The Potential of integrating PV in the Heritage Sites

Case Study of Dubai Museum

امكانية دمج الانظمة الكهروضوئية في المواقع التراثية – دراسة حالة متحف دبي

By

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Abstract

The conserved historic building presents a realistic and live scene of the past telling how the society has contributed in the development of the human civilization. The renovation work is complicated due to the lack of both expertise and active tailored solutions and undeveloped construction methods; it becomes more complicated when new technologies are intended to be integrated into the historical buildings.

The contradiction between the old fashion scene of the historic building and the contemporary appearance of the renewable energy systems (e.g. PV panels) is the main challenge for architects and designers to integrate these systems into such buildings.

This research aims to investigate the potential of integrating the PV panels in the heritage buildings (taking Dubai museum as a case study) considering the impact of the PV panels on the aesthetic characteristics of the building and the environmental benefits from the reduction of annual energy consumption by utilizing the PV system to generate and feed the building with clean and eco-friendly energy.

Various integration configurations have been proposed and the power generation of each one has been calculated using the Integrated Environmental Solutions - Virtual Environment (IES-VE) software. The 3D visual models of 3 configurations that annually produce the highest power amount (21.7MWh, 9.53MWh and 3.81MWh) have utilized for on-site and online surveys to explore public acceptance about the visual impact of these proposals on the historical scene of the building.

The surveys found that the proposals are in harmony with the places where to be installed and the public acceptance is significantly correlated with their awareness about the environment impact of utilizing the solar energy. In general, the idea of this study is applicable as per 93% of the participant's feedback.

The face-to-face interview with three heritage buildings specialists reveals that there are local and international obstacles prevent the adoption of the proposed concept. Locally, the building regulations prohibit integrate any additional features within the historical building and internationally, the UNESCO roles are very restricted in this regards as the fort is accredited as one of the world heritage sites.

It was concluded that applying these three configurations will cover about 65% of the annual building's energy demand and reduce the CO_2 emission about 66.7%.

ملخص

تقدم المباني التراثية مشهداً حياً وحقيقياً لماضي المجتمع ويحكي عن إسهاماته في تطور الحياة البشرية. إن عملية احياء وتجديد هذه المباني يعتبر من الأعمال المعقدة بسبب قلة الخبرات وعدم وجود نظم انشائية متطورة تقدم حلول فعالة في هذا الجانب, وتزداد هذه التعقيدات مع محاولة دمج وإدخال التكنولوجيا الحديثة كعناصر إضافية ضمن المباني التراثية.

التناقض الكبير بين المنظر التراثي لهذه المباني والمظهر المعاصر لأنظمة الطاقة المتجددة (الألواح الشمسية على سبيل المثال) يعتبر التحدي الأكثر صعوبة للمعماريين والمصممين في عملية دمج هذه الأنظمة في مثل هذه الأبنية.

تهدف هذه الدراسة إلى بحث إمكانية دمج الألواح الشمسية في المباني التراثية (تم اختيار متحف دبي كحالة اختبار) مع مراعاة تأثير هذه الألواح على العناصر الجمالية للمبنى والفوائد البيئية لهذا الدمج من خلال تقليل استهلاك الطاقة التقليدية وتعويضها بالطاقة المتولدة من الألواح الشمسية باعتبارها طاقة نظيفة وصديقة للبيئة.

تم اقتراح تكوينات معقدة لأساليب الدمج وتم احتساب الطاقة المتولدة من كل اقتراح باحتساب أحد البرمجيات الخاصة بالنمذجة الحاسوبية والمعروف اختصاراً (IES-VE).

تم استخدام المشاهد الثلاثية الأبعاد للمقترحات الثلاثة الأكثر إنتاجاً للطاقة (21.7 ميغاوات, 9.53 ميغاوات, 3.8 ميغاوات) في الاستبيان الموقعي والاستبيان الالكتروني لاستكشاف مدى تقبل الجمهور للتأثير البصري لهذه المقترحات على المظهر التراثي للمبنى.

النتائج النهائية للاستبيانين أوضحت بأن المقترحات الثلاثة متناغمة مع الأماكن المقترحة للتثبيت وإن قبول الجمهور لهذه الافكار يعتمد بالدرجة الأساس على وعي الجهور بالتأثير البيئي لاستخدام الطاقة الشمسية. وبشكل عام فإن 93% من المشاركين في الاستبيان أشاروا إلى ان فكرة الدمج قابلة للتطبيق.

تم عقد ثلاث مقابلات مع المختصين في المباني التراثية لاستبيان آرائهم حول فكرة الدراسة والمقترحات الخاصة بها, واتفق الجميع على وجود عقبات محلية وعالمية تمنع اعتماد هذه الفكرة. محلياً، أنظمة البناء لا تسمح بإضافة أي عنصر جديد إلى المباني التراثية وعالمياً فان لوائح منظمة الأمم المتحدة للتربية والعلوم والثقافة (يونسكو) صارمة في هذا المجال باعتبار ان المتحف ضمن برنامج الامم المتحدة للحفاظ على المواقع التراثية.

وقد خلصت الدراسة إلى ان تطبيق المقترحات الثلاثة سيغطي حوالي 65% من الطاقة الكهربائية المطلوبة لتشغيل المبنى والذي يؤدي بدوره إلى خفض انبعاث غاز ثاني أكسيد الكربون حوالي 66.7%

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Chapter 1 – Introduction

1.1 Overview

Preserving historical buildings aims to protect the nation's cultural values and to tell new generations stories about their antecedents' lifestyle, thoughts, beliefs, culture and more. The preserved historic building presents a realistic and life scene of the past and how the society contributed in the development of the human civilization.

The United Arab Emirates as a state has established in the beginning of 70's of last century but its roots extend deep in the past. There are more than 330 ancient buildings and heritage sites dating back to the Stone, Bronze and Iron eras include human settlements, tombs and castles distributed all over the country especially at the coastal region and some islands such as Delma, Um Al Nar, Abu Dhabi and Marwah. Other Antiquities have been discovered away from the sea, in Hatta, Hili,Masfoot, Mowailah, Hafeet Mountain …etc.

The new cities such as Abu Dhabi (the capital) and Dubai grew up in 19th century when some Arabic tribes settled close to the Gulf coast and constructed forts, castles and houses using local materials such as coral, shell, wooden joists, palm trunks and woven mat.

The restoration work of the heritage buildings in Dubai has started in 1985; by 2012 the Architectural Heritage Department in Dubai Municipality has restored 160 heritage buildings and expected to add another 60 buildings to the list of the refurbished sites by 2016 (Pathak 2012).

The building's comprises forts, mosques, old villages, houses, schools, monitoring towers and bazaars. The function of original restored sites has been changed and utilized as museums, governmental office buildings, hotels, restaurants, coffee shops, non-profit establishment, galleries, cultural centers and traditional markets.

As per the Architectural Heritage Department regulations, all buildings built before 40 years and more can be evaluated and the valued one has a possibility to be listed as historic building.

The schedule of historic buildings in Dubai classifies 492 buildings in different categories, 45 of these buildings are registered in category A as their original form can be preserved with minor changes in addition to the precious cultural value and architectural theme of these buildings.

Functionally, the heritage sites are categorized into few types:

- Defensive buildings such as forts, monitoring towers and gates.

- Commercial sites include traditional market and linear stores.

- Religious buildings represented by mosques and katatibs (old teaching groups).

- Residential unites such as traditional houses that built from coral and shell stone with gypsum for wall and wooden joists (locally called chandals), palm trunks and woven mat for roofs.

Nowadays, the list of the preserved heritage buildings includes some monumental sites such as Al Faheidi Fort (Dubai museum), Sheikh Saeed House (museum of historic archive), Sheikh Obeid Bin Thani House, Al Ahmadiya School, grand souq, Al Bastakia Historic district and Hatta Village.

Dubai's government is encouraging the tourism market and the efforts towards more developed and attractant tourists destinations are rapidly increasing, these efforts are represented in the various renovation projects to conserve, maintain and recreate plenty of heritage places in Dubai, about 250 heritage places are nominated to be renovated comprise forts, Souq (group to shops), houses, heritage villages … etc. (Mohamed, 2004).

The tourism development strategies are not limited to the heritage field, various recreational, commercial aquatic and touristic developments have been established during last two decades associated with enormous infrastructure developments including diverse transportation networks (airports, Metro, highways and marine taxi), efficient and active communication networks, secured and contemporary life style that fulfill a wide range of residents and tourists from more than 200 nationalities.

Accordingly, and due to the huge construction projects established in the last decade, the percentage of CO_2 emission per capita in the United Arab Emirates is the highest and most of these emissions result from the fossil fuel operated energy generators to fulfill the high energy demand (Taleb & Pitts, 2008).

Figure 1.1 shows the comparison between the generated and consumed electricity in Dubai from 2009 to 2011, which reveals more than 10% increase in the energy consumption within two years.

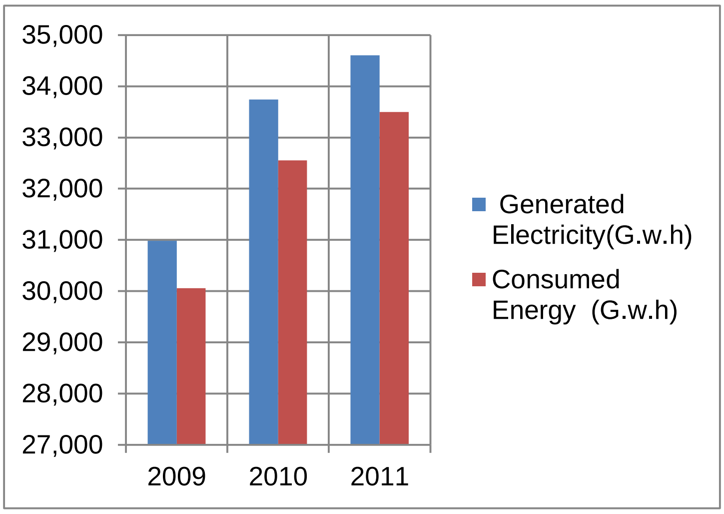


Figure 1.1 generated and consumed electricity in Dubai (Dubai Statistic Center)

Dubai's government is showing a great attention toward renewable energy sources and green building criteria to create healthy life and clean environment. In January, 2012 Dubai's ruler launched one of the biggest renewable energy projects in the region at a total cost of AED 12 billion. This project aims to produce 1% of the energy demand by 2020 and 5% by 2030. Recently phase 1 has been completed and operated to feed Dubai Electricity and Water Authority (DEWA) network with13 MW which will contribute in reduce CO_2 emission about 15000 ton/year.

As the preservation of historic buildings protects the nation's cultural values, the use of renewable energy sources such as solar energy is preserving and protecting the environment where we live, this syndrome can be the root of extensive researches to investigate the potential of integrating solar PVs in the heritage constructions.

Along 5 decades, the scientists and researchers have been continuously working to develop and improve the photovoltaic technologies technically and commercially to produce affordable and more efficient PV products. Nowadays, the adoption of renewable energy sources is significantly increasing and the PV technology becomes one of the promising energy producers with enormous spreading all over the world.

Between 1976 and 2008, the sales of PV systems has increased a hundred thousand times (Key & Peterson, 2009), furthermore the production costs has reduced 250 times between 1970 (150 $/WATT) and 2012 (0.6 $/WATT) and is predicted to reach 0.36 $/WATT in 2017.

Sousa (2012) states that enhancing the building's thermal conditions including lighting, consumes about 33% of the overall energy demand. The energy reduction / saving is the main concern of the sustainable designer, this can be achieved by utilize the renewable energy sources, improve the thermal performance of the building envelop, adopt the efficient appliances, apply diming systems …etc.

The energy cost accounts 50% of the overall operating cost, therefore the energy saving results in significant reduction in the running cost in addition to the environmental benefits, e.g. less CO_2 emission.

1.2 Aims and Objectives

The identification criteria of heritage buildings differ according to the people's cultural background, beliefs and life style as well as the geographical features of the area where these buildings were built.

This thesis aims to investigate the potential of integrating the PV panels in the heritage buildings (taking Dubai museum as a case study) considering the impact of the PV panels on the aesthetic characteristics of the building and the environmental benefits from the reduction of annual energy consumption by utilizing the PV system to generate and feed the building with clean and eco-friendly energy.

Consequently the investigation will focus on the integration possibilities of the PV systems into the heritage building's facades from the aesthetic point of view, and due to the cheap rate of fossil fuel generated power in the United Arab Emirates comparing with nowadays rate of PV generated power, the economic aspects won't be considered in this paper.

The objectives of the study are as follows:

1. Assessing the current energy consumption.
2. Study the building’s architecture to determine the suitable locations where PVs modules can be integrated.
3. Investigate the possible and applicable PVs configurations to be applied including:
    - The optimum PV’s module types that visually harmonize the existing feature where to be integrated.
    - The physical aspects of the selected PVs modules such as fixing techniques, available area, location, inclination, orientation and other factors that impact the PV’s performance and efficiency.
    - The influence of the climate characteristics on the PV systems productivity such as incident solar radiation, humidity, ambient temperature, wind trends and velocity, airborne dust and its accumulation, cloudy sky and the shading analysis of the surroundings.
4. Calculate the power generation of the various PV configurations to be applied and relative contribution to overall energy requirements. This will be done using a proper simulation software taking into account the climatic aspects of Dubai.
5. Investigate the CO_2 emission reduction associated with the energy saving.
6. Explore public acceptance about the integration approach and its influence on the overall scene of the heritage building, the questionnaire targets the tourists and museum visitors (from different nationalities and cultural backgrounds), Architects, Professionals (in restoration work) and academics from relevant fields.

Chapter 2 – Literature Review

2.1 Introduction

Integrating PV panels at the façade of heritage building is a challenge for the architects and engineers due to the sensitive architectural scene of such building and the notable contrast between the modern scene of the PV panels and the ancient appearance of the heritage building. On other hand the building's location and function, the climate characteristics and local power supply policies play substantial role in this subject.

Extensive papers have been published about the PV technology studying various aspects related to the performance, improvement, cost, types, installation techniques, environmental benefits and much more. As a modern technology, the integration of PV in the buildings facades are widely investigated especially when different PV configurations have been improved and got dual function, main façade element (construction material) and energy producer at the same time.

On contrast, there is notable gap in the literatures that investigate the visual impact of integrating PV module into the heritage building facades, most of the available paper attempts to find the proper installation techniques to integrate PV modules to the European heritage buildings where the architecture and design features of these buildings can be easily receive the PV modules and enhance the overall scene of the building and produce clean energy.

The following review focuses on some of the published paper investigated the opportunities of integrating PV modules in the historical buildings in addition to some studies related to the PVs' performance, public acceptance and the relation between the preservation / renovation works and the integration possibility.

2.2. Renovation Work and Adaptive re-use approach

The buildings are commonly constructed for limited life span and finally these buildings have to be demolished and new one will take place. Based on the physical condition of these buildings, the life span of some of these buildings can be expanded for tens of years and reused to meet the owners, occupiers and developers contemporary / new demands.

To maintain an ancient building, one of the following approaches can be adopted (Kandt et al. 2011):

- Preservation: The focal of this treatment approach aims to protect the existing material by maintain and repair the damaged parts and get more stability.
- Restoration: in this approach the aim is to present the building's features during a certain time of its history by eliminate any indications related to other periods.
- Rehabilitation: it is applicable for the buildings that intended to change its function by adding to or/and modifying these buildings while maintaining their outlook.

- Reconstruction: in case of partial destruction, rebuild the damaged parts will help in refresh the building and present it as explanatory tool refers to the past time.

Vanino (2011) divided the developing progress of the building's renovation work in Finland into three stages and clarified the drivers behind this activity and the barriers that facing it with percentage of the renovated commercial buildings from the total renovated buildings.

In 1980s the Energy Saving, Re-organization (change function) and to some extent the Deteriorated condition constituted the main reasons behind the adoption of the renovation works. These works were mostly carried out and financed by the landlords or their companies, and the commercial buildings counted 25% of the overall renovated buildings. This limited percentage explains the ignorance of the developers, designers and the other field's stockholders to involve in this activity and also the banks' abstention to finance such projects.

The lack of both expertise and active tailored solutions and undeveloped construction methods were the main barriers.

The aim of renovation works in 1990s was enhancing the building's use efficiency not only for old buildings but newer one as well and the percentage of the renovated commercial buildings formed 40% of the total renovated buildings.

The same barriers identified in 1980s remained exist in this decade in addition to the lake of surveying, planning and managing strategies of renovation works.

The building's age (in average 30 years), re-arranging building's content and improve the building's quality have increased the need of more renovation works in the 2000s and the renovated commercial buildings recorded about 70% of the overall renovated buildings in this decade.

In addition to the technical problems, the financial issues took place in this matter and became one of the particular barriers against more renovation work.

The author concluded that the renovation of existing buildings is one of the active techniques to improve the built environment which requires special skills, suitable materials, developed technologies, prefabricated inventions and funding resources.

The adaptive re-use approach is defined as “a process that reaps the benefit of the embodied energy and quality of the original building in a sustainable matter” (Bullen & Love 2011, p.32).

In this process, the ineffective parts or the whole building shall be improved and / or changed to suit a new function or purpose. This strategy can play a significant role to fulfill the constant popular needs for new, well performed and sustainable buildings avoiding demolish the existing buildings and preventing occupy new lands as well.

Comparing with the new construction, adaptive re-use approach requires less materials, consume less energy, reduces pollution and minimize the transport distance which eventually converts old, deteriorated and ineffective buildings to new, sustainable and functionally active building (Bullen & Love, 2010).

The owners and buildings occupiers' decision to adopt adaptive re-use strategy is basically affected by the political and economical status, the social and environmental aspects in addition to the innovative construction technologies.

Bullen & Love (2011) categorize a set of drivers and set of barriers that are influencing the buildings stakeholders' decision to demolish or renovate / re-use their buildings. The main drivers to adopt adaptive re-use are the energy cost escalating, minimize resources depletion, less energy consumption, minimize negative impact of humble buildings, new work patterns, change building's function, more convention, enhance building's life span, less construction waste, use less & local materials and financial incentives (figure 2.1).

On other hand there are some barriers that obstruct the adoption of adaptive re-use approach and direct the buildings' stakeholders to demolish and rebuild their properties which consequently increase the environmental loading.

These barriers include complexity, maintenance cost, external & internal building's condition, lack of professionals, building's design (layout), building regulations, health & safety requirements, uncertainty, economical risk, costly rent of reused building and inefficient constructing quality.

