Water proof + 10 cm Thermal Polystyrene + 10 cm slope Conc. +10 cm tiles cover].
- Building Location	Benha- Egypt	**- Building Envelope**	Perforated Clay bricks 25 cms.
- Building orientation	Almost: North-South	**- Facades Finishes**	Colored Cement plaster 3 cms.
- Construction Date	2008	**- Space Partitions**	Perforated Clay bricks 12 cms.
- Building Dimension	59.0 L X 26.0 W X 15.0H	**- Flooring Finches**	W. Cement Tiles+ wooden panels
- Building Roof Area	1535.0 m2 ~	**- Inner Wall Finches**	Acrylic Paints + Ceramic tiles
- Ventilation System	Hybrid Ventilation (Natural + Split AC) On demand - "Base-Case" model: Artificial Mechanical ventilation (HVAC) system with set point (24 °C).	**- Building Functions**	Ground: workshops- storages First: Drawing halls+ Double heights of workshops. Second: Lecture/Drawing Hall + Classes+ offices Third: Labs/Drawing Hall + Classes+ offices
- Lighting System	Natural day lights/Lambs	**- Clear Floor Height**	3.40 m



(Fig. 16) -"Design builder" Simulation Model - (a) Exterior model, (b) 2.nd. Floor Tested Zones model, [Ref., Author].

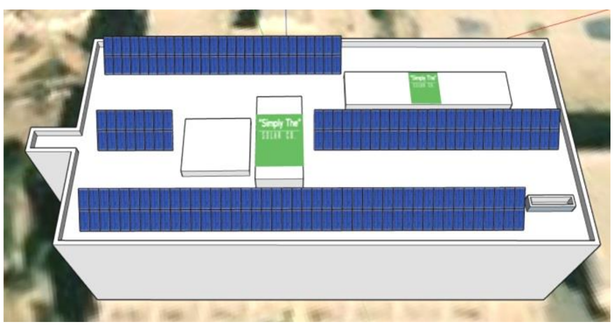
5.5 (PV) Simulation Parameters [For "PV.SYST"-Ver.7.0.16 Simulation Tool]

Thirdly, research preceded a simulation Model by "PVSYST-Ver.7.0.16" as a "Case-study" for building (PV) application for both: building Rooftop and Facades, as shown in (Table: 3).

(Table: 3) – Data & Parameters of (PV) application on "PVSYST", [Ref. Author]

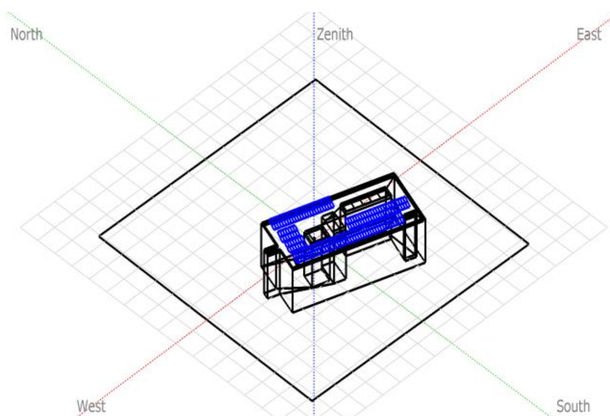
Parameters	Type (Variables)
- **Simulation Parameters**	Tables on a building Rooftop & Facades
- **Collector Plane Orientation(s)**	South, East, West
- **Tilt Angel(s)**	[15 º,20 º ,26 º ,30º ,35º] - Azimuth 18 º
- **No. of Panels**	210 (Roof) – (210 South façade – 105 East and West facades)
- **Array Operating Characteristics (50c)**	523 V – Impp 200A
- **Total module Area**	542 m2 – Cell area 499.0 m2
- **PV Array**	Si-Mono (JKM545M-72HL4-V)
- **Number of PV modules**	14 modules – In parallel 15 strings
- **Total Number of PV modules**	210 – Unit Nom. Power 545 Wp
- **Array Global Power**	114 kWp – At operating Cond.105kWp
- **Inverter Model**	SUN2000-100KTL-M1-400Vac – 100KW ac

Simulation sequence followed simulation Scenario as in (Figs.17a, b, c, d) and (PV) application parameters as shown in (Table 3) for both: building Rooftop and Façades, to get the produced energy (Monthly/yearly) in each run which can be injected directly to the grid, then classify the final results for each parameter and place of application (Rooftop – Facades) to be analyzed.

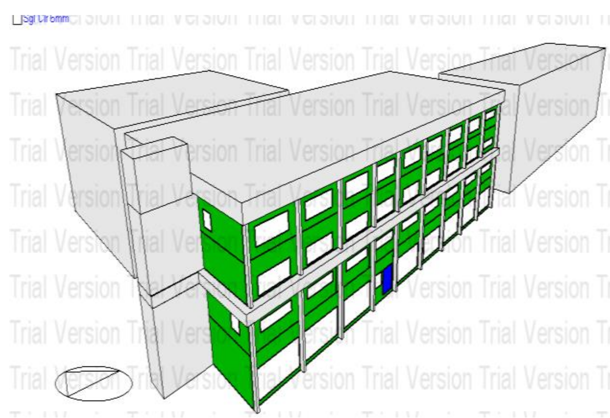


(a)- (PV) Rooftop, South orientation , (30 º) Tilt angel

(b)- (PV) Rooftop, East orientation , (26 º) Tilt angel



(c)- (PV.SYST) Rooftop, Model implementation in-site



(d)- (PV) Application on Facades:(South, East &West)

(Fig. 17 a, b, c & d)- Samples of (PV.SYST) Simulation Models Outputs according to parameters, [Ref., Author].