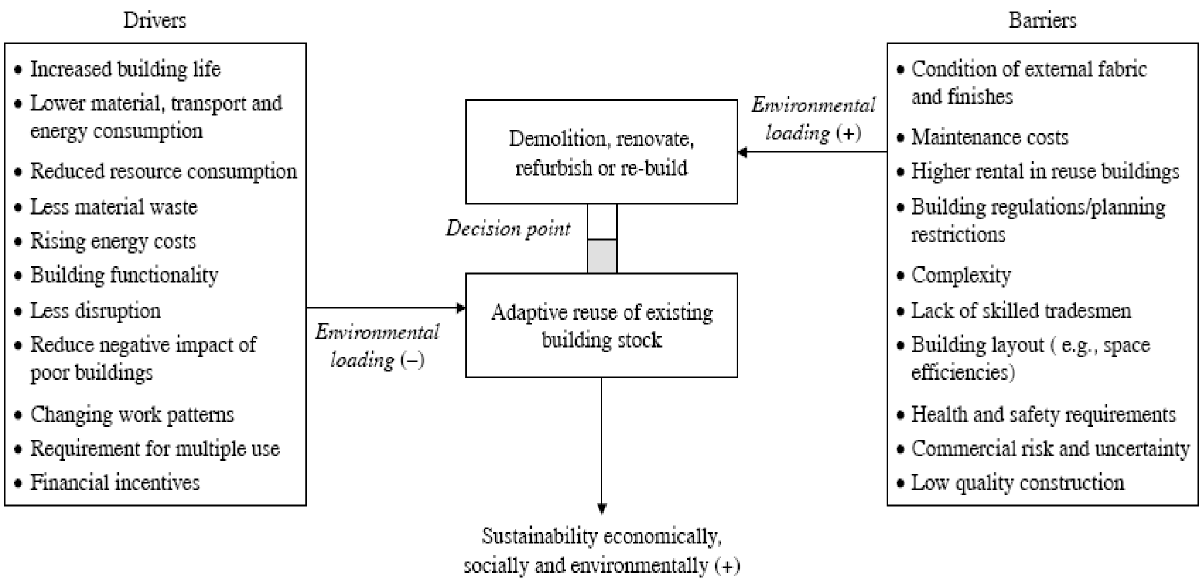


Figure 2.1 Drivers and barriers of adaptive re-use (Bullen & Love, 2011)

Langston et al. (2008) stated that outdated buildings can be considered as source of raw materials to construct new buildings. The concept of adaptive re-use presumes utilizing whole building's structure to produce new building with new function rather than demolish it, this approach can play significant roles in preserve the society culture especially for the valued historic buildings.

The advantages of buildings' restoration can be classified into three benefits. Economically, the rehabilitation work is faster than demolish and rebuild wok for same area in addition to the low – cost comparing with the new construction as less materials are required.

Environmentally, the use of recycled materials and utilizing the existing structure result less wastes and reduce the environmental loads. On other hand, the bulky envelope of old a building is significantly contributed in reduces the energy consumption and consequently CO_2 emission.

Socially, rehabilitate old buildings preserve the nation historic value and retains the streetscapes and city's architectural style. More social benefits can be gained as re-use vacant and abandoned buildings reduces offences and improves the life style of the occupants' working environment as the old buildings are commonly located in the heart of cities and close to the transports stations.

2.3 Renovation work and Embedded Energy

Environmentally, the embedded energy is one of the main benefits of re-use, renovate and preserve the historic buildings. It is defined as the sum of various type of energy required to extract, mine, produce, transport, supply and install various materials needed to build a building.

Jacson (2005) stated that the estimated embedded energy of the historic building is higher comparing with the same of similar new construction due to the space volume (the ceiling height of the ancient building is commonly higher than the new building) and the bulky / massive bearing masonry walls.

The author allocated 50% of the embedded energy of a building for manufacturing the construction materials, 20% for MEP (Mechanical, Electrical and Plumping) services, 15% for delivery / transport, 1% for furnishings and other 1% for construction equipments and machinery.

2.4 Renovation work and PV

Globally, the need of new constructions is an ongoing process to fulfill the public demand. Vainio (2011) stated that replacing old buildings by new one is preferred in the developed countries instead of renovating these buildings, but the vast growth in the new construction has increased the public interest in the renovation of the exits buildings especially the valued one (culturally and/or historically) as the renovation work consumes less energy than the new construction and reduces the demand for new land.

Statistically, the expression 'renovation' is used to clarify the construction works that are carrying out on the existing buildings and aim to renew the building totally or partially (refurbishment), Improve the building's quality (modernize, rehabilitate and upgrade), change the building's function (reconfigure/rebuild) and preserve the architectural and the historical values of the building (restoration).

The building's renovation becomes one of the active strategies to reduce the CO_2 emission as a result of the energy saving which can be achieved by improve the building's thermal performance (consequently reduce the energy demand) and integrate the renewable energy technology in the building to cover the energy demand totally or partially.

Kaan & Reijenga (2004) attribute the limitation in the integration of PV in the building to many architects who have inadequate knowledge about PV systems and the vast potentials of using these systems as architectural features contribute in adding a considerable value to the building where these systems to be integrated.

This gap in the awareness and knowledge about the aesthetical value of the PV systems and their positive influence on the revenues during the operation period result in no more or at least improper integration solutions that convince the owners or/and developers to adapt these systems in their projects.

PV suits the built environment better than other renewable energy sources such as hydropower, wind energy and biomass because it can becomes part of the building envelope rather than additional element.

This is true for new construction where the PV can easily be integrated and installed, but for the historical buildings the principle is different especially for those in Dubai due to the construction materials of the ancient buildings which form tricky barriers and turn the idea of integrate PV in such building big challenge for architects.

A set of aesthetic criteria has been defined by a group of 10 experts have architectural background to be used as measurement tool to evaluate and assess the PV projects. Some of the criteria are applicable for the historic buildings and can help the architects to establish a proper integration approach to integrate PV's in the heritage construction.

Due to those criteria the PV panels to be naturally integrated and appear as existing part of the building and not visibly look as an additional feature, therefore, the color of the PV panel is a considerable issue especially for heritage building in Dubai where the color feature of external façade is significantly in contrast with the standard color and feature of the PV panels.

Accordingly the flexible and amorphous PV's are more appropriate for the heritage building as the color of PV can be changed to match the location properties where the PV is aimed to be installed.

Contextually, the integrated PV system should match the building's context to avoid the obvious contract between the ancient scene of the heritage buildings and the modern view of the PV systems.

Integrating PV system in the heritage buildings requires elegant and professional details and the designer/architect has to be creative and use an innovative installation technique to present a successful PV project as these two factors, the elegant detail and innovative approach are listed in the set of the said aesthetic criteria.

Kandt et al. (2011) state that integrating PV's at the historic buildings might be applicable by replacing shingles at the rooftop or the glass of the skylight. These two features (the inclined rooftop and skylights) are widely used in European and American historic building and do not exist in the Gulf's countries architecture, therefore integrating this technology is not easy as it is in the Western countries and forms a big challenge for the architects and engineers.

Integrating PV's in the historical building is not an easy issue, many constraints are still exist for architects, public and other stakeholders make the potential of integrating this new technology within the historic construction very limited especially from the aesthetic, culture and regulation aspects.

In Europe and due to the costly energy production, the main concern of the renovation or / and re-design the historical buildings is to reduce the energy consumption and improve their energy performance where integrating the PV technology is applicable.

Scagnamiglio et al. (2009) classify three approaches to justify the suitability of the PV Panels to be integrated or/and installed to the building envelop. Technically, the BIPV products are widely available with various choices. Energetically, integrate BIPV enhances and improves the thermal efficiency of the building envelope. Visually, the contemporary scene of PV components promotes to the construction material market an appropriate element for new construction and renovation or re-design of building envelope.

The authors stated that fulfilling occupants’ needs was the main function of the traditional / historical building with no concern about the energy consumption, but convert the “just building” to “eco – building”. The performance of the building should be enhanced to present a built environment that meets the inhabitants’ needs associated by minimum energy consumption.

Tagliabue, Leonforte & Compostella (2012) studied the approaches of historical buildings' renovation from the energy efficiency aspect. They stated that the solar radiation is one of the abundant energy sources in the Mediterranean region and can be utilized to generate electricity power by integrating the photovoltaic system in the new constructions and even in the historical buildings but with full respect to the aesthetic and cultural values.

Four of eleven local historical buildings in Palazzolo Acreide downtown in Italy which are protected by UNESCO were selected as study case and the renovation strategy involved re-function and utilize these buildings as a hotel while preserving their historical characteristics.

Basically, the climate conditions were analyzed and evaluated to appraise the utilization of natural resources such as solar gain and daylight in winter to reduce the energy consumption and the potential of integrating photovoltaic systems into the building's envelop to produce electricity power that fulfill the buildings' energy demands (fully or partially). In addition the buildings characteristics were studied to evaluate their thermal performance as it is one of the main parameters that impact the energy consumption of the building.

Two main strategies were adopted in this project, first, the thermal performance of the buildings' envelop were improved by apply 10 cm polystyrene insulation layer on the stone walls and the U value achieved 0.34 W/m²K which equalizes 20% of the U value of the existing wall.

The glazing system was also enhanced by replacing the existing single-glazed windows by low-E double glazed windows to achieve U value of 1 W/m²K which equalizes triple glazing performance. In addition, the exiting windows frames provided by timber frames to minimize the infiltration and reduce the heat losses as much as could through the frames.

The second strategy included the utilization of the available renewable energy sources to reduce the building energy consumption and produce electricity power as well. In this context, three techniques were used, passively, the ground slab was utilized as heat sink to modulate the internal temperature in summer by absorbing the sun radiation admitted through wide glazing panels installed at the south elevation and in winter, the thermal mass of the ground slab stores the sun radiation as heat during day hours and release it in the evening hours to warm the internal spaces.

Actively, a thermal plant and building integrated photovoltaic system (BIPV) were installed. The thermal plant is a combination of an air source heat pump (ASHP) and a ground radiant heating system, this plant provides heating in winter and cooling in summer by utilizing the external air temperature (by ASHP) and the water flow temperature (by radiant system) which contributed in a significant reduction in the energy consumption in both winter and summer seasons (almost 76%).

The south-face of the pitched roof was used to integrate 40m² of 100 Wp monocrystalline PV modules aligning the roof inclination angle (20°) which allows for maximum collection of solar radiation. The energy production of this PV configuration (about 4MWB/year) covers the overall energy demand of the building including heating and cooling needs, heat pump and all common electrical appliances used in such buildings.

The results of this projects reveals that the renovation of the historical building from the thermal and energetic point of view is a big challenge due to the sensitive architecture of these buildings, the local regulations and to some extent the global identification criteria of historical building which stand as major constraints to change the traditional features as a result of integrating the renewable energy devices into the historical buildings' facades but on the other hand, the successful integration approach promotes more convenient built environment and enhance the buildings' thermal performance.

The actual energy consumption of one of the four buildings called Primosole has been calculated and compared with the energy consumption of the design project, the comparison shows 76% reduction in the annual consumption mostly in winter as result of the envelop improvement which reduce the heat loss through the windows and the heat transmission through the wall (under the effect of the applied insulation layers).

2.5. PVs Integration Techniques

Integrating renewable energy sources in the historic buildings as part of refurbishment work of these buildings can cover the excessive energy demand because these buildings are commonly inefficient from the energy point of view (Lucchi et al., 2014).

The augmentation in the popular awareness about the environmental impact of utilizing the renewable energy sources and energy consume reduction associated by instable fossil fuel prices are the main factor behind the continuous growth in the photovoltaic technology market in Italy and European countries (Frontini, Manfren & Tagliabue, 2012). This growth will significantly impact the PV's cost and the anticipations refer to 50% reduction by 2020 and the power unit rate will be ranging between 0.08 to 0.18 €/kWh.

The study aims to identify the most effective integration technique and the innovative products that can be integrated within a sensitive construction. In this regard six heritage buildings in Bellinzona city, Italy were selected to install solar thermal and PV systems within the building envelops.

Technically, there is no doubt that integrating solar thermal and photovoltaic system into the buildings facades is possible, but in the heritage building the potential of roof installation is the most.

The authors has developed a particular check list to enable the owners, architect and planners take their decision and select the proper configuration.

As the existing buildings in Bellinzona are extremely varied and in order to identify the proper integration technique, the roof typologies have been identified and a set of six criteria to improve the design quality and insure more durable installations for solar systems considering the shape and positioning of the solar panels. These criteria include:

- Co-planarity: the solar system and building surface to receive these systems has to be in same plane.
- Respect of the lines: the construction outline to be followed.
- Grouping: assembling solar modules has to be organized.
- Accuracy: smart, intelligent and professional integration techniques to be considered.
- Visibility: to consider the overall scene of the construction where the solar system to be installed (for both new and restored building)

The solar system market, nowadays, presents wide range of developed and innovative products that can be integrated in the heritage building. These products are varied in technologies, performance and form. The more advanced products become not additive elements but part of main envelope components.

The six criteria and roof typologies with a set of five recommendations are combined to promote a check-list to improve the public awareness to identify the proper solar system configuration considering the user's acceptance with full respect to the cultural and heritage values.

The compatibility between the criteria/recommendations is categorized into three levels: easily respected, can be easily respected (when the decision of install solar system is initially taken) can be respected with full consideration of specific aspects.

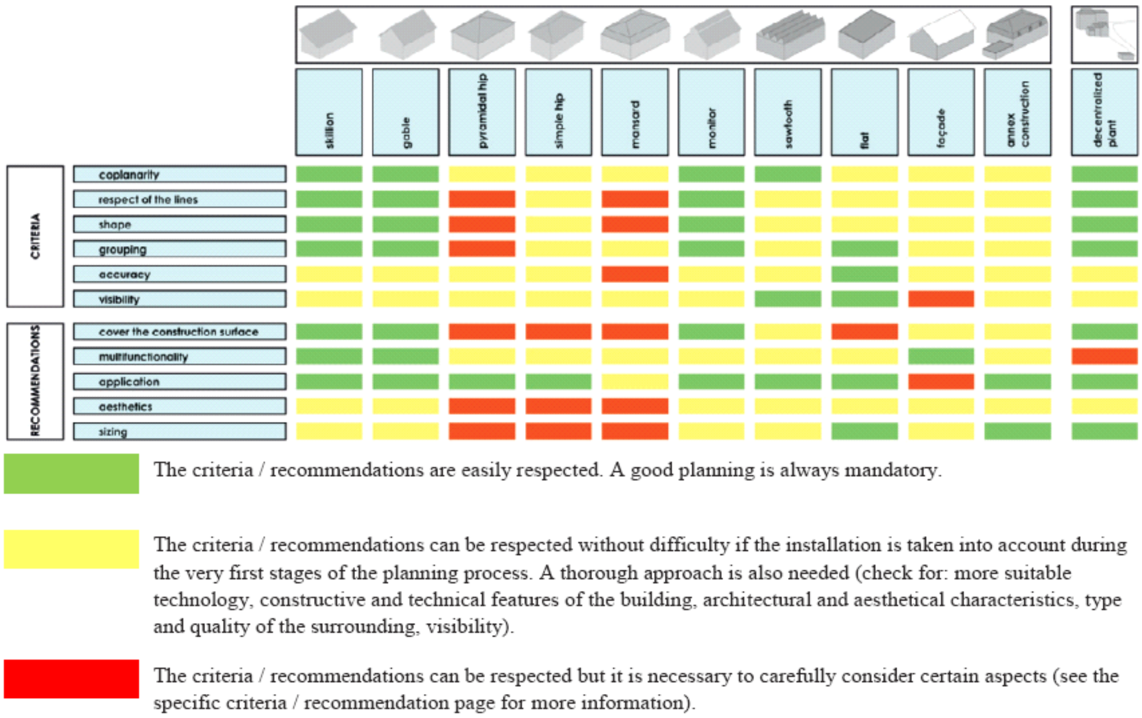


Figure 2.2 Criteria and recommendations proposed for different roof configurations
(Frontini, Manfren & Tagliabue, 2012)

2.6 Photovoltaic System Components and Properties

World wild concerns about energy shortage and environmental issues constitute it necessary to consider clean energy as an option for the future. "Photovoltaic power is the fastest-growing power generation technology". Many reasons gave the photovoltaic power its importance, it costs less than other renewable power suppliers, it is a stable energy source since the sunlight needed is totally free and it is a clean energy that doesn't harm the environment where we live (Ding et al. 2013).

Some problems might appear while integrating PV technology such as the capacity of energy that the electric gird can handle and the extensive produces power (more than the optimum power flow) will cause instability and affect the power quality.

To avoid these issues, knowing the technical properties of solar photovoltaic power are something critical and the power-integration process has to be well studied with conjuction to the photovoltaic system components wich commonly compris:.

a) Photovoltaic Cells and Modules

Simi-conductor materials represent the major part of the photovoltaic cell and Silicon is the most common material that being used in PV cells.

"The efficiency of photovoltaic cells decreases with increases in temperature", also, any change in weather condition that will block sunlight will take the efficiency rate down since the main source of energy is not available anymore.

The PV cells are connected to create PV modules which are connected in groups to create the PV array. Different ways of connecting serve different properties of the modules. Parallel connection increases the current output while in-series connection increases the voltage.

b) Battery

Storing electricity is needed in any power system, battery is the device that being used to store DC electric power. Batteries are categorized due to the ability of recharging, non-rechargeable and rechargeable batteries. Although the increase in temperature will increase the capacity, at the same time it will decrease the life time of the battery.

c) Inverter

Inverter is the device that converts the DC electric power into a usable type of electricity (AC electric power).

d) Photovoltaic Controller

The main purpose of these controllers is to prevent batteries from being overcharged. One important factor that should be consider while choosing the type of controllers is to make sure that the maximum voltage in the system doesn't exceed the maximum voltage that the controllers can handle.

e) Environmental impacts of solar photovoltaic power

The environmental impacts of the photovoltaic technology is very limited, the first one is the appearance of the buildings that the PV systems are plugged at, the second one is the some poisons materials that being used in the process of producing the PV cells.

Solar photovoltaic power is an effective, clean and advanced technology that uses natural sources (sunlight) to produce energy needed in our life. Batteries invertors, controllers and PV cells are the basic parts of the system. Environmental impacts are very limited that we can consider this type of energy friendly to environment.

2.7 Selecting Proper PVs

By 2030, the global investment in the energy production is estimated to achieve 22 trillion US dollars as reported by the International Energy Agency (IEA) in 2010 and the PV sale will be continuously growing and expected to account 10-20% of the said investment.

Comparing with the conventional energy production, the power unit rate ($/W) of solar energy production is the highest (Ababei, Yuvarajan & Schulz, 2010). This rate is affected by the manufacturing, installation and maintenance cost of the photovoltaic systems along its life span which represents one of the main obstacles against fast growth of this technology.

Gaur & Tiwari (2013) state that the selling of the PV modules have increased 30% in one year (2008 - 2009) and reached 1.3 GWp Pv cells and modules comprise about 46% of the said amount monocrystalline cells (c-Si), 32% Polycrystalline and 22% thin films (a-Si, CIGS, CdTe and nc-Si). In spite of the fact that PV systems produce electricity from abundant energy source (sun) and promote a double, eco-friendly and cheap operation cost power with minimum regular maintenance, but there are some concerns still exist such as substantial upfront cost, heavy weight and not easy to deal with.

The performance of semitransparent and opaque of different PV products has been assessed using results of experiments carried out under standard test conditions considering the metrological data of Delhi (India) in winter represents by January and Summer represents by June. The on-site performance of the same PV modules available in the market has been tested and evaluated too.

The study covered different PV generations (products) such as monocrystalline and Polycrystalline cells which represent the first generation, the second generation represents by thin film PVs comprise copper indium gallium diselenide (CIGS), amorphous silicon (a-Si) and cadmium telluride (CdTe) while the third generation represents by organic semiconductors and organic dyes.

The evaluation criteria include annual power production, upfront cost, generated power unit cost and the consistent cost on annual basis.

The laboratory test reveals that the efficiency of the first PV generation is ranging from 25% (moni-Si) to 20.4% (poly c-Si) and the efficiency of the second generation is ranging from 10.1% (a-Si) to 20.3% (CIGS) while the efficiency of the third generation is almost 11%.

In general the performance evaluations show that the C-Si photovoltaic modules are more efficient than the a-Si type by 80% and 90% for the commercial and laboratory-made modules respectively and the PVs made in laboratory produce 50% more power compared with the commercial type, as that the behavior of the semitransparent and opaque modules for all PV's generations are almost identical.