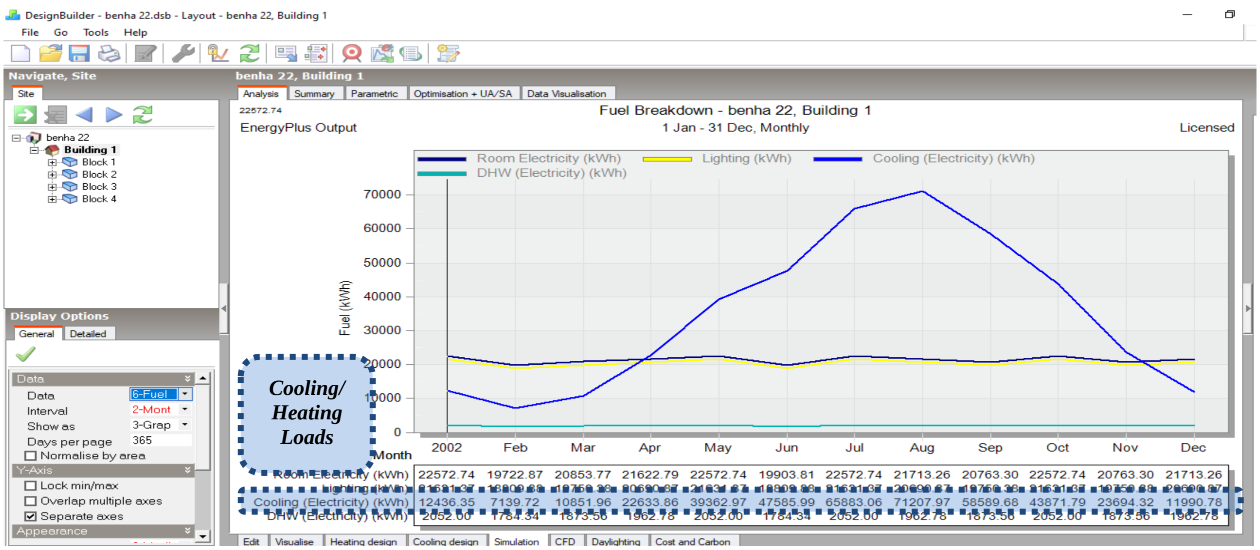
6. SIMULAION RESULTS ANALYSIS

According to simulation scenario research gets the following results from the two simulated models: “Base-Case” model by “Design Builder” and “Case-Study” model by “PVSYST”.

6.1 Results of “Base-Case”: Building Energy Consumptions [Using “Design Builder”]

By the aid of “Design Builder”, research proceeded three simulation scenarios to get the Total (Energy /Electricity) Consumptions (Monthly/Yearly) of the” Case-study” educational building for (Lighting –Cooling/Heating–Appliances/Machines used -…) (Fig.18), compared as follows:-

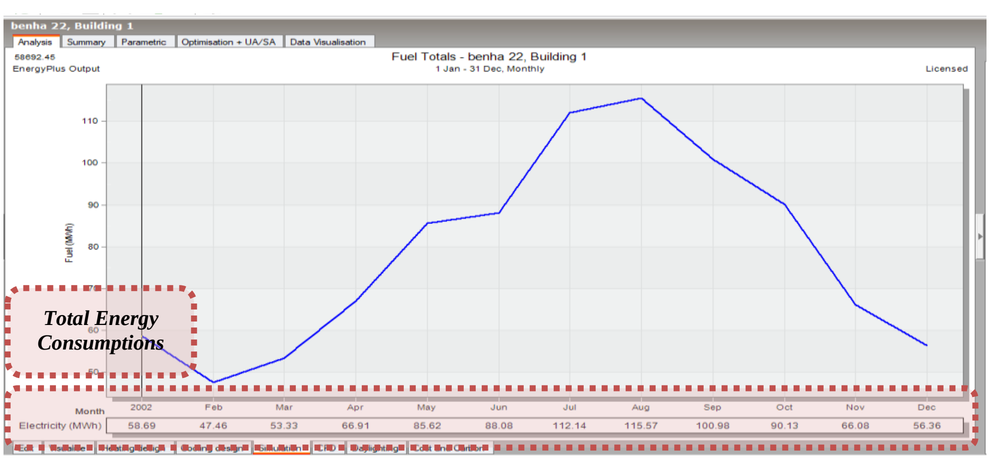
- As a “Base-Case” Conventional use (with-out any of (PV) applications).
- With (PV) Rooftop application (to get Roof shading impact).
- With (PV) South façade application (to get solid façade insulation impact).



(Fig. 18) - Building Total Energy Consumptions “Base-Case”, [Ref., “Design Builder”& adapted by Author].

6.1.1 With respect to “Base-Case” [with-out any of (PV) Applications]

According to “Design Builder” simulation results; the total amount of energy consumptions by building spaces in conventional use as a “Base-Case” was (910.97 MWh/Year), and distributed along year months as shown in (Fig. 19), that with-out any of (PV) applications.



(Fig. 19) – Building Monthly/Annual total Energy /Electricity Consumptions “Base-Case”,

[Ref., “Design Builder” results output & adapted by Author].

6.1.2 With respect to (PV) "Rooftop" application [(PV) Shading impact on "Roof top"]

According to "Design Builder"; the total amount of Energy consumptions with (PV) "Rooftop" application decreased to be (779.15 MWh/Year), which reduced to be about (85.0%) of total annual Electricity consumption of "Base Case" [without calculations of any additional energy produced/Injected from (PV) panels yet].

This Electrical Energy Reduction (133.79 MWh/Year) gained from both: Shading of (PV) tilted panels on "Rooftop" and raising "Time Lag" impact of upper space Heating in night times, which reduced the annual electrical (Cooling/Heating loads), as illustrated in (table:4).

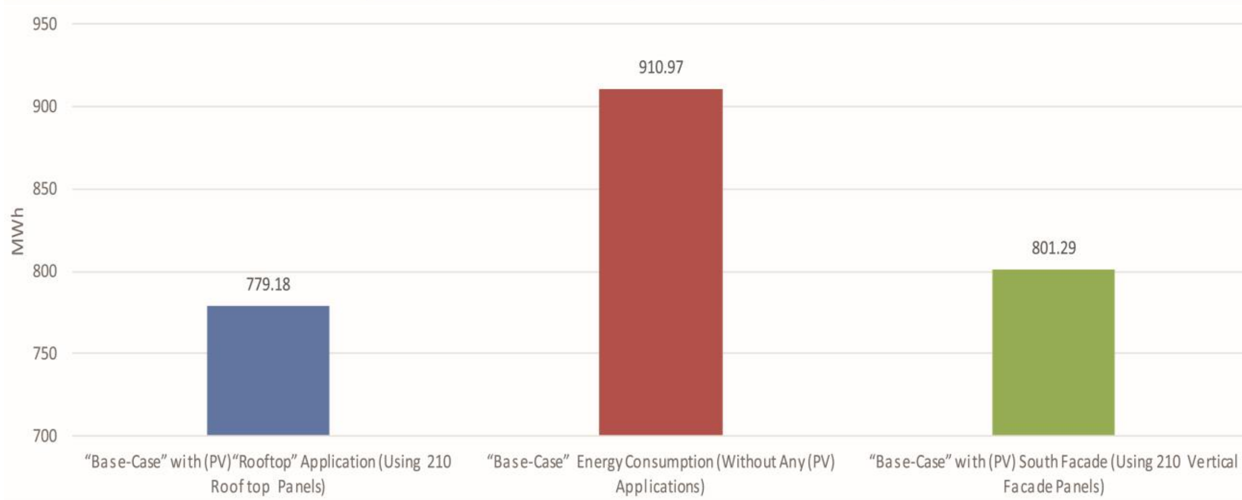
6.1.3 With respect to (PV) South Façade application [(PV) Insulation impact of "Facade"]

According to "Design Builder"; the total amount of Energy consumptions with (PV) South Façade application decreased to be (801.29 MWh/Year), which reduced to be about (88 %) of total annual Electricity consumption of "Base Case" [without calculations of any additional energy produced/Injected from (PV) panels yet].

This Electrical Energy Reduction (109.68 MWh/Year) gained from of thermal insulation impact of (PV) vertical panels' application on South Façade, which reduced the annual Electrical (Cooling/Heating loads), as shown in (Fig.20).

(Table:4) - Records of Building Energy Consumptions ["Base-Case"- (PV) "Rooftop"/ South Facade Applications]
(With-out calculations of any additional Energy produced / Injected from (PV) panels)
[Ref., Adapted by Author, "Design Builder" Records].

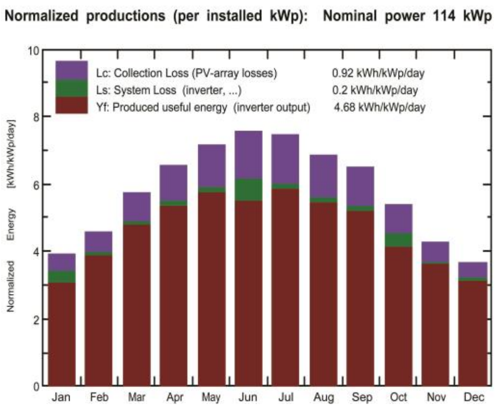
Energy Consumption Monthly(MWh) / (PV) Application Scenarios	January	February	March	April	May	June	July	August	September	October	November	December	Total Energy Consumption Yearly (MWh)
"Base-Case" Energy Consumption	58.69	47.46	53.33	66.91	85.33	88.08	112.1	115.6	100.9	90.13	66.08	56.36	**910.97**
"Base-Case" with (PV)"Rooftop" Appl. [Roof Shading Impact]	55.58	45.82	49.85	57.18	67.61	67.15	84.75	86.4	75.65	70.83	56.11	53.25	**779.18**
"Base-Case" with (PV) South Facade Appl.[Façade Insulation Impact]	56.82	46.06	50.62	59.89	72.73	71.43	88.38	89.26	77.89	73.46	60.55	54.2	**801.29**



(Fig. 20) Impact of (PV) "Rooftop" Shading and (PV)South Façade Insulation with respect to "Base-Case" On Building total annual Energy Consumptions - [Ref., Author].

6.2 Results of "Case-Study" (PV) Rooftop applications [Using PVSYST]

According to "PVSYST" simulation results; the total annual amount of Energy generated/produced from (PV) array panels applied on: "Rooftop" and Facades represented and distributed along year months by (Mwh/Year), data entry parameters, and (PV) shading graphs and calculations, as shown in (Figs. 21 a, b, c & d).



(a)- (PV) Normalized Production Graph

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	97.6	42.22	14.09	120.9	113.0	12.27	11.06	0.799
February	110.6	55.54	15.15	128.1	120.2	12.88	12.62	0.861
March	161.5	73.04	18.48	178.2	167.6	17.51	17.12	0.840
April	187.9	83.65	21.48	196.2	184.5	18.92	18.48	0.823
May	221.8	87.03	25.37	222.1	209.0	21.01	20.50	0.806
June	231.0	75.87	27.97	226.0	212.7	21.17	18.91	0.731
July	232.9	74.83	29.81	230.3	216.7	21.45	20.92	0.794
August	207.0	80.28	29.61	212.5	199.9	19.92	19.44	0.799
September	179.2	62.56	27.34	194.5	183.0	18.46	18.01	0.809
October	144.4	59.12	24.34	166.7	156.6	16.18	14.82	0.777
November	104.8	40.42	19.56	128.4	120.5	12.77	12.50	0.850
December	90.1	38.92	15.81	113.4	106.0	11.48	11.25	0.867
Year	1968.7	773.50	22.46	2117.3	1989.6	204.02	195.64	0.807

Legends: GlobHor Global horizontal irradiation; DiffHor Horizontal diffuse irradiation; T_Amb T amb.; GlobInc Global incident in coll. plane; GlobEff Effective Global, corr. for IAM and shadings; EArray Effective energy at the output of the array; E_Grid Energy injected into grid; PR Performance Ratio

(b)- (PV) Rooftop Monthly Detailed Energy Production table

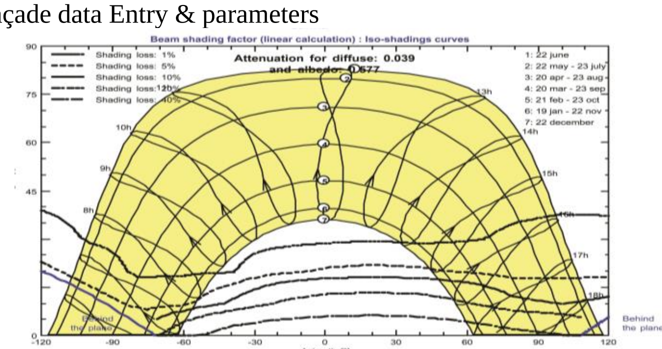
By classify results of (PV) Roof-top applications/runs with Tilt angels: [15 º – 20 º – 26 º – 30º – 35º] respectively with the same number of (PV) array panels 210; (maximum proper number for the same building roof).
The same done with applications/runs of (PV) Facade orientation: [South – East– West].
South façade with number of 210 (PV) array panels (same number of roof panels), but 105 (PV) array panels for each of East and West facades due to their smaller area.