For instant the efficiency of the various PV modules are correlated with their hotness, as the ambient temperature increases by the time passes from morning to noon, the module efficiency declines and begin increases when the time passes towards the night and the temperature tends to be dropped. In the same context and due to the temperature impact on the PV module performance, an increasing of 2% in the module's efficiency has been observed in January comparing with the same module's efficiency in June.

In detail, table 2.1 shows a comparison between the commercial and the laboratory-made PV modules with regard to the minimum and maximum annual power generation and the unit cost.

Table 2.1 Power Generation and unit cost comparison (Gaur & Tiwar, 2013)

PV module type	Annual power generation		Power unit cost	
	Maximum	Minimum	Maximum	Minimum
Commercial	a-Si / nc-Si	Poly-Si	Poly-Si	a-Si / nc-Si
Laboratory-made	CdTe	a-Si / nc-Si	C-Si	CdTe

Regarding the third evaluation criteria, the CIGS photovoltaic module shows the minimum capitalized cost among other commercial PV modules.

It is well known that the building integrated photovoltaic (BIPV) is correlated with the plane PV panels represented by monocrystalline cell and polycrystalline cell. These two PV types differ in the efficiency and the appearance which are practically interdependent (Katanbfnasab & Abu-Hijleh, 2013).

The mono-crystalline cell is made from a slice of single crystal which gives the homogeneous appearance while the shattered scene of the polycrystalline cell relates to the multifaceted silicon crystal where the cell made from, that’s why the mono-crystalline cell is more expensive and more efficient (17% & 15% respectively) than the poly-crystalline cell.

The gap between the efficiencies was wider but due to the vast development in the poly-crystalline technology, the gap has been diminished to 2% only. However, the vertical integration (usually at the building façade) of both PV's types are impacting the overall efficiency about 50% less than the inclined integration (usually at roof or on ground).

The authors identified two categories to assess the suitability of the building façade to PV module integration, first the environmental suitability represented by the solar radiation amount considering the construction's location, orientation and PV's module inclination angle, second the architectural suitability with regards to some limitations related to the construction itself and the surfaces applicable for PV's installation with minimum or no shading effect.

Katanbafnasa & Abu-Hijleh (2013) identified some essential criteria to select the proper simulation software to fulfill the study aims. The ability, reliability, validity and the wide range construction materials data base that allows frequent simulation for various configurations are the main criteria that present the Integrated Environmental Solutions - Virtual Environment (IES-VE) as one of the active and applicable simulation software for scholars, researchers and students.

2.8 Public Acceptance

Taleb & Pitts (2008) conducted an online survey supported by follow-up interviews to investigate the potentials of using BIPV in the Gulf Cooperation Council's Countries (GCCC).

Although the GCC countries lay in a region receives high level of solar radiation which theoretically encourage and enhance the adoption of the BIPV in these countries, but the real situation reveals a contrast vision due to the cheapest rate of the conventional energy supply versus the PV generated power and the lack of public awareness regarding the negative environmental impact of the high consumption of the fossil fuels generated power.

In spite of this fact the authors prepared an online survey to investigate the potential of adopting the BIVP systems in the GCC countries. The survey questionnaire was prepared considering the different awareness level of the stakeholders.

The targeted stakeholders have categorized into five groups Homeowners, Academics, Building Developers, Architects and Decision Makers, which was neglected later due to the misconnection with this group.

The questionnaire was distributed via e-mails to about 1300 stakeholders all over the GCC countries distributed among the targeted categories as following: 53 Homeowners, 102 Academics, 43 Building Developers and 46 Architects, and the feedback from about 19% of those invited received after one month.

The academics represented about 42% of the total participant's involved in this survey which reflects the high concerns of this group regarding the environment and power aspects. From Homeowner point of view, the uncompetitive price of the existing PV technology versus the cheep rate of the conventional power is the main challenge against the use of BIPV in these countries.

The Academics turned the limitation of the BIPV to the lack of people consciousness regarding the global warming. They proposed two approaches to enhance the adoption of the BIPV, first one by improve the public awareness via different media tools and training courses especially for the youth generation in the universities and colleges.

Second approach is a financial political issue to enhance the economic side of the BIPV by introduce incentives for those adopt the PV generated power within their buildings and on the same time reduce the government subsides of the price of the conventional power supply (fossil fuel plants).

The building developers appeared disregard about the environmental aspects and refused the renewable energy technologies due to the high coasted of such power sources. The Architects revealed high interest in the solar energy as a proper energy source able to be integrated in the buildings but they thought that such systems has no influence on the design process which reflects their limited knowledge regarding this technology.

The feedback of the participants was analyzed using '"Force field analysis" technique due to the flexibility of this analytical tool and its ability to quantify the various factors of the subject of the survey.

After weighting these factors via numerical scale stretched between 1 (weak) and 5 (strong), these factors was classified into facilitating group and restraining group. By comparing the strength of the two groups, the researchers concluded that the BIPV is unviable for the time being due to the powerful of the restraining forces versus the relatively weak facilitating forces in addition to the economic issues and public unfamiliarity with the BIPV.

This type of investigation methods provides almost clear vision about the public opinions (from different knowledge background) regarding a specific topic at certain area. This study explorers to what extend that BIPV is acceptable within the GCC region (taking into account the opinion of the various people categorize) regardless the technical aspects of this technology.

2.9 Advanced Building Regulations

Many countries are improving the building regulations towards produce more energy efficient, high thermal performance and less energy demand buildings. Aste, Adhikari & Tagliabue (2012) stated that the consumers nowadays are continuously searching for secured, opportune, flexible and friendly environment energy sources.

The new regulations in European Union Countries are intending to adopt the idea of the "nearly zero energy buildings" for all new buildings by the end of this decade in addition to the pursuit of 20% reduction in the energy consumption and utilize the renewable sources to produce 20% of the overall energy demand as well.

In parallel, the public awareness about the environmental problems of the use of conventional energy (from fossil fuel) is rapidly increased and the properties' owners become more interested in the integration of the renewable energy systems in their projects not only in the new construction but also in the refurbishment of the existing buildings.

In this context, the Lombardy region in Italy has launched a program of integrating energy saving technologies in the buildings associated with an awareness campaign about the environmental hazards of the conventional energy production. The “Solar Integrated Roof” is one of the program's projects aims to integrate one of the innovative solar systems at the roof of the Professional Training Center in Casargo, Lecco, Italy.

Chapter 3 – Methodology

3.1 Introduction

The research subject, the targeted findings, the time frame, the cost, the researcher's qualification, aims, research scope /extent and the purpose of the research are the main parameters to determine the research methodology and identity the proper and applicable research tools.

One or multi methods can be used for a particular topic based on the research's subject, aims, results formula and methods' characteristics (limitations, applicability, validity and cost-efficiency).

The subject of this paper and its aims entail use more than one method to investigate and test all the research's aspects. The correlation between the historical buildings and the community imposes explore the public feedback about the PV's integration outcomes and its impact on the cultural value and aesthetic scene of the heritage building under study, therefore field and online survey is widely adopted by the researchers as verification and measuring tool for such topics.

On other hand, integrating PV modules in a building requires various testing and investigation methods to determine the proper PV technology, calculate the power generation, compute CO_2 emission reduction … etc.

These methods include experiments, use simulation software, mathematical calculation (computerized and manual) and literature review as it is one of the research methods promotes infinite information and substantial database for various scientific and academic research of all knowledge aspects.

The findings extracted from the relevant literatures are broadly used as verification and validation tools to measure the results accuracy as well as utilized as input data for other researches.

This chapter discusses the mentioned research methodology including the pros and cons of each method to identify the more proper and active methods that applicable for the objectives and aims of this paper.

3.2 Field / Online survey (Questionnaire)

It is the most appropriate research method especially for the subjects in touch with the public opinion and allows the researchers to obtain extensive local and overseas information, economically and within reasonable time.

Andrews, Nonnecke & Preece (2003) stated that two types of electronic survey have come out in 1986 and 1994 affected by the technology development, asynchronous email survey and synchronous Web-based survey respectively.

Various differences are recognized between the two types for instant, the feedback gathered from emails is manually stored even received as word attachment or embedded in the email message while in Web-based survey, the feedback is verified and stored automatically which means that this type is more accurate.

The authors identified five criteria to create a successful online survey; these include privacy and confidentiality, survey design, feedback management, survey piloting and sampling.

Taleb & Pitts (2008) adopted online questionnaire as research method to explore the public acceptance to integrate the photovoltaics system in their buildings within the GCC countries. The survey was targeted four groups of the construction stakeholders and intended to assess their awareness about the environmental challenges as a result of the use of fossil fuel generated power and the environmental benefits derived by adopt the building-integrated photovoltaic systems in the Gulf region.

The authors stated that the surveys are normally inflexible especially when the responses gathered from participants differ in their awareness about the survey subject; therefore in order to recoup this restrain, the stakeholders were categorized due to their relation to the construction field. These catogries include owners, developers, designers (architects) and academics.

The questionnaire has distributed online for about 1300 persons from the six Golf countries. After 30 days, the feedback from 53 homeowners, 102 academic, 43 developers and 46 architects which constitute about 19% of the total number of invitees.

The survey feedback has analyzed using Force Field Analysis system proposed by Kurt Lewin in 1951 as analytic technique for management field. The system is widely used due to its subjectivity, flexibility and simplicity in addition to its ability in quantifying the weight of the various parameters of the survey's subject.

The parameters were arranged into two groups; facilities factors and restraining factors. These factors were quantified via a numerical scale ranging from 1 to 5 (weak to strong relatively). The result of this analysis guided the authers to identify set of the recommendations to improve the public awareness toward accept the concept of integrate the photovoltaics system in their buildings.

Khondoker & Mueller (2010) adopted the online survey technique to save time and gather feedback from wide range of participants quickly and easily in addition to its suitability to the study topic. The authors identified the strength of this method which include Profissionality (using filters), Versatility (using various question formats), direct link to the database, support data quality check and the confidentiality is secured.

Scognamiglio et al. (2009) organized two days exhibition in coordination with the municipality to present their proposals of using the photovoltaic systems in the heritage buildings. The event aims to involve the public in the re-design projects decision and establish a well understanding about the new themes generated by this technology (figure 3.1).

Figure 3.1 Public's Involvement (Scognamiglio et al. 2009)

3.3 On-Site Monitoring Method

It is one of the examination / observation research tools aims to investigate and measure several variables related to the research subject, and the collected measures (records) to be utilized as input data for further analysis (Research Methodology c. 2005).

In addition to the monitoring and measuring tools, this method requires qualified staff (for monitoring), field surveyors (to get public feedback), implement the proposed design (e.g. photovoltaic systems) and for this research case study (Dubai Museum) a set of administrative permits from relative authorities are required and mandatory.

Aste, Adhikari & Tagliabue (2012) adopted the on–site monitoring approach to observe the performance of the "Solar Integrated Roof" system fixed at the Professional Training Center in Casargo – Italy. The solar system which comprises solar air heating system, solar water heating system and solar hybrid photovoltaic system has fixed on the inclined roof surface facing South (with approximately 390m²) and linked to a monitoring system for continuous measuring purpose.

The gathered data has been compared with the simulated energy performance of the system and utilized to estimate the economic and environmental benefits of integrating solar system at existing buildings as well.

This method is inapplicable for this study as it requests a significant budget to cover the cost of the photovoltic system, monitoring and measuring systems to be implemented / installed in the existing building as well as the operation cost along the monitoring time frame. On other hand, the long-term monitoring processes required for such study limits the potential of adopting this method especially for academic researches.

3.4 3D Modeling and Visualization Method

The creation of digital 3D models allows the designers to test the visual impacts of various features to be added at existing buildings, not only for renovation proposals but for improvement purpose too (Hadjri, 2014). Different 3D modeling software are available in the market at reasonable cost such as 3D Studio Max, Sketch up, Revit, AutoCAD, ArchiCAD ..etc and some of these are available as student version for free.

Essentially, the 2D digital drawing / map is required with some physical data such as building's height, architectural features, finishing materials and texture to create a more realistic model that simulates the existing building.

Scognamiglio et al. (2009) studied the visual impact of integrating PV panels into historic building. Three residential buildings built in a historic area called Pineto in Rome, Italy were selected as case study adopting 3D visual modeling method to present various design ideas and explore public response / acceptance about integrate new technology with contemporary appearance into heritage site with old fashion features.

Figures (3.2) & (3.3) show two 3D models of proposed facades with PV panels for two buildings to show the stakeholders how their valued buildings will impacted and appeared when PV panels become part of the buildings' elements.

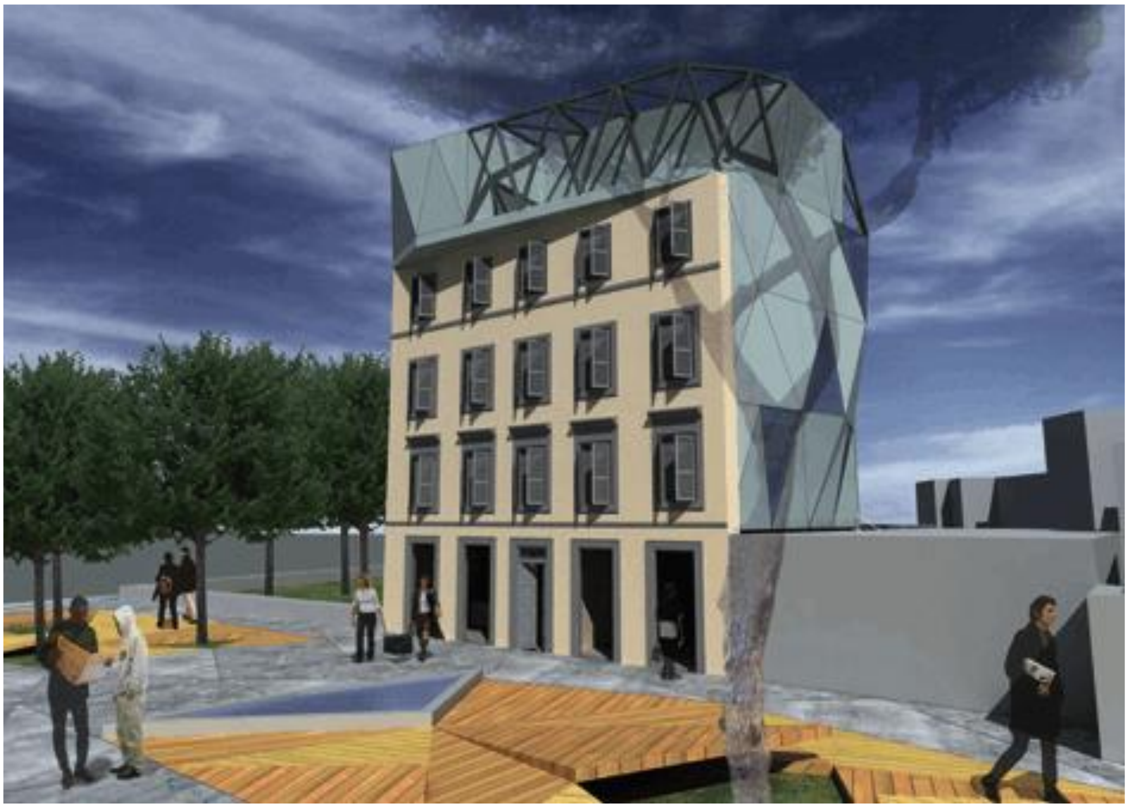


Figure 3.2 East façade and roof with Photovoltaic (Scognamiglio et al, 2009)

Figure 3.3 North façade with Photovoltaic (Scognamiglio et al, 2009)

3.5 Computer Simulation

Along last five decades, the Photovoltaic technology has rapidly developed. The main concerns of the scientists and researchers are producing more efficient and less cost PV systems in order to offer affordable renewable energy generators.

The vast advancement in computer technology (both hardware and software) with the increase of the global interest in the PV technology presents the most useful and accepted tools to the researchers and scientist represented in the wide range of simulation software which help in minimize the required time and somehow the cost comparing with the experimental method.

Since early sixties, extensive and different energy simulation software have been established and upgraded to support the designers with an active and accurate tool in investigate and determine the most efficient design approach (Crawley et al., 2008).

Tagliabue, Leonforte & Compostella (2012) adopted TRNSYS to evaluate the proposed photovoltaic systems' performance, which is capable to predict the performance of set of systems under dynamic conditions.

This simulation software is widely used due to its flexibility in change the configuration of the system's components and the minimal errors between actual and simulation results (less than 10%).

Parker, Copper & Shao (2012) adopted computer simulation method to evaluate the probable impact of various retrofit options of East Midland airport terminal building's context in United Kingdom from the environmental point of view.

Therefore the Integrated Environmental Solution's Virtual Environment (IES-VE) was utilized due to its diverse capabilities such as creating the simulation model with ease adjustability, energy consumption calculations for different fuel (electricity, natural gas, biomass …etc), plug-in with other software, PV's energy production calculation, CO_2 emission calculation, computing solar gain …etc.

Moreover, the main variables that affect the energy consumption can easily tuned such as occupancy profiles correlated with the building's function, lighting and appliances types, envelop materials and building's orientation (for design purpose) in addition to the ability of linking with various weather files as one of the main parameters of energy consumption calculation.

In spite of the mentioned advantages, this methodology has some limitations especially for the cases with numerous parameters as the simulation software cannot control these parameters and consequently affect the results' accuracy.

3.6 Experimental Method

The experimental method is widely used in the PV field to examine the performance and energy production of the different PV configurations and technologies, either under natural environment (outdoor experiments) or under controlled conditions (indoor experiments) where the researchers can tune and adjust the parameters that influence the energy production of the PV module such as the solar radiation (by simulating the sun radiation), the temperature, the wind speed, humidity, tilt angle, shadowing and light source direction.

Each of the mentioned experiment types has its own advantages and disadvantages due to the accurate results, time frame, expenses and required tools.

Ibrahim (2011) adopted the experimental method in his investigation about the influence of the shadow and dust on the operation and energy production of the PV cell. In the indoor experiments, he controlled the illumination level fall on the examined PV module and shaded different sections of the module to simulate the natural solar radiation and shadowing usually happened in the real situation. The results of this experiment has compared with the results of 10 days experiment under natural environments.

Such method enables the researcher to manipulate the environment parameters that impact the performance of the PV cell frequently within short period.

In same context, Árpád & István (2010) used the same method to study the impact of variable illumination levels on the PV performance via two artificial light sources.

This method requires a real mockup to be built and tested under real conditions associated by various equipment and tools to monitor and gather the experiment output, these mockups and tools are varied as per the subject of the research and the accuracy level of the obtained results.

The results' reality is the main advantage of this method as the test is carried out for an existing case or for a sample similar to the origin and for both, the actual weather condition should be considered.

The main limitation of the experimental method, especially for academic researches, represented in the high cost of the relevant tools and mockup, the monitoring process requires time and professional staff and the results' accuracy cannot be secured due to the potential of some errors may be caused by monitoring system component (e.g. sensors).

Consequently this methodology is inapplicable for this study as the time frame is very limited and enormous permits and approvals to be obtained from relevant authorities to build and monitor the mockup.

3.7 Literature Review Method

Vanino (2011) reviewed set of literatures about the building's renovation in his study. This technique provides massive information about what others have done with their recommendations which form the base for more investigation in similar field.

In addition to the computer simulation, Parker, Copper & Shao (2012) adopted literature review method to evaluate the environmental impact of different retrofit options of East Midland airport's terminal building in United Kingdom.

Various researches focus on airport architecture, terminal carbon footprints, developing of terminal facilities and refurbishment alternatives were reviewed to identify the main parameters of the research subject and determine the best and more active renovation options that produce less energy consumption built environment.