Grid-Connected System: Main results

Project :	**banha**			
Simulation variant :	**New simulation variant**			
	Simulation for year no: 1			
Main system parameters	System type	**Tables on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	15°	azimuth	18°
PV modules	Model	JKM545M-72HL4-V	Pnom	545 Wp
PV Array	Nb. of modules	210	Pnom total	**114 kWp**
Inverter	Model	SUN2000-100KTL-M1-400Vac		100 kW ac
User's needs	Unlimited load (grid)			
Main simulation results				
System Production	**Produced Energy**	**195.6 MWh/year**	Specific prod.	1709 kWh/kWp/year
	Performance Ratio PR	80.73 %		

(c)- (PV) Rooftop / Façade data Entry & parameters

The shading effect due to (PV) panels' array applications on both (Roof and facades), calculated as additional shading devices, are calculated along year by "PVSYST" to get the most suitable Roof-top tilt angel, that avoiding shading of panels arrays on each other's, with respect to building orientation and site data.



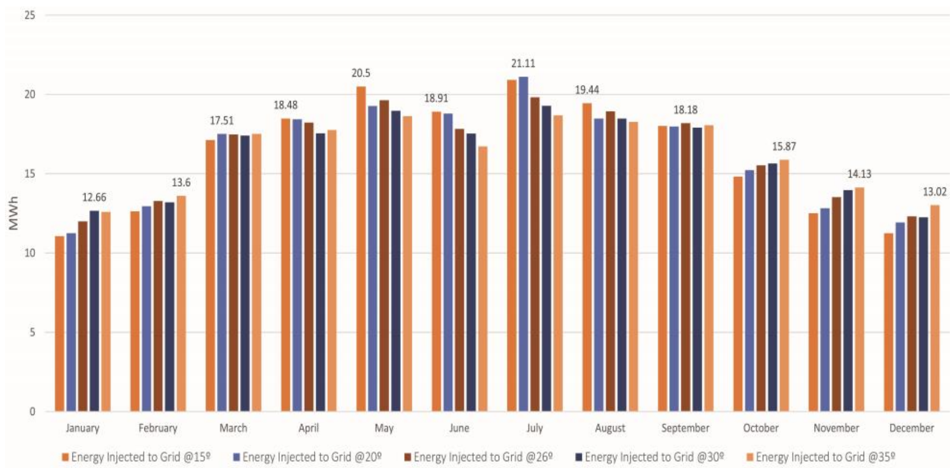
(d)- (PV) Rooftop "Iso-Shading" Diagram

(Figs. 21 a, b, c & d) - Samples of (PVSYST) Simulation Model Results according to parameters, [Ref., Author].

6.2.1 With respect to (PV) “Rooftop” Tilt Angel

According to “PVSYST” simulation results; the total amount of Energy generated/produced from (PV) array panels applied on Rooftop represented and distributed along year months by (Mwh/Year), as shown in (Figs. 22 a, b & c).

Roof top (Tilt Angels) / Energy Produced Monthly(MWh)		January	February	March	April	May	June	July	August	September	October	November	December	Total Produced Energy Yearly (MWh)
15°	Energy Produced from Array	12.27	12.88	17.51	18.92	21.01	21.17	21.45	19.92	18.46	16.18	12.77	11.48	**204.02**
	Energy Injected to Grid	11.06	12.62	17.12	18.48	20.50	18.91	20.92	19.44	18.01	14.82	12.50	11.25	**195.64**
	Energy Loses via Converter/Syst.	1.21	0.26	0.39	0.44	0.51	2.26	0.53	0.48	0.45	1.36	0.27	0.23	**8.38**
20°	Energy Produced from Array	12.68	13.15	17.72	18.94	19.86	20.43	21.65	19.33	18.34	16.32	13.18	12.27	**204.50**
	Energy Injected to Grid	11.25	12.95	17.51	18.43	19.26	18.79	21.11	18.47	17.98	15.22	12.82	11.92	**195.71**
	Energy Loses via Converter/Syst.	1.43	0.2	0.21	0.51	0.6	1.64	0.54	0.86	0.36	1.1	0.36	0.35	**8.79**
26°	Energy Produced from Array	13.32	13.55	17.88	18.65	20.10	19.93	20.32	19.40	18.64	16.96	13.82	12.58	**205.14**
	Energy Injected to Grid	11.99	13.27	17.48	18.22	19.62	17.82	19.81	18.93	18.18	15.53	13.51	12.31	**196.67**
	Energy Loses via Converter/Syst.	1.33	0.28	0.4	0.42	0.48	2.11	0.51	0.47	0.46	1.43	0.31	0.27	**8.47**
30°	Energy Produced from Array	13.40	13.31	17.79	18.26	19.35	19.81	19.97	19.07	18.42	17.13	14.21	12.74	**203.46**
	Energy Injected to Grid	12.66	13.19	17.41	17.55	18.96	17.53	19.28	18.48	17.91	15.64	13.97	12.25	**194.83**
	Energy Loses via Converter/Syst.	0.74	0.12	0.38	0.71	0.39	2.28	0.69	0.59	0.51	1.49	0.24	0.49	**8.63**
35°	Energy Produced from Array	14.01	13.89	17.91	18.17	19.09	18.66	19.14	18.72	18.51	17.33	14.46	13.31	**203.20**
	Energy Injected to Grid	12.59	13.60	17.51	17.75	18.63	16.71	18.67	18.27	18.06	15.87	14.13	13.02	**194.92**
	Energy Loses via Converter/Syst.	1.42	0.29	0.4	0.42	0.46	1.95	0.47	0.45	0.45	1.46	0.33	0.29	**8.28**
Actual Records Injected to Grid from Existed Real (PV) Rooftop Station in Sided building@ 22° *(to be Validated and after multiply by area Coefficient)*		11.13	12.24	18.03	17.62	18.57	17.83	19.93	18.04	17.58	15.57	11.82	10.47	**188.22**

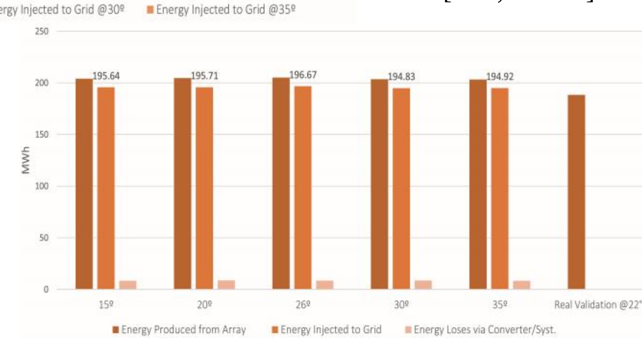


(a) - UP
Energy Data according to different Tilt Angels.