Al Sallal (2005) adopted the literature review method to determine the contribution of the buildings and urban planning in the total carbon emission all over the world. The author reviewed various type of literatures such as newspaper (Gulf News and The National), statistical leaflets, publication (from specialist organizations), researches and governmental regulations (e.g. Estidama 2011 a & b).

The literatures provide the researcher wide range of data, information and tested results / findings in the concerned topic usually utilized for validation, comparison and justification purposes only and no results can be obtained from this technique especially for the topic of this study.

3.8 Numerical Method

Numerical method is usually used in conjunction with other investigation methods especially to determine the influence of the environment characteristic on the PV cell performance. Ibrahim (2011) associated his experimental work by some equations to calculate the Isc and Voc of PV module when it exposed to the natural environment.

Hermenean et al (2011) used set of numerical formulas to calculate the partial solar radiation converted into heat, the caloric coefficient and the heat lost utilizing the findings of the experiments as inputs for those formulas.

Immeasurable PV parameters such as ideality factor, series resistance, saturation current and the photocurrent which the experimental and simulation are not applicable to calculate these parameters can be determined mathematically. Khezzar, Zereg & Khezzar (2009) utilized three numerical methods to determine these parameters and then validate the findings with experimental results.

Frontini, Manfren & Tagliable (2012) adopted a numerical method to analyze the electrical load data and the power generation of PV system installed on two heritage buildings in Bellinzona, Italy. Different mathematical expression have been utilized to calculate the load matching index in addition to the grid interacting index in monthly, daily and hourly basis. These calculations were carried out over the year and for various time samples.

This method usually depends on assumptions and approximations which influence the results accuracy and the complexity level of this method increases as the parameters number increases. it is widely adopted in the economic field, finance and feasibility studies.

Due to this study aims and objectives, the numerical methodology is inapplicable.

3.9 Selection and Justification of Research Method

Refer to this research aims and objectives mentioned in section 3.1, three methodologies have been selected to achieve the study's goals which comprise 3D visual modeling, Computer modeling & simulation and On-site & Online surveys.

- 3D Modeling and Visualization Method:
  Part of this study, the proposed integration scenarios need to be presented to illustrate their impact on the existing building scene, therefore a 3D modeling software is required to build and render the model based on the proposals parameters and the visual characteristics of the location where the proposal to be installed.
  On-site snapshots will be captured for the specific locations for comparison purpose and to be used as background layer for the 3D models.
  The 3D Studio Max is the most proper modeling software for this subject due to its advanced features and capability. The software allows for different view

angles (camera) and adjusting the lighting source, density, type (natural or artificial) and location to reach the required configurations.
The main advantages are the capability of inserting photos as background and manipulate the 3D model according to this photo to obtain the proper and best configuration. Various rendering process can be carried out considering the designed materials and lighting resource & density within reasonable time.
The modeling output provides very clear imagination about the proposals which simulation the real vision. The software is available in the market for reasonable cost and also as student version for free.

- Computer simulation:
  In addition to the visual impact of the proposed PV integration on the buildings view, this study aims to investigating the impact of the proposed integration scenarios on the building thermal performance and calculate the annual energy consumption of the existing building (as baseline) in addition to the PV power production calculation of each scenario.
  The computer simulation technique is widely used in this field due to the advanced facilities that this methodology promotes to the researchers.
  The study parameters can be easily adjusted for frequent simulations within short time and the results can be gained in different format.
  In this regards, the Integrated Environmental Solutions-Virtual Environment software has selected for this study due to its various features and capabilities. It is dynamic, performance analytic and quantitative software include various modules such as ModelIT (to build and edit the model’s geometry), SunCast (for shading and visualization analysis), ApacheCalc (for loads’ analysis), ApacheSim (to obtain thermal analysis), MarcoFlo (for natural ventilation analysis), FlucsPro/Radiance (for lighting design), Apache HVAL (for HAVC based components) and other models that allow for various analysis and investigations.
  In addition to the mentioned models, built-in weather files for various locations can be utilized as simulation parameters which include latitude & longitude, altitude, dry & wet bulb temperature, humidity and solar radiation.
  According to the study subject, the obtained results can be categorized in various groups such as:
  - Energy consumption comprises, consumed electricity for heating, cooling, lighting and miscellaneous in addition to the total energy consumption.
  - Cooling load to evaluate the thermal cooling load based on the simulation variables include location, orientation, glazing rational and U-value of construction components.
  - PV systems productivity to evaluate and analyze the electricity production compared with the total energy outcomes. The PV production can be tested for different parameters that impact the power production such as location, inclination angle, PV area and type.

The software is utilized by the specialist consultant in the UAE for energy modeling process as part of Estidama and LEED certificate application and numerous researches have adopted IES-VE software in their studies

The software is relatively costly but the provider promotes a student version for reasonable cost, therefore and in addition to the mentioned features, this simulation tool will be adopted for this study.

- On-Site and Online Survey:

The public acceptance constitutes the fundamental parameter to evaluate the concept of this study from the aesthetic point of view. Two approaches are commonly used by the researchers in this regards, On-site and online survey.

The advantages of the On-site survey represented by:

- The participant can actually and directly observe the case study and comes with a real feedback.
- The feedback will be gathered from the habitant in touch with the case study and their feedback is more considerable than the overseas feedback.
- Does not need advanced technology to distribute the questionnaire or collect the feedback.
- Allow for direct communications with the participants, Therefore, the researchers has opportunities to clarify any doubts or clarification might raise by the participants.

However the manual feedback storing constitutes the main limit of this approach due to the error possibility.

The main advantages of the online survey represented by:

- Wide range of participants locally and globally can be involved.
- Enormous survey websites are available with various facilities.
- Relatively less-cost than On-site survey as no paper, travel and demonstration tools are required.
- Automatic feedback verification and store
- Various output formats (tables, charts …etc) can be automatically generated.
- The questionnaire can be sent by emails or posted on the social media (Facebook, Twitter …etc).

However, the lack of direct communication between the researcher and the participants constitutes the main limitation of this approach.

According to the advantages of both approaches and due to subject of this paper, this methodology will be adopted to investigate the public acceptance and to evaluate the visual impact of the proposed integration approaches on the case study scene.

Chapter 4 – Simulation Models and Application Approaches

4.1 Introduction

The main intention of this research is to investigate the potential of integrating PVs systems in heritage sites taking Dubai Museum as case study due to its architectural features, location, function (former and current) and cultural values.

This chapter explains the main parameters that impact the PVs' power production, selection of the proper PV system and integration techniques such as weather, location, the case study features and public acceptance.

In addition, this chapter presents seven application approaches / scenarios showing various PV systems and installation techniques associated by computer simulations for each proposal to investigate the power production of the proposed PV systems and to what extend that this production contributes in CO_2 emission reduction.

The last section of this chapter describes the on-site and online surveys' feedbacks to explore the public acceptance about three of the seven proposals which produce considerable power and harmonize with the places where to be installed.

The integration technique should take into account that the PV panels appear as part of the place's features where these panels intend to be installed and not visibly look as an additional feature (Kaan & Reijenga, 2004).

The photovoltaic technology market nowadays promotes a wide range of PV modules types and structures which make the integration options / process more flexible and innovated especially for the buildings aimed to be restored and/or renovated.

Opaque, Semi-transparent, Transparent, Semi-flexible and Flexible PV panels are commercially available in different configurations and the proper one has to be carefully selected according to its visual impact on the whole scene of the building where to be installed.

4.2 The Case Study: Dubai Museum (Al Fahidi Fort)

Al Fahidi Fort is the most ancient building in Dubai, in several stages it was constructed close to the Creek coast in the beginning of the last decade of eighteenth century as a defense line in front of the city against neighboring clans' attacks. Along 170 years (1799-1971), the fort was used as Sheikh's palace, ammo's shelter, a garrison and Jail.

The fort was the kernel of the oldest neighborhood in Dubai called "Al Bastakiya" established at the East of the fort. From the beginning of 1890s, it was continuously grown and more houses had been constructed close to each other establishing narrow, tortuous and almost shaded pathways to protect the pedestrians against the harmful direct sun rays and to minimize the heat gain by reducing the exterior walls' area that exposed to the direct solar.

This section discusses Dubai's location and weather as main parameters that impact PVs' performance in addition to the fort's architectural features.

4.2.1 Dubai location

Between 25.18°N - 24.36°N (latitude) and 54.54°E - 55.43°E (longitude), Dubai occupies about 4,114 km^2 which represents about 5% of the overall United Arab Emirates area. It is engaging about 66 km of the Gulf coast and extended about 70 km in the desert (towards South – East).

Figure 4.1 Dubai's location (Google Earth)

The fort is surrounding by roads and car parking areas forming a wide open area that minimizes the shading of the neighboring buildings. The distance between the fort and other buildings is 85m from the South, 40m from the East, 35m from the West and almost free of buildings from the South-West corner which allows direct exposure to the sun and enhances the PV production performance (figure 4.2).

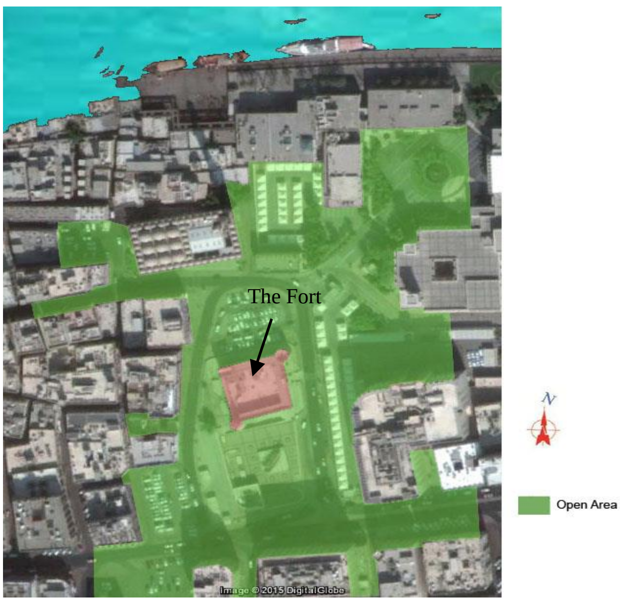


Figure 4.2 Fort's location (Google Earth)

4.2.2 Dubai weather

The PV's performance is extremely affected by the weather characteristics, especially the solar radiation (direct and diffused), winds (dust and particulates), prevailing temperature and relative humidity. These parameters vary depending on the geographical features of the region.

Dubai lies within the arid subtropical region and the weather characteristics of this region are highly recognized in Dubai which comprises three climatic intervals:

- From December to March, the weather tends to be moderate (20°C to 23°C).
- Between May and October, the temperature is around 39°C and reaches 45°C in July; these six months form the summer season in Dubai and the climate ranging between hot/dry and hot/humid.
- Two warm months, April and November, split between these periods at their end with an average temperature of 25°C.

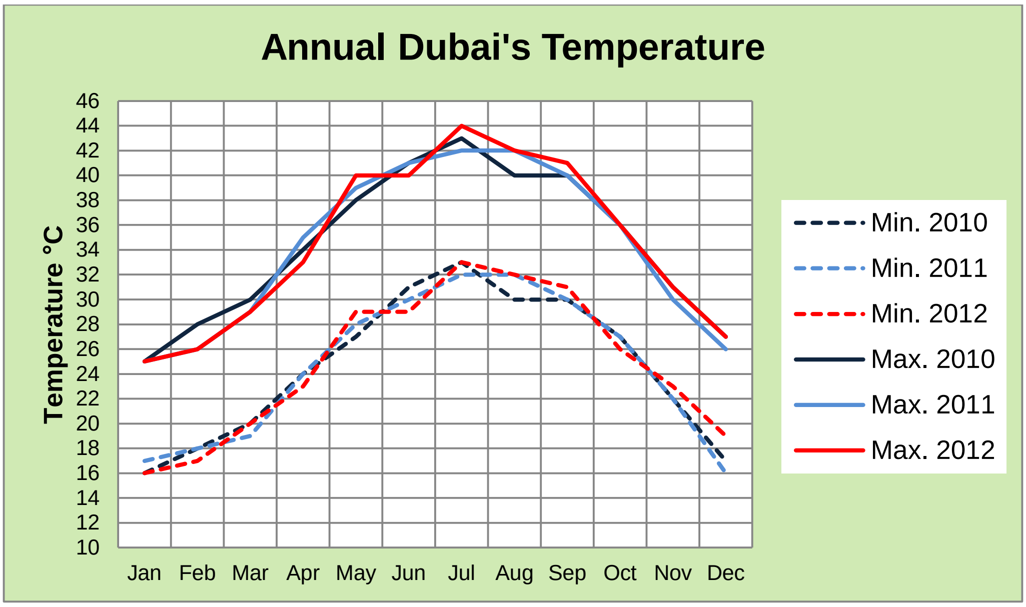


Figure 4.3 Dubai's Temperature (Dubai Statistic Center)

The prevailing wind is blowing from North West popularly called "Shamal Winds" and the ambient air temperature between 9:00 am and 3:00 pm is generally high all over the year, the annual average speed is around 24.7 km/h accompanied by dust.

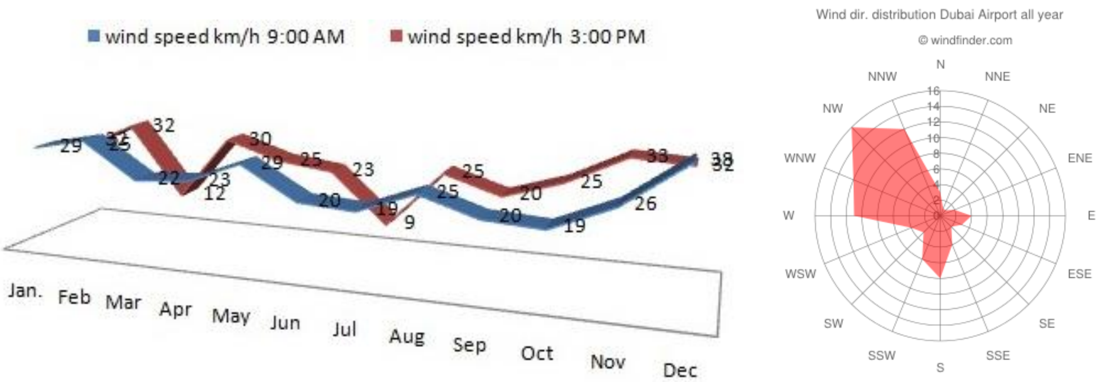


Figure 4.4 Wind speed (Dubai Statistic Center)

The solar radiation (direct and diffused) has negative and positive impacts. Negatively, the high radiation is significantly impact the building's thermal performance which has to be passively treated to diminish the direct heat transmission through openings and windows and indirect heat transmission by means of heat transfer via external envelop.

Positively, the photovoltaic power generation depends on both direct and diffused solar radiation. Dubai's weather file specifies the direct solar radiation for each month with annual average of 6.68 KWh/m².

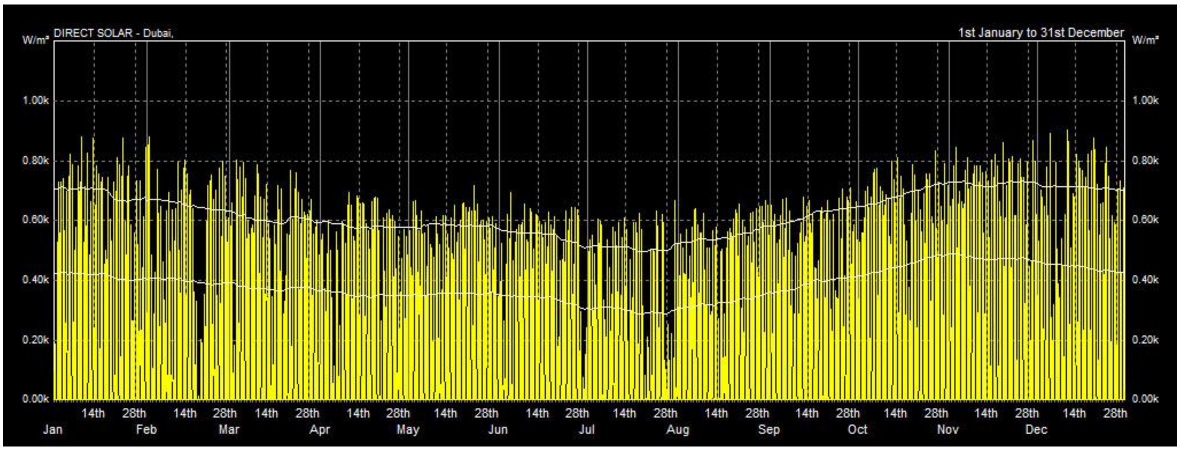


Figure 4.5 Direct Solar Diagram (Ecotect)

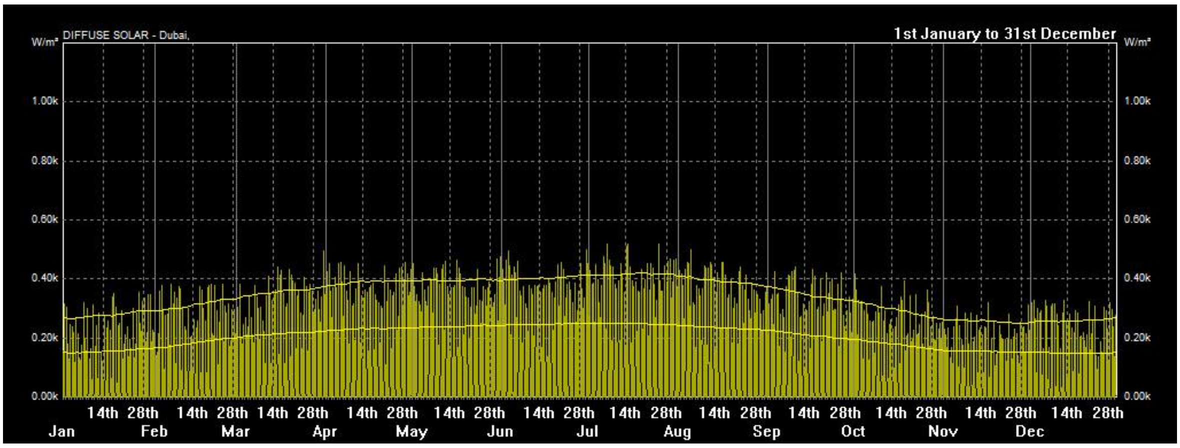


Figure 4.6 Diffused Solar Diagram (Ecotect)

4.2.3 Dubai Museum (Al Fahidi Fort)

The fort's shape is almost square occupying about 1340 square meter of land and comprises three halls at the North, East and South sides forming a central courtyard closed by a 1.1 m thick wall at the West to complete the squared fort's shape.

In addition, three towers are setting at the fort's corners, two circular towers are occupying the North East and South West corners with 9.4 m and 14.2 m height respectively, while a rectangular three stories tower which composes the third tower is standing at the North West corner with 12.6 m height.

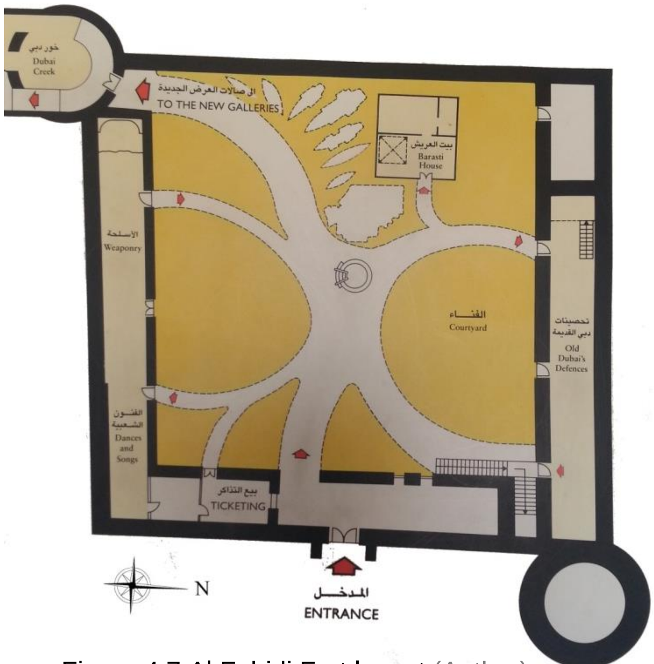


Figure 4.7 Al Fahidi Fort layout (Author)

The thick external and internal walls were built of coral stone extracted from the adjacent creek and cemented by lime. The wall thickness ranging from 0.5 meter (internal wall) to 1.6 meters (external wall) to provide strong, stable, doable and thermally high capacitor walls. The top roof was built in layers comprises clay tiles, woven mat of palm frond, palm's trunks and wooden rods imported from India, Zanzibar and other countries.

Figure 4.8 Fort’s construction elements (Author)

Similar to other forts, the external facades are totally solid with few narrow slots at the top of the towers used for monitoring and observation purposes. On the other side, the internal facades include small and squared openings at the top of the hall's walls to enhance the ventilation process. Nowadays, these openings have internally closed by glass panels to prevent the heat transfer and externally covered by wooden buckle usually used in the traditional houses.

Figure 4.9 Fort's external façade (Author)

Figure 4.10 Fort's internal façade (Author)

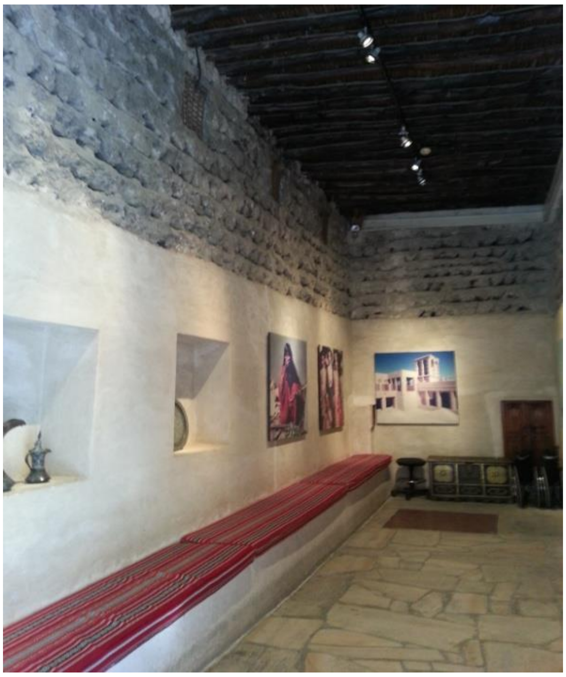
The architectural setup of this fort combines both of the castle's features and vernacular architectural characteristics via solid and thick walls, use local materials, small and few openings and full consideration to the environment and climatic characteristics (orientation, location, weather, site's topography …etc.).

As part of a grand restoration of heritage places program started in the late sixties, the fort was renovated and extended underneath the adjacent plot (at the south) to be utilized as Dubai Museum.

The museum aims to present the daily life activities of Emirates, traditional shipping boats and instruments, relics brought by Asians and Africans traders from their countries, local antiques pieces, former weapons, traditional well …etc. The renovation and construction activities completed in 1971 and opened by Dubai's ruler in the same year.

The refurbishment program of the existing three halls was not limited to the construction works but extended to the function of these halls which was changed to accommodate the new activity “Dubai Museum” including all the necessary modifications.

The Eastern wing was allocated to be the main entrance comprises sitting and waiting hall in one side and the other side is housing administration office and ticketing. The Northern and Southern halls were converted to galleries to display a collection of antiques, arms, old musical devices, archaic weapons and big screens to display documentary videos about Dubai's history associated by folkloric music.



Internal view

External view

Figure 4.11 Fort’s Main Entrance (Author)

The central patio has smartly arranged and utilized as outdoor display area; various exhibits are fixed all around the courtyard while a well has located at the center. A mockup of a traditional house called "Barasty" and locally "Arish" stands at the Northern West corner, it has totally assembled from palm's trunks, woven mat of palm frond and tree trunks with two types of roofs, the horizontal one is made of palms frond while the pitched type is made of fabricated canvases like a tent.

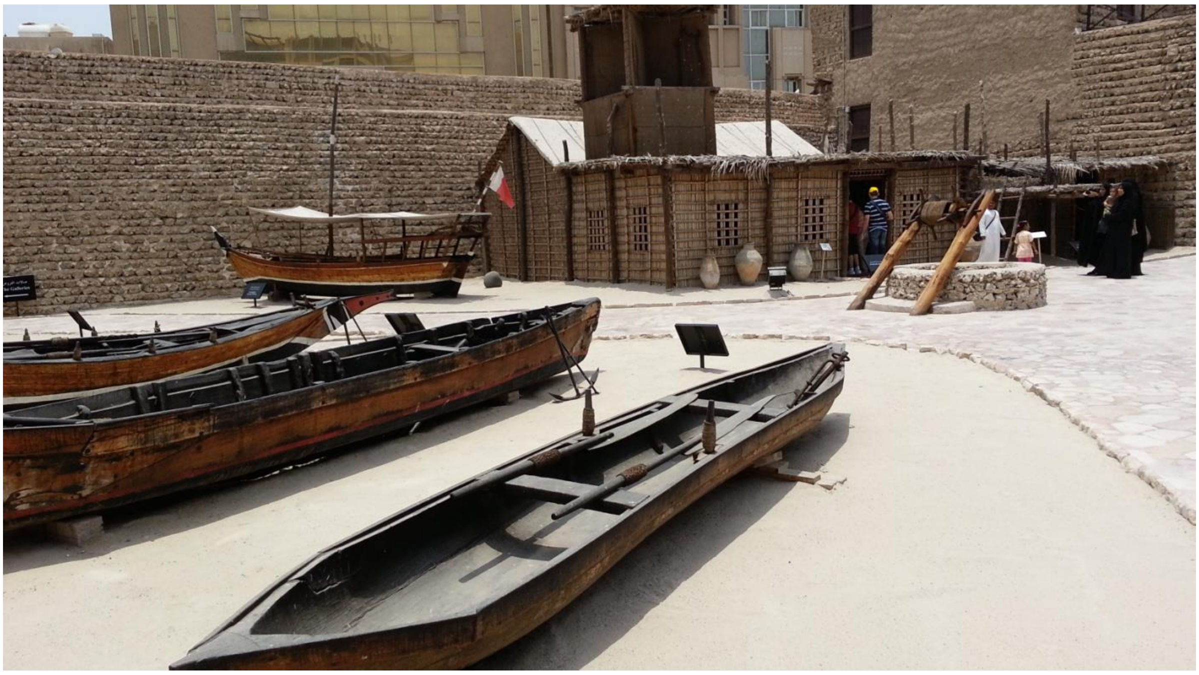


Figure 4.12 Fort's Central Patio (Author)

Two old cannons (made of bronze) with balls are fixed on both sides of the patio's entrance and several traditional boats are distributed in the courtyard showing two types, the small one called locally "Al Hourey" and the bigger with fabric shade called "Abrah" used as transportation means between the creek coasts. A third traditional boat stands out of the fort at the piazza above the new underground extension.

Figure 4.13 Cannons & Boats at Central Patio (Author)

The tourists' number has increased in 2008 affected by the vast development and the completion of many attractive projects which turn Dubai one of the tourism destinations in the region but the tourism activity has slightly inclined in 2009 due to the global financial crises which affected the construction industry and subsequently other related fields such as the tourism industry.

Figure (4.14) reveals the changing in the tourists' number between 2007 and 2012, in spite the slight decrease during 2009, the tourists number has rapidly increased up to 50% in 2012 compared with the 2007 record. Further statistic schedule for regarding the visitors' number is attached in Appendix A.

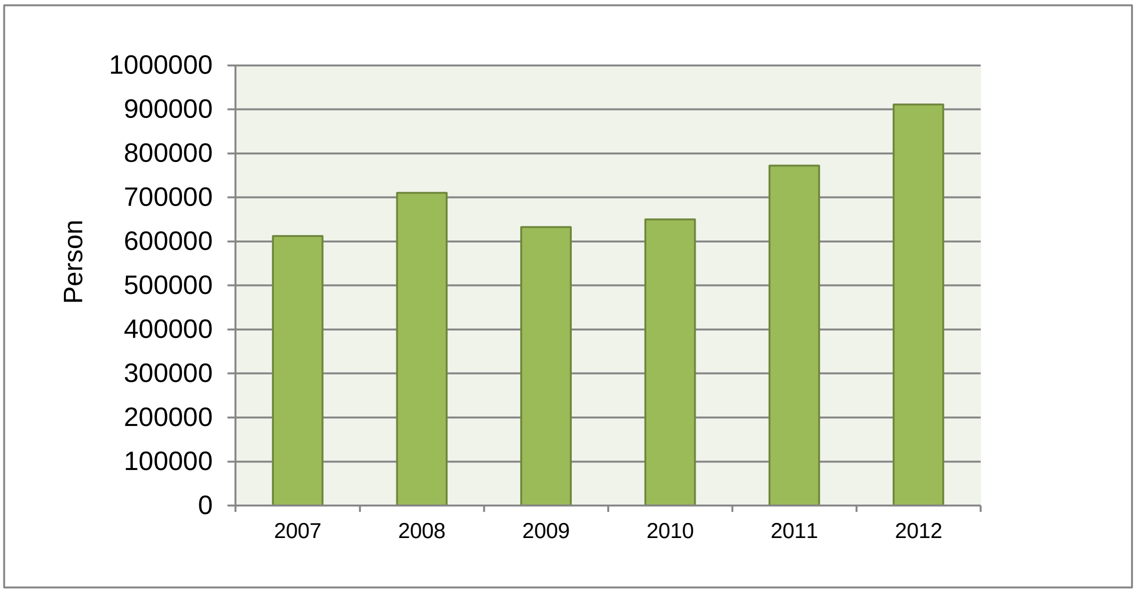


Figure 4.14 Visitors number between 2007 and 2012 (Dubai Statistic Center)

4.3 BASE SIMULATION MODEL

A baseline model for the existing fort has created using IES-VE simulation software based on the site and weather data and considering the building's physical conditions such as construction materials, architectural layout and wall thickness in addition to the thermal conditions which include room conditions, internal gains, system and air exchanges.

This section summarizes all modeling and simulation inputs and presents the simulation model and its output.

4.3.1 Geographical location

The fort (case study) is situated in Dubai city at the Southern coast of Dubai's Creek entrance and oriented 6° East North. The APLocate tool of IES-VE software was used to set the geographic setting and weather data of the fort's location as the location data is linked to IES-VE built-in data belongs to Dubai Intl Airport, United Arab Emirates.

Table 4.01 shows the location and site data to be used as simulation input.

Table 4.1 Location and Site Data (IES-VE APLocate)

• Location Data	Dubai Intl Airport
Region	United Arab Emirates
Latitude	25.25°N
Longitude	55.33°E
Altitude	5m above sea level
Time zone (hours ahead of GMT)	4 hours
Daylight saving time ➢ Time adjustment from through ➢ Adjustment for other months	 0.0 hour 0.0 hour
• Site Data	
Ground reflectance	0.20
Terrain type	City
Wind exposure (CIBSE Heating Loads)	Normal

4.3.2 Climatic Conditions

As stated before, Dubai lies within the arid subtropical region whereas the high temperature and shortage rainfall are the obvious climate characteristics (The UAE National Media Council, 2010).

The weather data file selected for this study is AbuDhabiWEC.fwt as a nearest location to Dubai and defined/generated by IES-VE and acquired by ASHRAE design weather database v4.0. Table 4.2 summarizes the design weather data and for the weather model data refer to Appendix B.

Table 4.2 Design Weather Data (IES-VE APLocate)

• **Design Weather Data Source and Statistics**	
Source of design weather	ASHRAE design weather database v4.0.
ASHRAE weather location	Dubai Intl Airport, United Arab Emirates.
Monthly percentage for Heating Loads design weather	99.60%
Monthly percentage for Heating Loads design weather	0.40%
• **Heating Loads Weather Data**	
Outdoor Winter Design Temperature	12.70°C
• **Cooling Loads Weather Data**	
Max. Outside Dry-Bulb	44.20°C
Max. Outside Wet-Bulb	23.90°C

4.3.3 Thermal Conditions

The assumptions and simulation input are required to generate the thermal conditions of the base model, some of the software default tools setting have been adjusted as the building is very old (built in 1787 and renovate in 1971) and the systems are relatively consumed.

In this regards, the building has divided into four zones according to the function and thermal conditions as following:

- Zone 1: Northern Wing, used as display gallery.
- Zone 2: Southern Wing, used as display gallery.
- Zone 3: part of Eastern Wing, occupied by the administration department.
- Zone 4: part of Eastern Wing, utilized as main entrance and waiting hall.

4.3.3.1 Room Conditions

According to the mentioned zoning, the room conditions are set to the following profiles:

- Heating: set off continuously for all zones.
- Cooling: zone 3 set off continuously as no cooling system has installed for this location. The cooling profile for other zones sets working as per the museum's working hours (08:30am to 08:30pm from Saturday to Thursday and 02:30pm to 08:30pm in Friday). According to ASHRAE, UCLA Energy Design Tools Group (2011), the cooling set point is 23°C.
- District Hot Water System (DHW): set to zero consumption.
- Model Setting: set to default with fraction of 0.05 for solar reflection and furniture mass factor set to 1.
- Plant Auxiliary System: set according to working hours.
- Humidity Control: according to thermal comfort guidelines of ASHRAE, UCLA Energy Design Tools Group (2011), the relative humidity set within 30% - 70% for zones 1, 2 & 4 and set zero for zone 3 as it is non-air-conditioned.

4.3.3.2 Systems

The A/C system installed in the building comprises two types, decorative split unit for administration offices and package unit for the display halls. The Coefficient of Performance of the A/C system has significant impact on its components power consumption.

Shekarchian et al (2011) found that as the COP of the system increases its efficiency increases. This enhancement is related to the vast development in the air conditioning industry in the last three decades.

Using a systematic method, Yu & Chan (2012) evaluated the efficiency of chiller system, it was found that about 0.36% energy saving can be achieved by increase the system's COP from 5.73 to 5.85.

The COP assumption set to 3.8 complies with ASHRAE/IES standard 90.1 (2010). According to this standard, the coefficient of performance of the air conditioning systems have rapidly improved to minimize the power consumption for instant, the COP of the split units has improved along 30 years from 1.7 to 3.8 (figure 4.15).

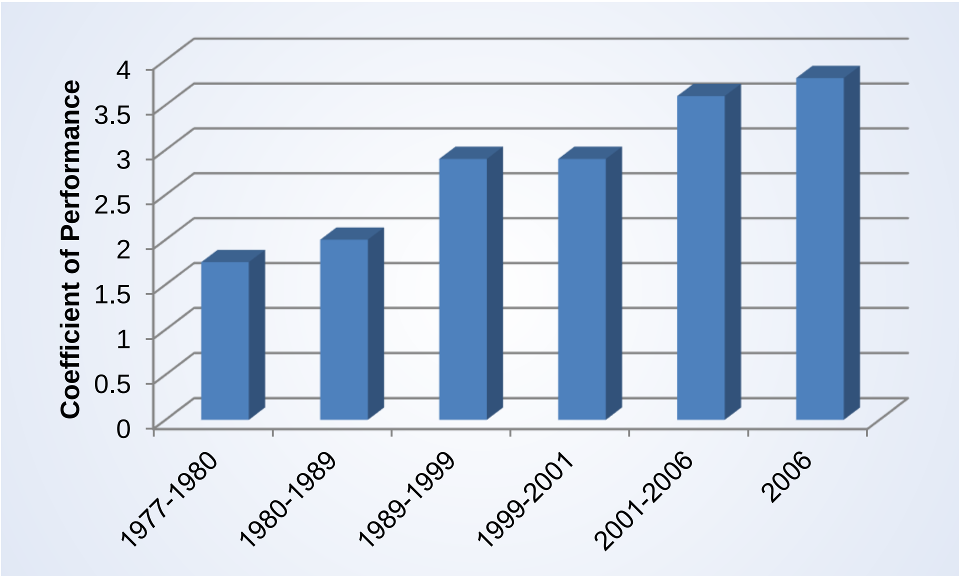


Figure 4.15 COP improvement from 1977- 2006 (ASHRAE/IES Standard 90.12010)

4.3.3.3 Internal Gains

The internal gains varied as per the function of each zone as following:

- Zone 1 & 2: both zones are functionally identical and the internal gains assumed to the existing light fittings and audio systems which include spotlight assigned to 4W/m², fluorescent lighting assigned to 2.7W/ m², sound system assigned to 1.5W/m², display screen set to 1.5W/m², air curtain set to 3W/m² and computer set to 1W/m² (only one PC).
  Due to the zone's function and area whereas the visitors' number is inconstant, the people occupancy assumption set to 8 meters per person.
- Zone 3: occupied by administration department and ticketing, the internal gains include fluorescent lighting set to 2.7W/m², computers and printers set to 25W/m² and people occupation set to 4 persons.
- Zone 4: utilized as main entrance and waiting area. No equipments installed at this space and the internal gains limited to spotlights set to 3W/m² (max.) and fluorescent lighting set to 2.7W/m².

4.3.3.4 Air Exchanges

The infiltration rate of zones 1, 2 and 4 are set to 0.25 air change/hour and according to the museum working hours, the auxiliary ventilation set to 2 air change/hour (max.).

Various screen prints showing the room condition, systems, internal gains and air exchange are presenting in Appendix C.

4.3.4 BASE MODEL

Utilizing IES-VE software, a base simulation model has built based on the architectural drawings received from the archive of the Architectural Heritage Department in Dubai Municipality and considering all the simulation input explained previously.

The IES-VE Building Template Manager has used to identify the construction materials properties as one of the main simulation parameters. As stated, the wall built of coral stone extracted from the creek and cemented by lime, this material not included in the software built-in construction material, therefore the wall material set to lime bricks properties considering the actual thickness of each part.

Figure 4.16 shows the 3D view of the simulation model created by IES-VE software and the solar radiation fall on the exposed surfaces.