(b) - Left
Energy Generated-Distribution according to Monthly Production.

(Fig. 22 a, b & c) - (PVSYST) Simulation Results Analysis for Rooftop Tilt Angels, [Ref., Author].

- Descending, the most profit / produced (Energy Injected to Grid) annually was obtained from tilt angels respectively: [º 26, º 20, º15, º30 and º35] for the same (PV) array panels modules.
- The most profit (Energy Injected to Grid) annually obtained from rooftop tilt angels ranges between [º15: º32] in the same region/site climatic conditions.



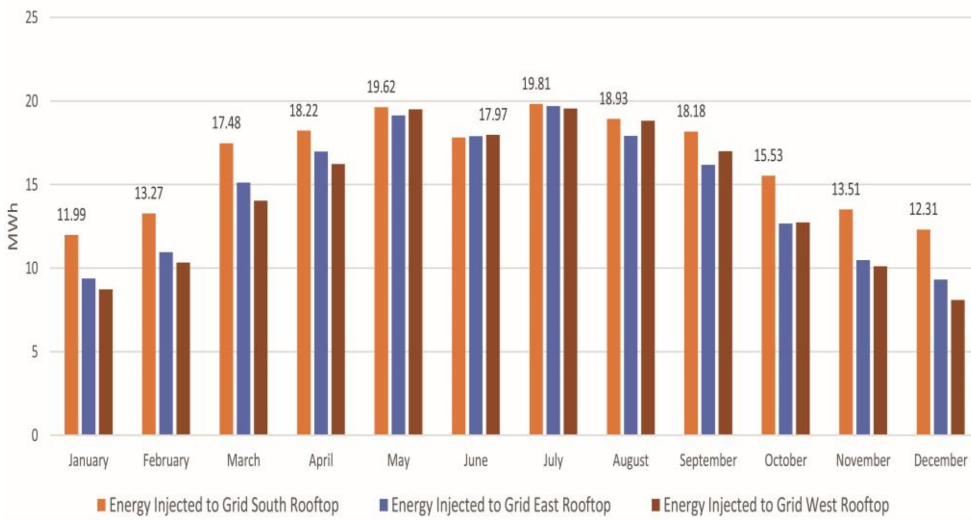
(c)- Energy produced according to different Rooftop Tilt Angels

- The Maximum total annually produced (Energy Injected to Grid) was (197.70 MWh) obtained/ produced from rooftop (PV) array with (º 26) tilt angel south oriented.
- The Maximum annual reduction of total building Energy consumption was (22 %); due to (PV) rooftop application with (º 26) tilt angel as Energy Injected to Grid.

6.2.2 With respect to (PV) "Rooftop" Array panels Orientation

According to "PVSYST" simulation results; the total amount of energy generated/produced from (PV) array panels applied on Rooftop by different panels orientations represented and distributed along year months by (MWh/Year), as shown in (Figs. 23 a, b & c).

Roof top Array Orientation (At Optimum Tilt Angel 26 °)	Energy Produced Monthly(MWh)	January	February	March	April	May	June	July	August	September	October	November	December	Total Produced Energy Yearly (MWh)
South	Energy Produced from Array	13.32	13.55	17.88	18.65	20.10	19.93	20.32	19.40	18.64	16.96	13.82	12.58	**205.14**
	Energy Injected to Grid	11.99	13.27	17.48	18.22	19.62	17.82	19.81	18.93	18.18	15.53	13.51	12.31	**196.67**
	Energy Loses via Converter/Syst.	1.33	0.28	0,4	0.43	0.48	2.11	0.51	0.47	0.46	1.43	0.31	0.27	**8.47**
East	Energy Produced from Array	10.32	11.19	15.46	17.36	19.63	20.15	20.21	18.35	16.58	13.89	10.73	9.51	**183.37**
	Energy Injected to Grid	9.38	10.96	15.12	16.97	19.15	17.89	19.70	17.91	16.19	12.68	10.49	9.32	**175.76**
	Energy Loses via Converter/Syst.	0.94	0.23	0.34	0.39	0.48	2.26	0.51	0.44	0.39	1.21	0.24	0.19	**7.61**
West	Energy Produced from Array	9.58	10.76	14.34	16.75	19.76	20.08	20.12	19.33	17.37	14.07	10.38	9.32	**181.86**
	Energy Injected to Grid	8.73	10.34	14.02	16.23	19.49	17.97	19.54	18.83	16.98	12.74	10.11	8.09	**173.07**
	Energy Loses via Converter/Syst.	0.85	0.42	0.32	0.52	0.27	2.11	0.58	0,5	0.42	1.36	0.27	1.23	**8.79**

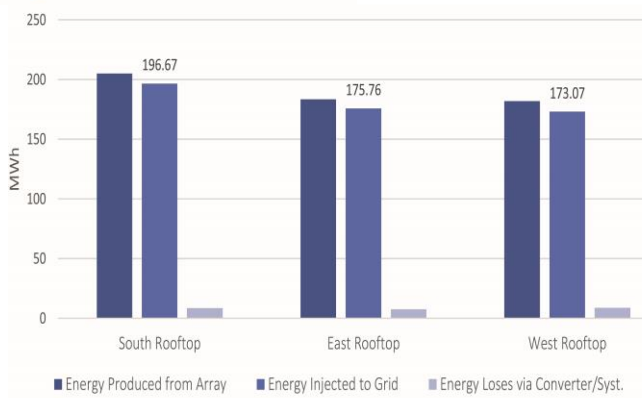


(a)- UP
Energy Data according to different Rooftop Panels Orientations

(b)- Left
Energy Generated-Distribution according to Monthly Production.

(Fig. 23 a, b & c)- (PVSYST) Simulation Results Analysis for Rooftop Orientations [Ref., Author].

- Descending, the most profit/produced (Energy Injected to Grid) annually was obtained from rooftop orientation respectively: [South, East, West, South east, then South west], North orientation neglected due to no direct irradiance, for the same (PV) array panels modules.
- The most profit/produced (Energy Injected to Grid) annually obtained from (PV) rooftop South orientation for the same region /site climatic conditions.



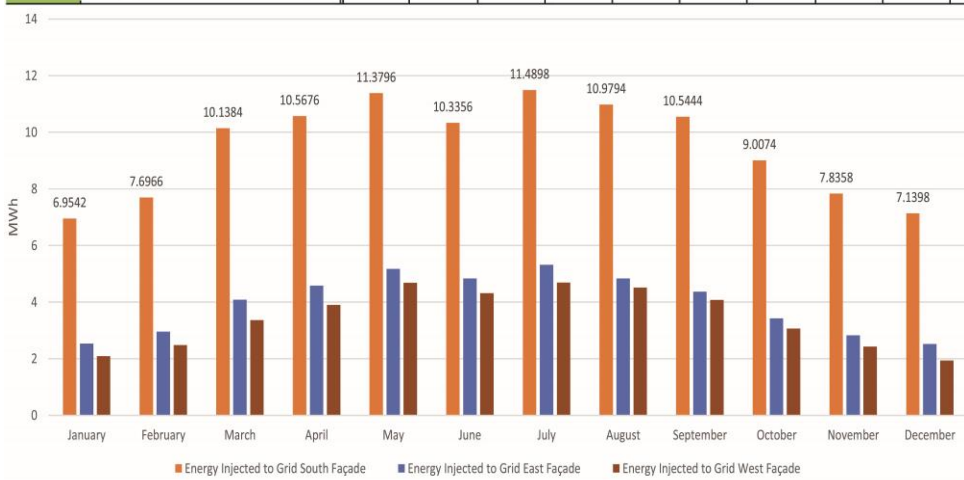
(c)- Energy produced according to different Panels Orientations

- The Maximum total annually produced (Energy Injected to Grid) was (196.70 MWh) obtained/ produced from (PV) rooftop south oriented at tilt angel of (° 26).
- The Maximum annual reduction of total building Energy consumption was (22%); due to (PV) rooftop south oriented at tilt angel of (° 26) as Energy Injected to Grid.

6.3 Results of “Case-Study” (PV) Façade applications

According to “PVSYST” simulation results; the total amount of energy generated/produced from (PV) array panels applied on building facades by different orientations represented and distributed along year months by (Mwh/Year), as shown in (Figs. 24 a, b & c).

Facade (PV) Array Orientation (At Tilt Angel 26 º)	Energy Produced Monthly(MWh)	January	February	March	April	May	June	July	August	September	October	November	December	Total Produced Energy Yearly (MWh
South (210 panels)	Energy Produced from Array	7.73	7.86	10.37	10.82	11.66	11.56	11.79	11.25	10.81	9.83	8.02	7.31	**119.00**
	Energy Injected to Grid	6.95	7.70	10.14	10.57	11.38	10.34	11.49	10.98	10.54	9.00	7.84	7.14	**114.07**
	Energy Loses via Converter/Syst.	0.77	0.16	0.23	0.25	0.28	1.22	0.30	0.27	0.267	0.83	0.18	0.16	**4.91**
East (105 panels)	Energy Produced from Array	2.77	3.02	4.17	4.69	5.30	5.44	5.46	4.95	4.48	3.7503	2.90	2.57	**49.51**
	Energy Injected to Grid	2.53	2.96	4.08	4.59	5.17	4.83	5.32	4.86	4.37	3.42	2.83	2.52	**47.46**
	Energy Loses via Converter/Syst.	0.25	0.06	0.09	0.10	0.13	0.61	0.138	0.19	0.10	0.33	0.06	0.06	**2.06**
West (105 panels)	Energy Produced from Array	2.30	2.58	3.44	4.02	4.74	4.82	4.83	4.64	4.19	3.38	2.4912	2.2368	**43.65**
	Energy Injected to Grid	2.10	2.48	3.36	3.90	4.68	4.31	4.69	4.52	4.08	3.06	2.43	1.94	**41.54**
	Energy Loses via Converter/Syst.	0.20	0.10	0.07	0.12	0.06	0.51	0.14	0.12	0.09	0.32	0.065	0.30	**2.12**

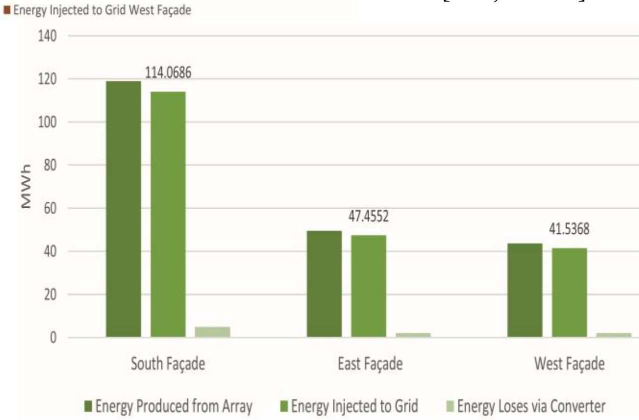


(a)- UP
Energy Data according to (PV) Facades Orientations

(b)- Left
Energy Generated-Distribution according to Monthly Production.

(Fig. 24 a, b & c)- (PVSYST) Simulation Results for (PV) Facades Orientations [Ref., Author].

- Descending, the most profit/produced (Energy Injected to Grid) annually was obtained from (PV) Facade orientation respectively: [South, East, then West], North Facade orientation neglected due to no-direct irradiance, for the same (PV) array panels modules.
- The most profit/produced (Energy Injected to Grid) annually obtained from (PV) South facade orientation for the same region/site climatic conditions.