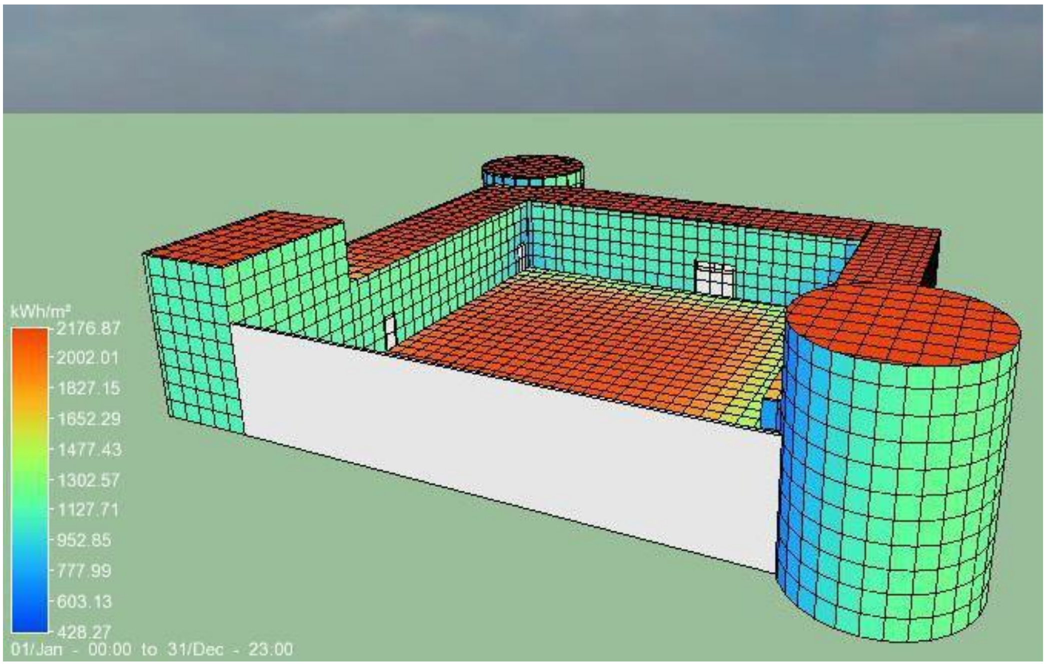


Figure 4.16 Base Simulation Model (IES-VE)

4.4 Application Approaches

The fort's architecture is tricky and minimizing the potential of integrating the photovoltaic systems into its facades. The solid, blind, rough and muddy appearance elevations are the main constrains due to the vast contrast between the old-fashioned scene of the fort and the modern appearance of the PV systems.

Due to the fort's facades style, the PVs integration into these facades is restricted and negatively impacts the antic fashion of the building, instead, seven approaches/scenarios are proposed to apply photovoltaic systems internally within the courtyard and at the top of the fort's wings which are fully exposed to the sun during day time. Figure 4.17 shows the exposed area and the annual average of the solar radiation falls on the courtyard and top roof of the fort's wings.

The selection of the proper PV system depends on the location's properties where the PV to be applied such as orientation, area, exposed / not exposed, shaded / not shaded, capable to install PV and to what extend that the proposed PV configuration will impact / enhance the overall building's scene.

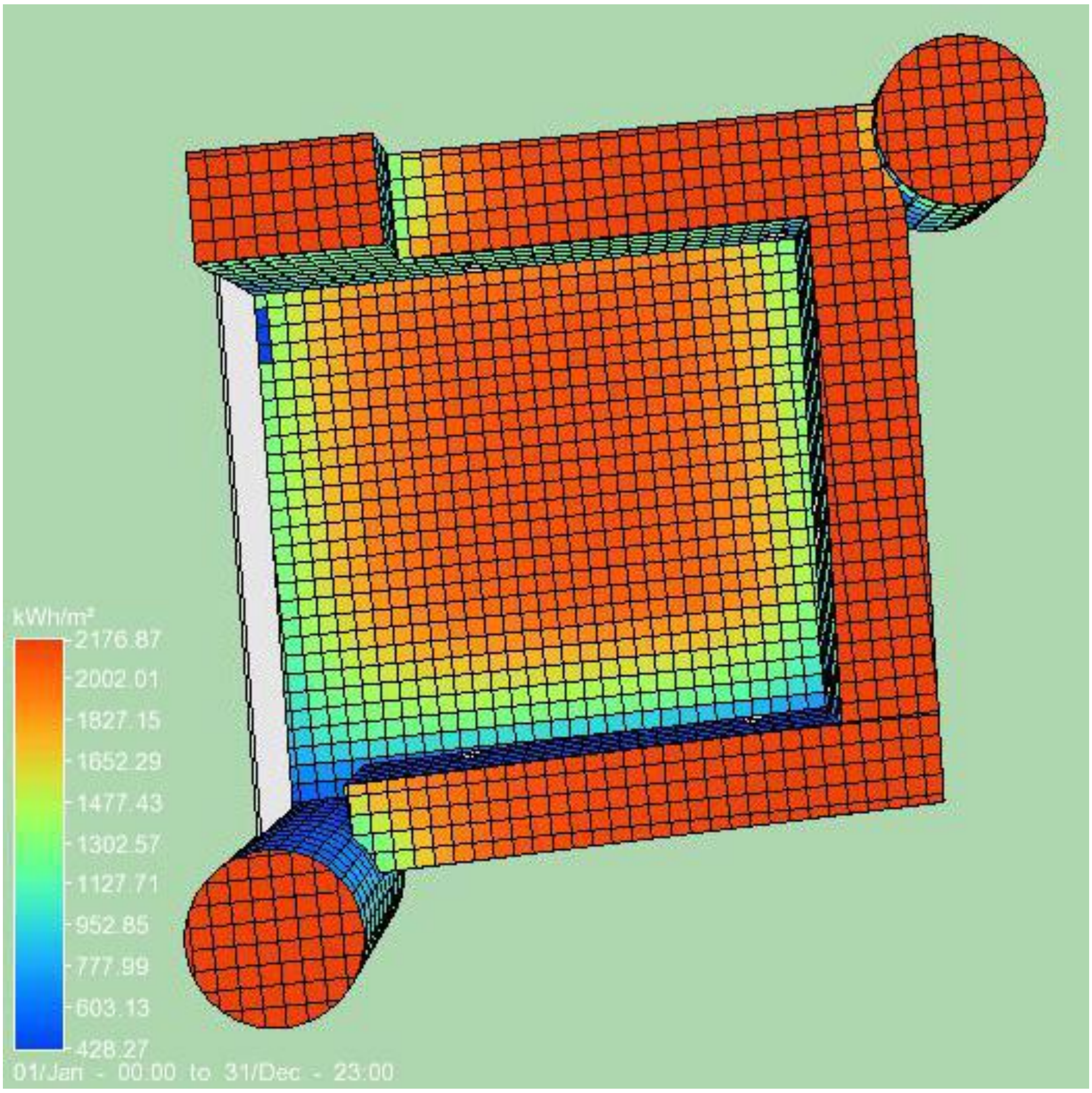


Figure 4.17 Solar Radiation distribution (IES-VE)

4.4.1 Scenario 1

Similar to all ancient forts in the gulf and Middle East countries, a central patio (courtyard) forms the fort's heart where the main activities were carried out and all spaces are directly opined to this patio.

Currently, the central patio of Al Fahidi fort is utilizing as outdoor exhibition area to display various exhibits such as traditional boats, cannons and potteries. This courtyard occupies 56% of the fort's area and fully exposed to the sun during day time which adversely impacts the tourists' tour especially in summer when the temperature reaches 44°c (under shade).

An asymmetric radial passage way arises from the well at the courtyard center links the three fort's wings and leads to the new underground gallery through the South – West tower (figure 4.18).

The passage way arms with the courtyard walls outline sandy zones where number of exhibits that reflect the former lifestyle are displayed but the weather circumstances and full exposure to the ambiance compel the visitors passing the courtyard speedily to avoid hot air and direct sun rays.

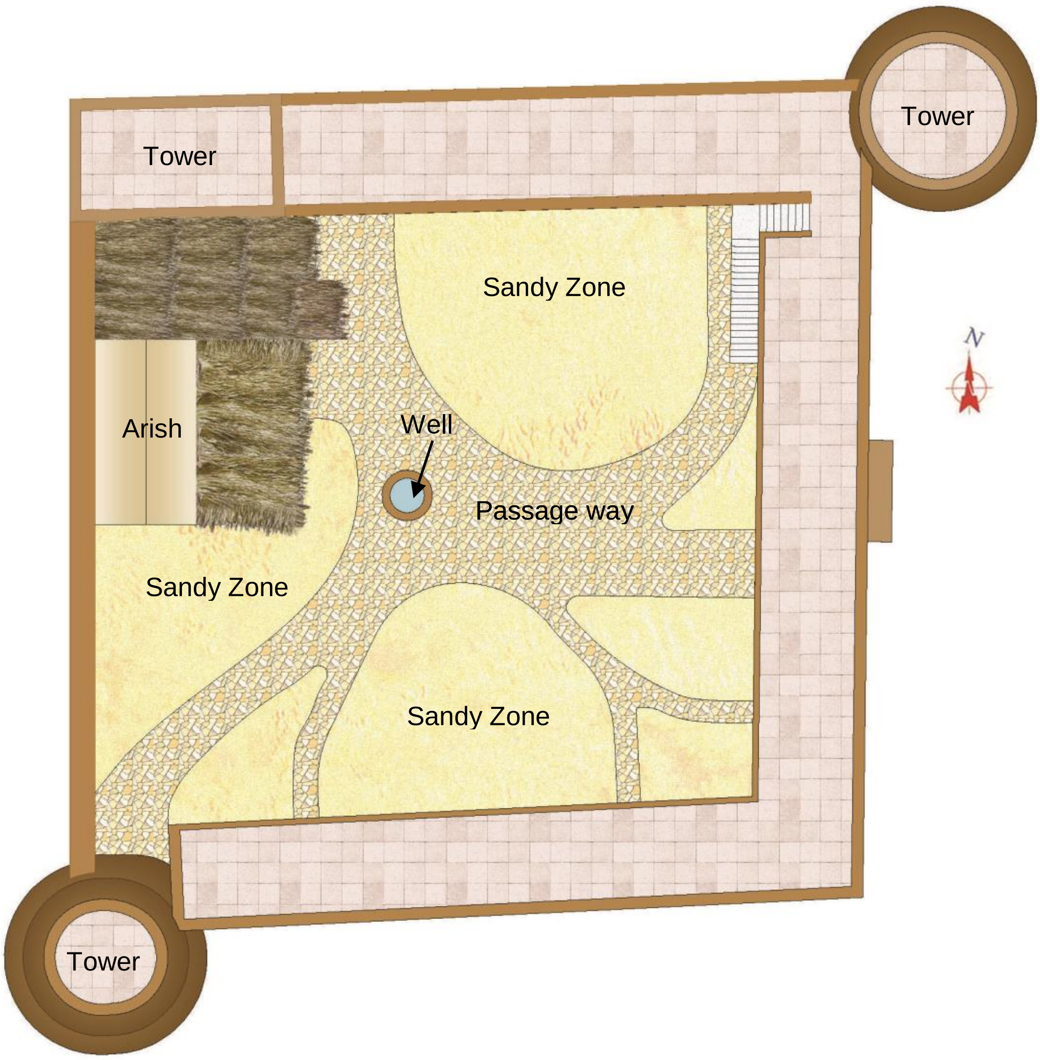


Figure 4.18 Existing Courtyard layout (Author)

To mitigate the impact of these obstacles, a central fabric shade is proposed to cover about 32.5% of the courtyard area at the South – East corner, the shade is extended up to the external parapet of the Southern and Eastern wings for fixation purpose and covers 52% of these wings' roof.

This coverage enhances the roof thermal performance and reduces the annual energy consumption about 300 KWh, from other side the shade to be fixed at central pole near the well forming three segments of an umbrella which emulates the traditional tents.

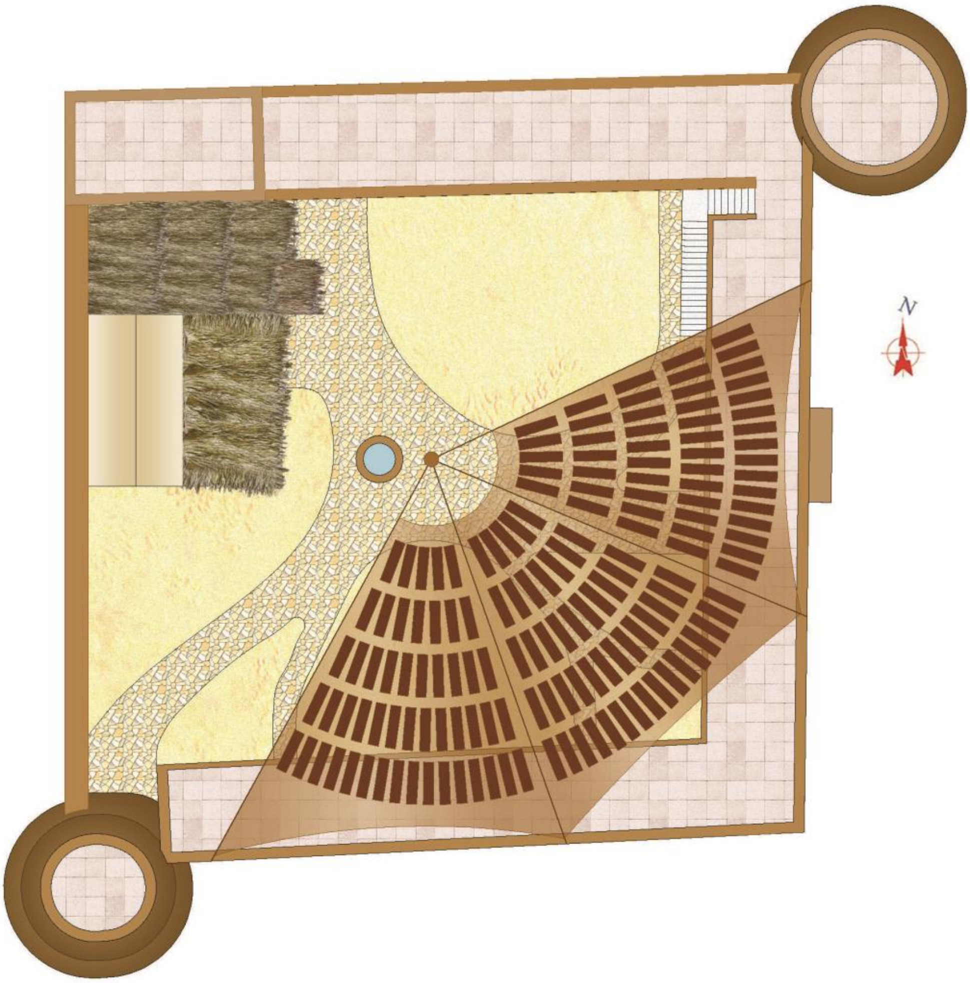
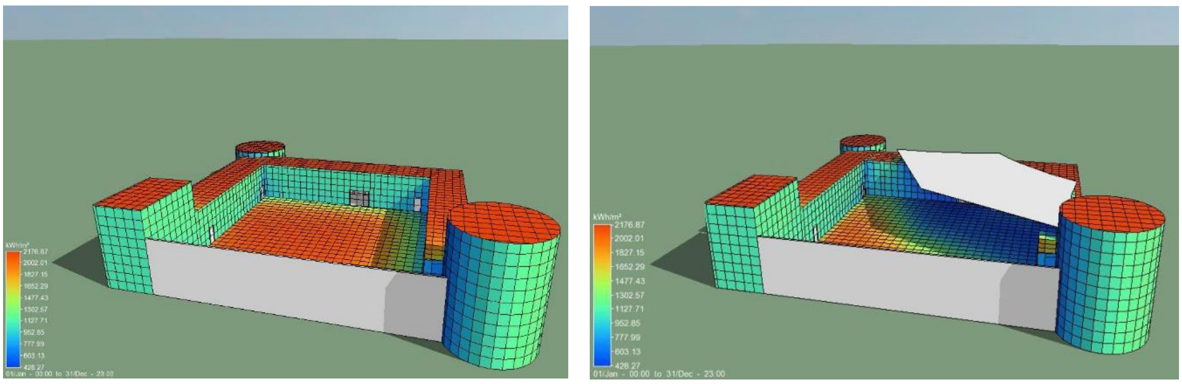


Figure 4.19 Proposed shade at courtyard layout (Author)

The total area of the proposed shade is 380 m² and applicable to install 153 number of 2 x 0.5 m flexible solar panel and each panel comprises 38 No. of 210 x 100mm CIGS cells. The net PV area of each panel is 0.798 m^2 and the overall PV area to be installed at the shade is 122 m². The module efficiency recorded by the manufacturer data sheet is 10.5% measured at the standard condition (refer to Appendix I figure I.2).

Figure 4.20 shows the impact of the central shade (scenario 1) on the solar radiation fallen on the central patio.



Base module

Proposed Shade

Figure 4.20 Base module and proposed shade at courtyard layout (IES-VE)

Figure 4.21 illustrates the existing internal scene of the courtyard while figure 4.22 shows the 3D visual model of the proposed shade to explore the visual impact of this proposal on the overall internal scene of the fort.

Figure 4.21 Existing courtyard (Author)

Figure 4.22 Proposed shade at courtyard (Author)

4.4.2 Scenario 2

Integrating PV panels in the historical building should visibly match the building's context to avoid obvious contrast between the old-fashioned scene of the heritage buildings and the contemporary feature of the PV modules (Kaan & Reijenga, 2004).

As stated before, the fort's architecture is very strict but adding traditional features such as tents and fabric shades increases the potential of integrating PV panels without distorting the overall ancient scene of the forts as these elements were locally used in the same period when the fort was built.

The terrace at the Northern wing of the fort which is linked to the main courtyard by an external staircase is an opportune place to install flexible PV panels within a fabric shades. Figure (4.23) shows the existing terrace as appears from the central courtyard.

Figure 4.23 Existing Northern Wing's Terrace (Author)

The proposal comprises install eight shades (4x4.5m for each) in one row at 2.1m high above the terrace level and inclined 25° towards South.

The total shades area is 144m² which applicable to accommodate 64 flexible solar panel (2 x 0.5m) similar to those proposed for scenario 1. The total PV area is 51m² distributed equally over all shades (8 panels for each). This configuration emulates the traditional shades usually fixed above the shop's entrance in old GCC cities.

In addition to the fabric shades, wooden rods similar to those used at the fort's roof structure are proposed as supports to fix the shades. These wooden rods to be fixed in two rows, one along the existing handrail at the terrace internal edge and the other row at the rear parapet of the Northern wing in level higher than the first row to occur the required inclination. Figure (4.24) shows the proposed shades with PV panels integrated within these shades.

Figure 4.24 Proposed shade at Northern Wing's Terrace (Author)

4.4.3 Scenario 3

The fort is surrounding by public car parking area at North side, main road at East, big boat at South and 10m width open area at West with low-high boundary wall running at the plot limits which defines with the fort's Western wall an opened enclosure (figure 4.25) can be utilized for various external activities such as display area, assembling point for tourist groups and sitting area with refreshment services.

Figure 4.25 Existing open area at West (Author)

A 50m² fabric shade is proposed to cover area close to the fort's wall and fixed on this wall from one side and other side is supported on three wooden poles fixed on the ground (figure 4.26).

Figure 4.26 Proposed shade at West wall (Author)

This configuration was commonly used in historical markets and public external area to prevent direct exposure to the sun. The proposed shade is applicable to receive 22m² of flexible PV panels made of CIGS cells.

4.4.4 Scenario 4

Twenty-four 2.067x1.046 m monocrystalline Solar Panel are proposed to be installed at the Northern wing terrace. Currently this terrace is publicly inaccessible and can accommodate such PV type to avoid the vast contrast between the modern scene of the PV panel and the ancient appearance of the building as the floor level of the terrace where the solar panel to be installed is invisible.

Figure 4.27 Proposed Monocrystalline PV panels at Northern Wing's Terrace (Author)

Each panel comprises 128 pieces of 130x130 mm monocrystalline cells and the overall PV cells area of the 24 panels is 51.3 m^2. The cell efficiency is 22.5% while the panel efficiency recorded by the manufacturer data sheet is 20.1% measured at the standard condition (refer to Appendix I figure I.1).

4.4.5 Scenario 5

The mockup of a traditional house (locally known "Areesh") stands at the Northern West corner of the central courtyard shows the common house of the poor families in the pre-oil era which can be utilized to install flexible PV panels (figure 4.28), but the setup of this mockup needs to be re-arranged and re-oriented to face the sun.