(c)- Energy according to different (PV) Facades Orientations

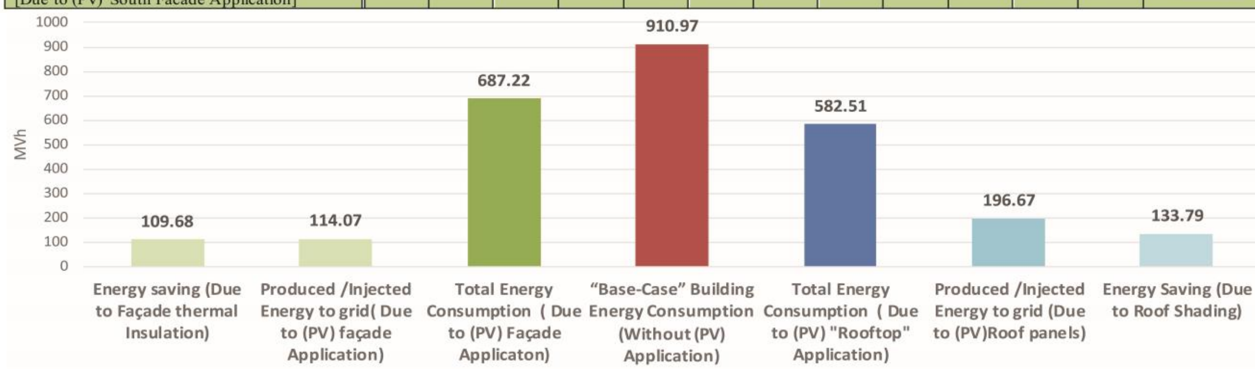
- The Maximum total annually produced (Energy Injected to Grid) was (114.00 MWh) obtained/ produced from (PV) Application on opaque areas on South Façade orientation.
- The Maximum annual reduction of total building Energy consumption was (13 %); due to (PV) Application on opaque areas on South Façade orientation as Energy Injected to Grid.

7. FINDINGS AND CONCLUSION

By analysing and classifying simulation results/records, as shown in (Table: 4), and comparing with validated records from real existing "Rooftop" (PV) array panels (existing in nearby another building); research can conclude the next findings and conclusion, as in (Fig.25), [with respect to greater Cairo and Delta climatic zone, and low and mid-rise buildings with a proper/Standard educational building flat roof sample].

(Table: 4) - Comparative Analysis records of Building Total Energy Consumptions "Base-Case"+ (PV) Applications, [Ref., Simulation Results and validated Real Records - adapted by Author].

Energy Consumption Monthly(MWh) / (PV) Application Scenarios	January	February	March	April	May	June	July	August	September	October	November	December	Total Energy Consumption Yearly (MWh)
"Base-Case" Building Energy Consumption	58.69	47.46	53.33	66.91	85.33	88.08	112.1	115.6	100.9	90.13	66.08	56.36	**910.97**
"Base-Case" With (PV) "Rooftop" Appl. [Roof Shading Impact]	55.58	45.82	49.85	57.18	67.61	67.15	84.75	86.4	75.65	70.83	56.11	53.25	**779.18**
Produced /Injected Energy to grid [Due to (PV) "Rooftop" Application (210 panels)]	11.99	13.27	17.48	18.22	19.62	17.82	19.81	18.93	18.18	15.53	13.51	12.31	**196.67**
Total Energy Consumption [Due to (PV) "Rooftop" Application]	43.59	32.55	32.37	38.96	47.99	49.33	64.94	67.47	57.47	55.30	42.6	40.94	**582.51**
"Base-Case" With (PV) South Facade Appl. [Façade Insulation Impact]	56.82	46.06	50.62	59.89	72.73	71.43	88.38	89.26	77.89	73.46	60.55	54.2	**801.29**
Produced /Injected Energy to grid [Due to (PV) South Facade Application (210 panels)]	6.95	7.70	10.14	10.57	11.38	10.34	11.49	10.98	10.54	9.00	7.84	7.14	**114.07**
Total Energy Consumption [Due to (PV) South Facade Application]	49.87	38.36	40.48	49.32	61.35	61.09	76.89	78.28	67.35	64.46	52.71	47.06	**687.22**



(Fig. 25) - (Design Builder& PVSYST) Simulation Results & Validated Records for (PV) applications on "Base-Case" [Ref., Author].

7.1 General Findings

- Application of (PV) tilted Panels on building "Rooftop" is more Benefit/Visible than application of (PV) on Façades; with total Active/Passive reduction ratio about (37 %), and (25%) respectively of total "Base-Case" (Standard mid-rise Educational building), for the same number of array panels, same orientation and a proper flat roof area.
- Direct Active impact of (PV) application: on building "Rooftop" can reduce the total annual building Energy consumption by (22%) of "Base-Case", by direct Electric Energy Produced/ Injected to grid. Otherwise, this reduction was (13%) due to south Façade (PV) application (With the same number of (PV) array panels used).
- Indirect Passive impact of (PV) application: on building "Rooftop" can reduce the total annual building Energy consumption by (15%) of "Base-Case", due to (PV) tilted panels Shading, and "Time Lag" effects on Roof. Otherwise, this reduction was (12%) due to South Façade (PV) application, due to (PV) Extra Thermal insulation (With same number of panels used).

- For (PV) array applications on both (Rooftop and Facades); South orientation is the most benefit/production of energy generated, then [East, Southeast, southwest, and West] orientations respectively.
- The difference /Looses of Energy between East and West array panels' orientation; due to the evolving heat of the system and panels surface in the second half of daytime.
- Application of (PV) Tilted panels on building flat "Rooftop" is more practical in application than (BAPV) and (BIPV) on façades; because of: [More safe – Cleanable – Easier in running maintenance & Service – More Energy productive for the same array panels area – More economic in operation].

7.2 Focused Findings

A. As for (BAPV) "Rooftop" applications

- (PV) "Rooftop" application reduces total annual building Energy consumption by about (36.5 %) of "Base-Case" due to both: Roof shading and Energy produced/injected to grid.
- The maximum Energy produced/Injected to grid obtained at (º26) South orientation.
- The proper/suitable (PV) "Rooftop" Tilt angels ranges between (º15: º30) oriented south with total variation (+/– 1.5 % of total annual Energy production).
- Summer months (July, May, August, April, June, and September) respectively descending, are the most of energy produced/Injected to grid, than Winter months (January, December, February, November, October, and March) respectively ascending with average ratio (34%) as shown and concluded in (table:5).