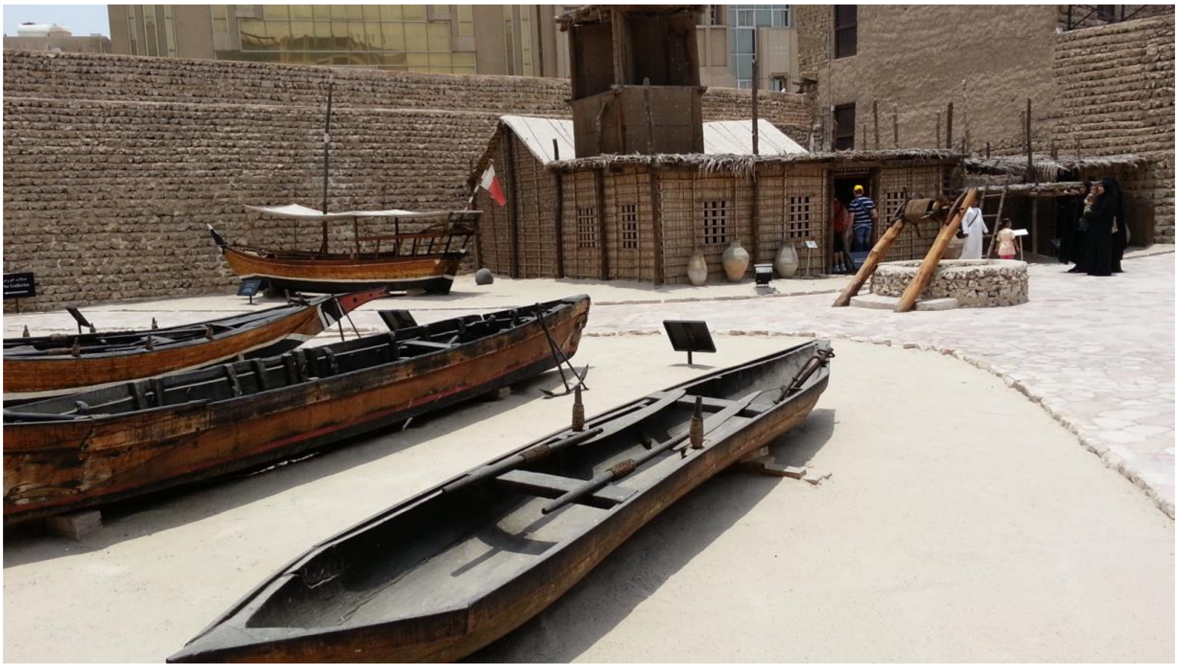


Figure 4.28 Existing "Areesh" (Author)

The fabricated canvas pitched roof is applicable to receive flexible PV panels but its direction has to be changed from West – East to South – North direction to face the sun, figure (4.29) shows the modified pitched roof that allow PV installation.

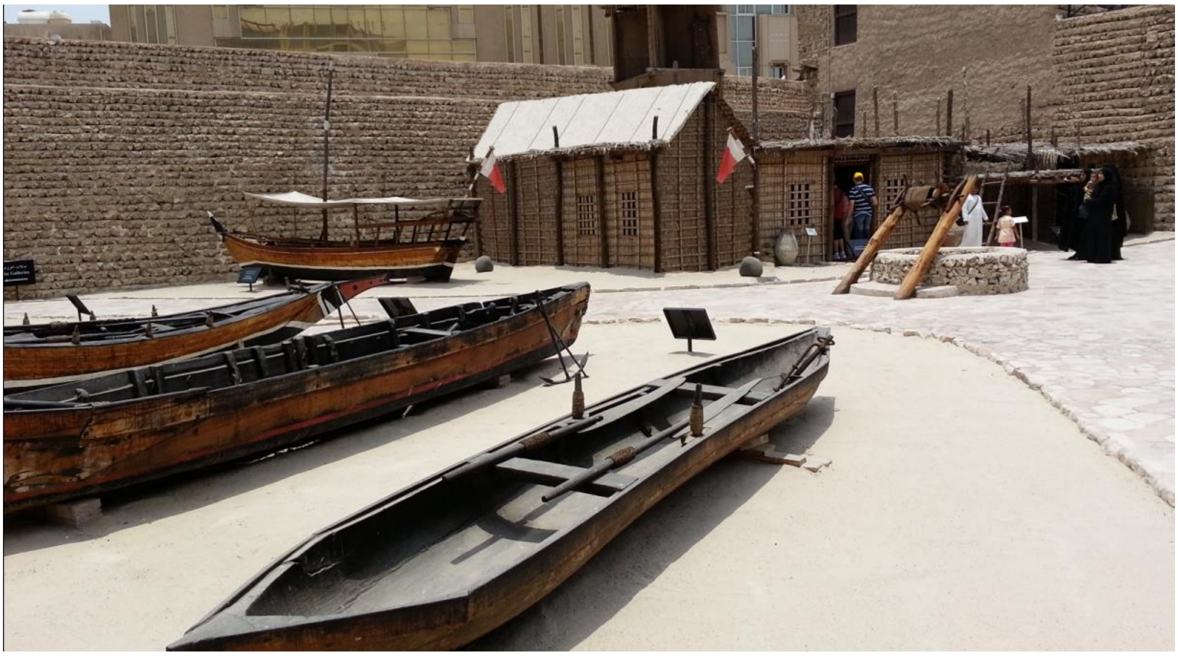


Figure 4.29 Modified "Areesh" (Author)

The proposed South-face pitched roof area is 20 m^2 and applicable to receive 14 No. of 2 x 0.5m flexible solar panel similar to those proposed in scenario 1 and the overall PV area can be installed at this roof is 11 m^2 (figure 4.30).

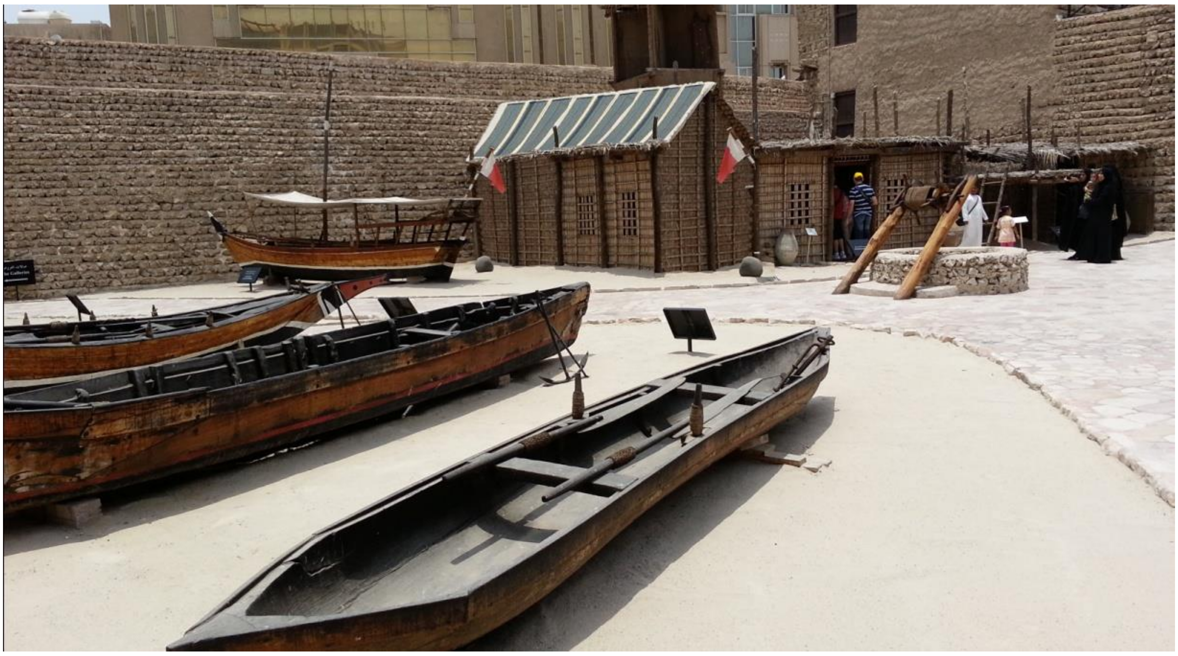


Figure 4.30 Proposed PV panels at "Areesh" roof (Author)

4.4.6 Scenario 6

Opposite the “Areesh”, an external staircase constructed at the North – East corner of the courtyard leads to the Northern and Eastern wings roofs. This staircase is totally exposed to the sun and faces the South.

Figure 4.31 Existing staircase (Author)

Three fabric shades are proposed to cover the staircase at 2.4 m height from the steps level and diagonally to be fixed at 25° which is almost parallel to the stair inclination. The area of each shade is about 4 m^2 (2.2x1.8m) and applicable to integrate 3 flexible PV panels (CIGS) similar to those proposed at “Areesh” roof, the total area of the PV panels to be installed at the fabric shades is about 7 $m^{2.}$

Figure 4.32 Proposed shade at the staircase (Author)

4.4.7 Scenario 7

In addition to the CIGS flexible PV panels and monocrystalline solar panels proposed for the mentioned scenarios, a semi-transparent monocrystalline PV panels are proposed to be installed at the existing wooden handrail along the terrace edge of the Northern wing (figure 4.33).

Figure 4.33 Existing handrail at Northern wing (Author)

The 23 m length handrail is applicable to receive 31 number of 1 x 0.72 m PV panels, each one comprises 28 (4 x 7) monocrystalline cells (125 x 125 mm) and the total PV area can be integrated in this handrail is 13.5 m².

The proposed semi-transparent PV panel is available in various colors allows the designers / architects select the proper color that matching the features of the place where to be integrated (figure 4.34), the data sheet of the proposed PV panel is presented in Appendix I (figure I.3).

Figure 4.34 Proposed transparent PV at Northern wing handrail (Author)

Chapter 5 – Results and Discussion

5.1 Introduction

The result of this study will be discussed and analyzed in this chapter. Initially, the outcomes of the base simulation model will be presented to explore the existing energy consumption, then the results of all simulations carried out for all proposals will be discussed and compared with the baseline outcome to identify the energy saving of each proposal.

Based on the simulation results, the most applicable and feasible proposals from the energy production and aesthetic value point of view will be determined for On-Site and Online surveys to explore the public acceptance.

Finally, the surveys feedback will be presented and analyzed to explore to what extend the people will accept the concept of integrating the PV systems in the heritage buildings.

5.2 Simulation Results

In this section, the simulation results of the base model and all proposals will be presented associated by graphs and tables to identify these results.

5.2.1 Base Model

The IES-VE simulation software has used to obtain the energy consumption of the existing building. The simulation output to be utilized for comparison purpose to investigate the impact of the proposed scenarios on the annual energy consumption and the building's thermal performance.

The annual energy consumption shown in figure 5.1, it is obvious that the consumption is the highest in summer months and the peak consumption records in August (above 6.5 MWh). The lowest consumption records in winter months as the air conditioning systems are usually switched off.

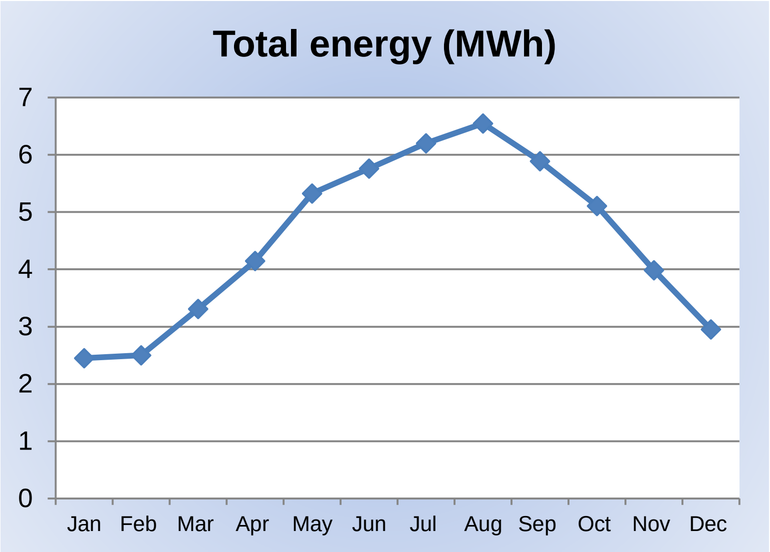


Figure 5.1 Annual energy consumption of Base Model (IES-VE)

Table 5.1 shows the total energy consumption and the breakdown of each month include system, lights and equipments energy with carbon emission.

Table 5.1 Energy consumption breakdown of Base Model (IES-VE)

Date	Total system energy (MWh)	Total lights energy (MWh)	Total equip. energy (MWh)	Total energy (MWh)	Total CE ($kgCO_2$)
Jan	0.3108	1.7539	0.3853	2.4501	1267
Feb	0.5491	1.6002	0.3517	2.501	1293
Mar	1.1328	1.785	0.3924	3.3102	1711
Apr	2.081	1.6923	0.3717	4.1451	2143
May	3.1492	1.785	0.3924	5.3265	2754
Jun	3.6572	1.7234	0.3788	5.7593	2978
Jul	4.0616	1.7539	0.3853	6.2008	3206
Aug	4.3703	1.785	0.3924	6.5477	3385
Sep	3.7861	1.7234	0.3788	5.8883	3044
Oct	2.9708	1.7539	0.3853	5.11	2642
Nov	1.8821	1.7234	0.3788	3.9843	2060
Dec	0.8136	1.7539	0.3853	2.9528	1527
Total	28.7646	20.8333	4.5782	54.1761	28009

It should be noted that the base model has utilized for the simulation process of all proposals with all necessary modifications required to fit the proposal's components such as adding fabric shades to the model's geometry for scenarios 1 and 2 and the platform below the proposed PV panels for scenario 4.

In order to calculate the power generation of the proposed scenarios, the PV specific data has loaded includes PV type, area, efficiency, temperature coefficients and inclination angle (various simulations have carried for different inclination angles to investigate the best angle that produce the maximum power).

Various screen prints showing the photovoltaic panel performance parameters of all scenarios are presented in Appendix D while Appendix E shows the energy consumption and PV power generation charts of these scenarios.

5.2.2 Scenario 1

Various IES simulations were carried out to investigate the best inclination angle that produce the maximum power. Figure (5.2) reveals that the maximum power generation is recorded at 25° (about 22.8 MWh/y).

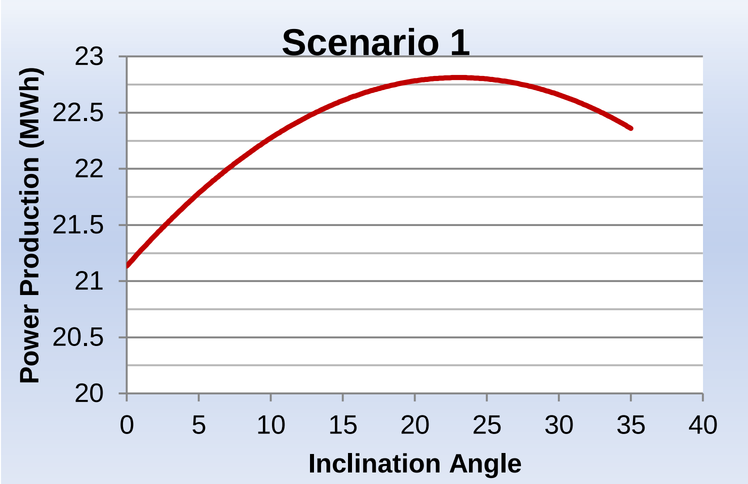


Figure 5.2 Annual power productions for various inclination angles (IES-VE)

Due to the site's condition and surroundings, the distant construction is located at 85m away from the Southern side where the shade can be easily seen if its inclination is 10°, 15° and 25°. In order to avoid the obvious appearance of the shade and its visual impact on the fort's scene, it has to be installed at 5° from horizon.

Figure (5.3) shows various fixation angles to explore the proper inclination angle to keep the shade away from the fort's periphery lines and avoid the visual impact of this shade on the overall fort's scene.

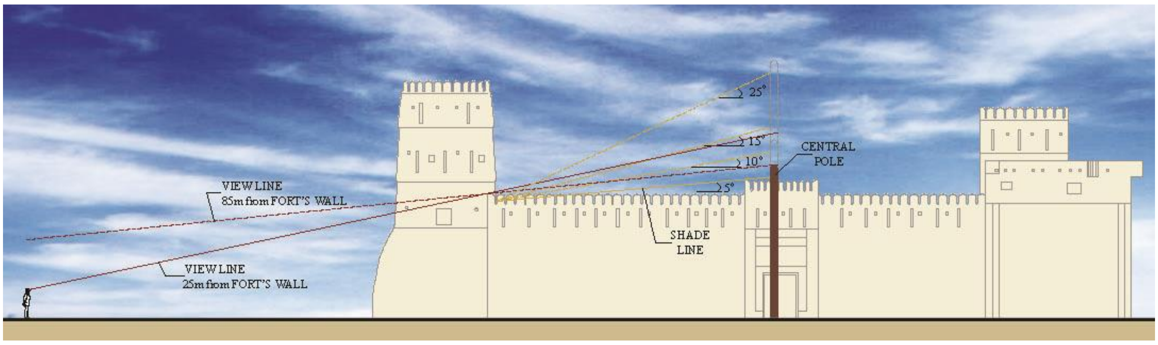


Figure 5.3 Shade's inclination angles and view positions (Author)

The annual energy production of the 122m^2 CIGS flexible PV panels at 5° inclination angle (considering 10.5% efficiency under standard conditions) is 21.78 MWh constitutes about 40% of the annual energy consumption and contributes in 41.7% reduction in CO_2 emission.

The energy consumption breakdown of the building under the effect of the proposed PV systems shown in table 5.2, it is clear that the thermal performance of the building is enhanced under the effect of the proposed shade as it covers 52% of the Northern and Eastern wings. Accordingly, the annual energy consumption is reduced about 300 KWh comparing with the base model.

Table 5.2 PV production and Energy consumption breakdown of Scenario 1 (IES-VE)

Date	Total system energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total energy (MWh)	Total consumption (MWh)	PV generated electricity (MWh)	Total CE ($kgCO_2$)
Jan	-1.0878	1.7539	0.3853	1.0514	2.4371	-1.3857	527
Feb	-1.0237	1.6002	0.3517	0.9282	2.4867	-1.5585	461
Mar	-0.6431	1.785	0.3924	1.5343	3.2881	-1.7538	772
Apr	0.1352	1.6923	0.3717	2.1992	4.1235	-1.9242	1114
May	0.8551	1.785	0.3924	3.0325	5.3001	-2.2676	1541
Jun	1.4179	1.7234	0.3788	3.5201	5.7261	-2.2061	1793
Jul	1.8547	1.7539	0.3853	3.9939	6.1599	-2.166	2039
Aug	2.2072	1.785	0.3924	4.3845	6.5119	-2.1274	2241
Sep	1.8125	1.7234	0.3788	3.9147	5.8522	-1.9375	2001
Oct	1.1729	1.7539	0.3853	3.3121	5.0852	-1.7731	1691
Nov	0.4574	1.7234	0.3788	2.5596	3.9653	-1.4057	1306
Dec	-0.4746	1.7539	0.3853	1.6646	2.9407	-1.276	845
Total	6.6837	20.8333	4.5782	32.0952	53.8768	-21.7816	16332

5.2.3 Scenario 2

The proposal includes 51m^2 CIGS flexible PV panels to be installed within 144m^2 fabric shades at the Northern Wing terrace similar to those proposed in scenario 1. Several IES simulations were carried out at different inclination angles to determine the best fixing angle that produces maximum power.

Figure (5.4) shows that the annual power production at 15°, 20° and 30° are almost same but the maximum power production can be gained at 25°.