(Table:5)-(PV) Rooftop Tilt angels, Difference Ratio of Summer/Winter months Energy produced/Injected, [Ref. Author]

Energy(MWh) / **Tilt Angels**	**Energy Produced/Injected to Grid** (MWh)		**Difference Ratio (%)**
	Summer Months	Winter Months	
º15	116.26	79.38	46.4
º20	114.04	81.67	39.6
º26	112.58	84.10	33.8
º30	109.70	85.12	28.7
º35	108.20	86.72	24.5

- The optimum (PV) Rooftop array panels' orientation is South, which more than East by (12%), then West by (14%) of total annual Energy produced/Injected to grid.
- Summer months (July, May, August, June, April, and September) respectively descending, are the most of Energy produced/Injected to grid, then Winter months (January, December, February, November, October, and March) respectively ascending with average ratio (54.21 %) as shown and concluded in (table:6).

(Table:6)- (PV) "Rooftop" Orientation, Difference Ratio of Summer/Winter months Energy produced/Injected, [Ref. Author]

Energy(MWh) / **Orientation**	**Energy Produced/Injected to Grid** (MWh)		**Difference Ratio (%)**
	Summer Months	Winter Months	
South	112.58	84.10	33.8
East	107.81	67.95	59.2
West	109.04	64.03	70.2

B. As for (BAPV) and (BIPV) Facades applications:

- (PV) South Façade application reduces the annual building Energy consumption by about (12 %) of "Base-Case" due to South façade panels as thermal insulation impact only.
- (PV) Façade application reduces the total annual building Energy consumption by about (25 %) of "Base-Case" due to both: Façade insulation impact and Energy produced/injected to grid.
- The annual optimum application of Façade (BAPV) and (BIPV) orientation is on South façade; which more than East by (20%), then West by (35.7%) of Energy produced/Injected to grid.
- Summer months (July, May, August, June, April, and September) respectively descending, are the most of energy produced/Injected to grid, then Winter months (January, December, February, November, October, and March) respectively ascending with average ratio (55.72 %) as shown and concluded in (table:7).

(Table: 7) - (BAPV/BIPV) Facades, Difference Ratio of Summer/Winter months Energy produced/Injected
[Ref. Author]

Energy(MWh) / **Orientation**	**Energy Produced/Injected to Grid** (MWh)		**Difference Ratio (%)**
	Summer Months	Winter Months	
South	67.23	46.77	43.7
East	57.92	37.68	53.3
West	54.34	28.74	70.2

7.3 General Conclusion

- By optimizing the application of (PV) Panels on educational building as: (BAPV) or (BIPV) we can save more than (37 %) of conventional annual building Energy consumptions with (PV) application on "Rooftop" only; while this ratio can reach (25%) by (PV) South Façade application-[for same number of (PV) array panels used].
- By optimizing the whole application of (PV) Panels on educational building as: (BAPV) or (BIPV) on "Rooftop" and the three visible Façades (South, East, and West respectively) we can save more than (81%) of "Base-Case" Energy consumptions, as illustrated in (Table:8), which can be reached to be a Zero Net energy Building (ZNB).

(Table: 8)-Optimizing Whole (BAPV/BIPV) Application: Energy produced/Saved Vs. "Base-Case" Energy Consumptions
[Ref. Author]

" Base-Case" Energy consumptions (MWh)	**(PV) Rooftop** *(210 Panels)*		**(PV) Façade**						**Total Energy Produced/ Saved**
			South *(210 Panels)*		**East** *(105 Panels)*		**West** *(105 Panels)*		
	Energy Produced /Injected	Energy Saved by Roof Shading	Energy Produced /Injected	Energy Saved by Insulation	Energy Produced /Injected	Energy Saved by Insulation	Energy Produced /Injected	Energy Saved by Insulation	
910.97	**196.67**	**133.79**	**114.07**	**109.00**	**47.46**	**42.37**	**41.54**	**38.15**	**723.0**
Saving Ratio	**37 %**		**25 %**		**10 %**		**9 %**		**81%**
	37 %		**44**						

8. RECOMMENDATIONS

As mentioned in literature review, the awareness by the triad of Sustainability of: [Economic – Environmental and Social] importance of shifting to renewable energies, because of: (rapid evolving of electricity prices, environmental and future impact of enhancing the built-environment – Spreading the culture of clean energy through different students ages), research states the next recommendations.

8.1 General Recommendations

- Educational buildings [According to its large and Extended Roof areas, and limited rise (Low &Mid-rise)] consider the second prior building types (after industrial ones) to be focused on renewable energies applications, especially with evolving (PV) applications.
- Government should provide urgent laws, legalizations for educational buildings codes for both: (Existing and new) to organize the application of (BAPV) or (BIPV) within maximum next (3:5) years.
- Ministries of education and higher education should embedded/dragged the applications of renewable energy strategies / techniques within (Quality Accreditation Parameters); to induce educational establishments spreading the renewable energies and (PV) applications within educational community.
- Government should offer more incentives: (Material, Rewards and Moral) to educational establishments that applies renewable energies strategies.

8.2 (PV) Developers and Users Recommendations

- For low and mid-rise public buildings (PV) Rooftop considers a top priority to (BAPV) and (BIPV) applications, then facades.
- The optimum (BAPV) or (BIPV) application on Rooftop is with Tilt angel at (26º) South orientation.
- The proper/suitable (PV) Rooftop Tilt angels ranges between (º15: º30) oriented south with total variation (+/– 1.5 % of total annual energy production/injected to grid).
- Descending, For (BAPV) or (BIPV) application on both: (Rooftop and Facades); South orientation is the most benefit/production of energy generated, then [East, South east, South west, and West] orientations respectively.

8.3 (BAPV) and (BIPV) Future Researches

- In Tall and high-rise building; Facades (BAPV) and (BIPV) consider the prior to application than Rooftop (small roof area in comparative with façade areas), then more researches should be developed on economics of (PV) flexible façade modules.
- (BAPV) / (BIPV) developers and research centers should to develop more advanced technology for (PV) panels with self-clean technology, or any of “NANO-Technology” coated materials to be applied easily in high-rise facades, to reduce additional maintenance and cleaning costs, and to enhance their efficiency.
- Improving the components of (PV) cells to be more: [Efficient, Productive and Economic]

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