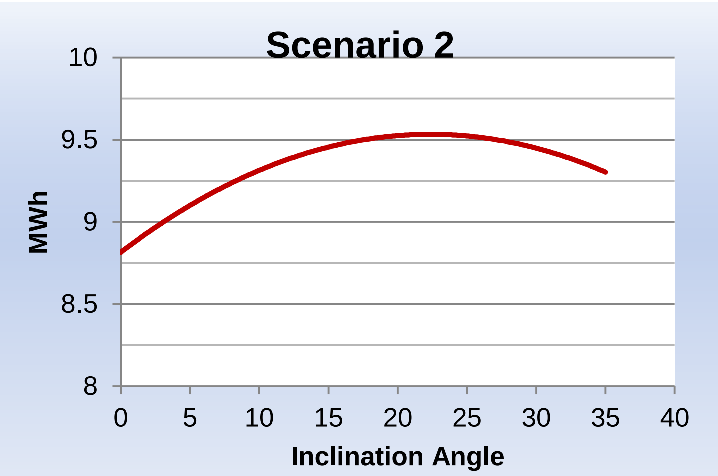


Figure 5.4 PV power production at various inclination angles (IES-VE)

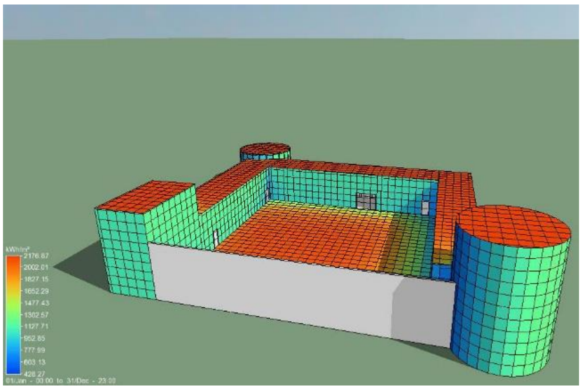
The annual energy production of the proposed PV panels at 25° inclination angle is 9.53 MWh constitutes about 17.7% of the annual energy consumption and contributes in 18% reduction in CO_2 emission.

Table 5.3 PV production and Energy consumption breakdown of Scenario 2 (IES-VE)

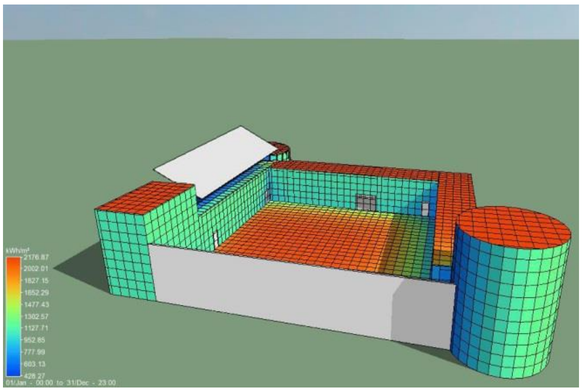
Date	Total system energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total energy (MWh)	Total consumption (MWh)	PV generated electricity (MWh)	Total CE (kgCO2)
Jan	-0.42	1.7539	0.3853	1.7192	2.4462	-0.727	880
Feb	-0.2308	1.6002	0.3517	1.7211	2.4907	-0.7695	881
Mar	0.3381	1.785	0.3924	2.5154	3.2942	-0.7787	1291
Apr	1.2674	1.6923	0.3717	3.3315	4.1232	-0.7917	1713
May	2.2475	1.785	0.3924	4.4248	5.2977	-0.8729	2277
Jun	2.8091	1.7234	0.3788	4.9113	5.7333	-0.822	2529
Jul	3.2077	1.7539	0.3853	5.3469	6.1706	-0.8237	2754
Aug	3.482	1.785	0.3924	5.6593	6.5125	-0.8532	2916
Sep	2.9155	1.7234	0.3788	5.0177	5.8577	-0.84	2584
Oct	2.1085	1.7539	0.3853	4.2477	5.0904	-0.8427	2186
Nov	1.1453	1.7234	0.3788	3.2475	3.9741	-0.7266	1670
Dec	0.1255	1.7539	0.3853	2.2647	2.9483	-0.6837	1163
Total	18.9958	20.8333	4.5782	44.4072	53.9389	-9.5317	22844

In addition to the power production, the proposed shade enhances the thermal performance of the Northern wing's roof as it is shading 70% of the roof area. This enhancement reduces the overall annual energy consumption about 238 KWh.

Figure 5.5 shows the simulation model of this scenario in addition to the base model to illustrate the impact of the proposed shade on the solar radiation fallen on the Northern Wing roof.



Base module



Proposed Shade

Figure 5.5 Proposed shade at Northern wing terrace (IES-VE)

Figure 5.6 shows the combination of the central shade (scenario 1) and the Northern terrace shade (scenario 2) and their extended shadow on the central patio and the Northern wing roof.

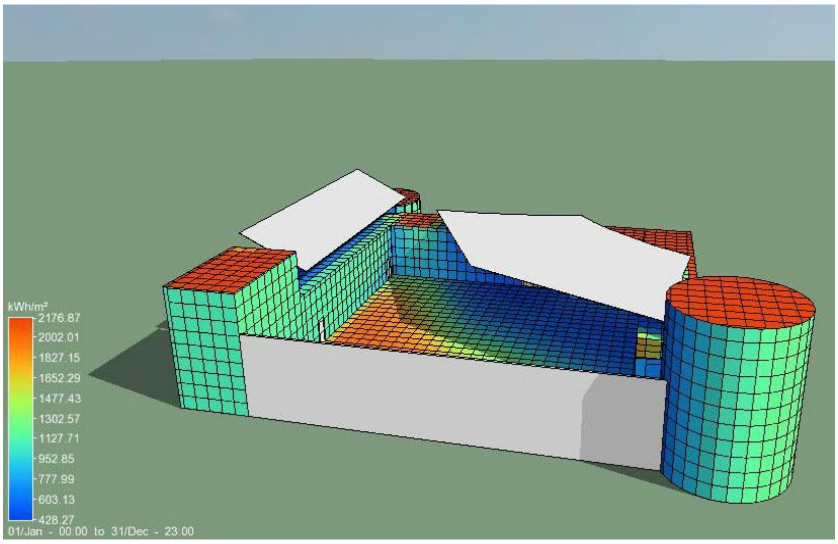


Figure 5.6 Combination of the central shade and the terrace shade (IES-VE)

5.2.4 Scenario 3

Using IES simulation software, the annual power production of the 22m^2 CIGS flexible PV panels of this approach calculated for horizontal set up (0° inclination) is 3.81 MWh, which constitutes about 7% of the annual energy consumption and results 7.2% reduction in the annual CO_2 emission.

The energy consumption breakdown and PV system energy production shown in table 5.4, it is clear that this proposal has no impact on the building's thermal performance as it is out of the building.

Table 5.4 PV production and Energy consumption breakdown of Scenario 3 (IES-VE)

Date	Total system energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total energy (MWh)	Total consumption (MWh)	PV generated electricity (MWh)	Total CE ($kgCO_2$)
Jan	0.082	1.7539	0.3853	2.2213	2.4501	-0.2288	1146
Feb	0.2864	1.6002	0.3517	2.2383	2.501	-0.2627	1154
Mar	0.8269	1.785	0.3924	3.0042	3.3102	-0.306	1550
Apr	1.7383	1.6923	0.3717	3.8024	4.1451	-0.3427	1962
May	2.739	1.785	0.3924	4.9164	5.3265	-0.4101	2537
Jun	3.2552	1.7234	0.3788	5.3574	5.7593	-0.402	2765
Jul	3.6685	1.7539	0.3853	5.8078	6.2008	-0.393	2998
Aug	3.9893	1.785	0.3924	6.1666	6.5477	-0.381	3184
Sep	3.4462	1.7234	0.3788	5.5484	5.8883	-0.3399	2864
Oct	2.6682	1.7539	0.3853	4.8075	5.11	-0.3026	2482
Nov	1.6489	1.7234	0.3788	3.7511	3.9843	-0.2332	1936
Dec	0.6043	1.7539	0.3853	2.7436	2.9528	-0.2092	1416
Total	24.9533	20.8333	4.5782	50.3648	54.1761	-3.8112	25993

5.2.5 Scenario 4

A 2.067x1.046 m monocrystalline Solar Panel are proposed to install at the Northern wing terrace, the total PV area is 51.3m² and the cell efficiency is 22.5% while the panel efficiency as per the manufacturer data sheet is 21.1% which is considered in the simulation process.

Using IES-VE software, multi simulations were carried out to investigate the best inclination angle that produce maximum power. Figure (5.7) reveals that the maximum power generation is recorded at 25° from horizontal.

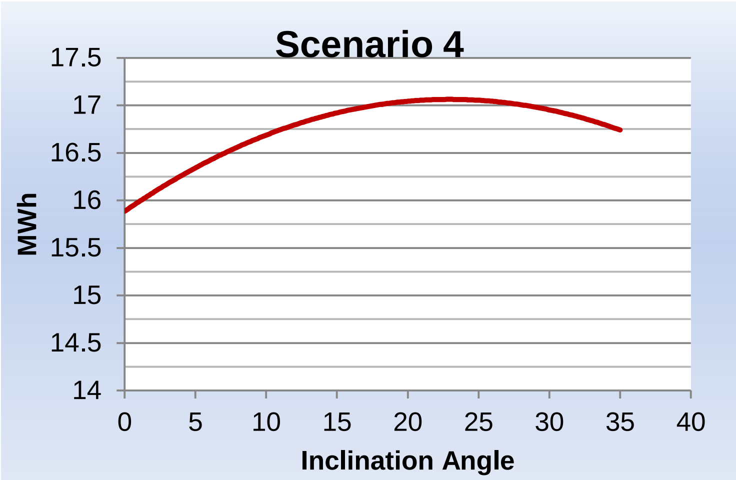


Figure 5.7 PV power production at various inclination angles (IES-VE)

Table 5.5 shows the power generation of the proposed PV system at 25° inclination angle and the annual energy consumption breakdown of the building.

Table 5.5 PV production and Energy consumption breakdown of Scenario 4 (IES-VE)

Date	Total system energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total energy (MWh)	Total consumption (MWh)	PV generated electricity (MWh)	Total CE ($kgCO_2$)
Jan	-0.9919	1.7539	0.3853	1.1474	2.4502	-1.3029	578
Feb	-0.8221	1.6002	0.3517	1.1298	2.4994	-1.3696	568
Mar	-0.2653	1.785	0.3924	1.9121	3.3059	-1.3938	972
Apr	0.6581	1.6923	0.3717	2.7222	4.1386	-1.4163	1390
May	1.579	1.785	0.3924	3.7564	5.3174	-1.561	1923
Jun	2.172	1.7234	0.3788	4.2742	5.7487	-1.4745	2192
Jul	2.57	1.7539	0.3853	4.7092	6.1892	-1.48	2417
Aug	2.8338	1.785	0.3924	5.0112	6.5367	-1.5255	2572
Sep	2.2806	1.7234	0.3788	4.3828	5.8791	-1.4963	2248
Oct	1.464	1.7539	0.3853	3.6033	5.105	-1.5018	1845
Nov	0.5784	1.7234	0.3788	2.6806	3.9827	-1.3021	1370
Dec	-0.4154	1.7539	0.3853	1.7238	2.9532	-1.2294	876
Total	11.6414	20.8333	4.5782	37.0529	54.1062	-17.0532	18952

In addition to the power generation, the installation of the PV panels enhances the thermal performance of the Northern wing roof by shading 42% of the roof area and reduces the annual energy consumption about 70 KWh.

Furthermore, the annual CO_2 emission is 32% less than the annual CO_2 emission associated with the conventional consumed energy.

5.2.6 Scenario 5

The pitched roof of “Areesh” mockup is applicable to receive 11m² of CIGS flexible PV panels, similar to scenario 4, multi IES simulations carried out to investigate the pitched roof inclination angle that produces the maximum power. Figure 5.8 shows that the maximum power production is at 25°, which is compatible with the roof inclination.

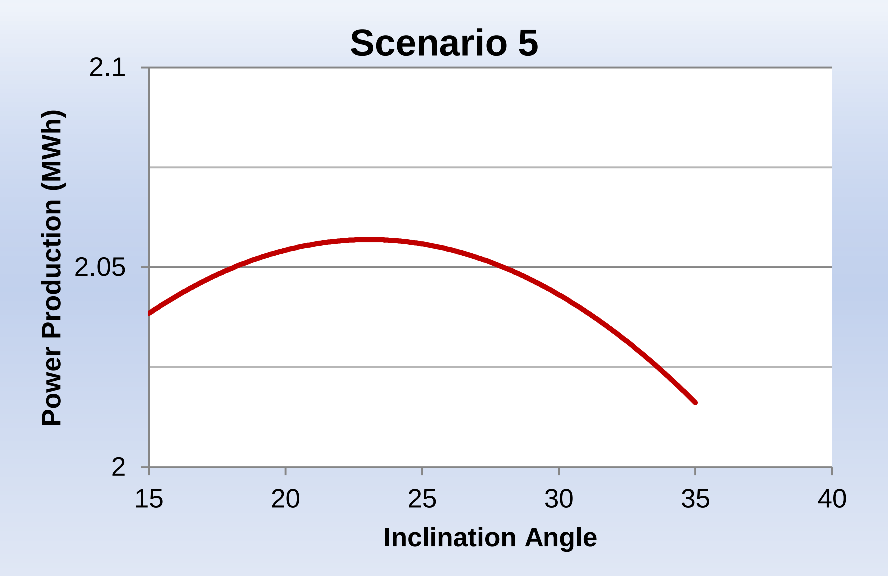


Figure 5.8 PV power production at various inclination angles (IES-VE)

The power generation of the proposed PV system exceeds little bit 2 MWh which consequently contributes in 4% reduction in the annual CO_2 emission. The energy consumption and power generation of the PV system shown in table 5.6 measured at 25° inclination angle.

The proposal has no impact on the building’s thermal performance as the PV panels to be installed at a place out of the built-up area.

Due to the major changes in the mockup composition required to face the sun and the limited power generation of the proposed PV panels, this proposal is worthless and inefficient from visual and power generation point of view.

Table 5.6 PV production and Energy consumption breakdown of Scenario 5 (IES-VE)

Date	Total system energy (MWh)	Total lights energy (MWh)	Total equip. energy (MWh)	Total energy (MWh)	Total consumption (MWh)	PV generated electricity (MWh)	Total CE ($kgCO_2$)
Jan	0.154	1.7539	0.3853	2.2933	2.4501	-0.1568	1184
Feb	0.3831	1.6002	0.3517	2.335	2.501	-0.166	1205
Mar	0.9649	1.785	0.3924	3.1422	3.3102	-0.168	1623
Apr	1.9102	1.6923	0.3717	3.9743	4.1451	-0.1708	2053
May	2.9609	1.785	0.3924	5.1382	5.3265	-0.1883	2654
Jun	3.4799	1.7234	0.3788	5.5821	5.7593	-0.1773	2884
Jul	3.8839	1.7539	0.3853	6.0231	6.2008	-0.1777	3112
Aug	4.1863	1.785	0.3924	6.3636	6.5477	-0.184	3288
Sep	3.605	1.7234	0.3788	5.7071	5.8883	-0.1812	2948
Oct	2.7891	1.7539	0.3853	4.9283	5.11	-0.1818	2546
Nov	1.7254	1.7234	0.3788	3.8276	3.9843	-0.1567	1977
Dec	0.6661	1.7539	0.3853	2.8053	2.9528	-0.1475	1449
Total	26.7088	20.8333	4.5782	52.1202	54.1761	-2.0561	26921

5.2.7 Scenario 6

The fabric shades proposed to cover the staircase at the central courtyard can accommodate 7m² of CIGS flexible PV panels, the annual power production of this area at 25° inclination angle is 1.3 MWh and results about 2.5% reduction in the annual CO_2 emission (table 5.7). Due to the limited power generation, this proposal is worthless especially for lonely use.

Table 5.7 PV production and Energy consumption breakdown of Scenario 6 (IES-VE)

Date	Total system energy (MWh)	Total lights energy (MWh)	Total equip. energy (MWh)	Total energy (MWh)	Total consumption (MWh)	PV generated electricity (MWh)	Total CE ($kgCO_2$)
Jan	0.2111	1.7539	0.3853	2.3503	2.4501	-0.0998	1214
Feb	0.4435	1.6002	0.3517	2.3954	2.501	-0.1056	1237
Mar	1.0259	1.785	0.3924	3.2033	3.3102	-0.1069	1655
Apr	1.9723	1.6923	0.3717	4.0364	4.1451	-0.1087	2086
May	3.0294	1.785	0.3924	5.2067	5.3265	-0.1198	2690
Jun	3.5443	1.7234	0.3788	5.6465	5.7593	-0.1128	2918
Jul	3.9485	1.7539	0.3853	6.0877	6.2008	-0.1131	3146
Aug	4.2532	1.785	0.3924	6.4306	6.5477	-0.1171	3323
Sep	3.6708	1.7234	0.3788	5.773	5.8883	-0.1153	2983
Oct	2.8552	1.7539	0.3853	4.9944	5.11	-0.1157	2581
Nov	1.7824	1.7234	0.3788	3.8846	3.9843	-0.0997	2007
Dec	0.7197	1.7539	0.3853	2.859	2.9528	-0.0938	1477
Total	27.4563	20.8333	4.5782	52.8678	54.1761	-1.3083	27317

5.2.8 Scenario 7

Considering the temperature coefficient (0.41%), PV area (13.5 m²) and module efficiency (19%) of the proposed semi-transparent PV panels, various IES simulations were carried out to investigate the inclination angle that produces the maximum power. Figure 5.9 reveals that the maximum power production can be gained at 25°.

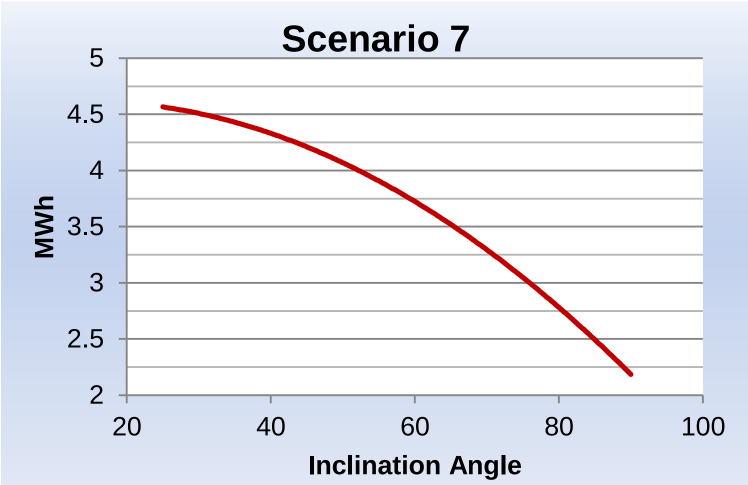


Figure 5.9 PV power productions at 25°, 60° & 90° inclination angles (Author)

Commonly, the handrail setup is vertical and the power production at this angle is 2.18 MWh (table 5.8). According to the limited power production comparing with the system price (about 0.6 $/WATT) and the mismatch between the irregular shape of the wall brick units below the handrail and the sharp geometric pattern of the proposed PV panel, this proposal is unfeasible and inapplicable.

Table 5.8 PV production and Energy consumption breakdown of Scenario 7 (IES-VE)

Date	Total system energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total energy (MWh)	Total consumption (MWh)	PV generated electricity (MWh)	Total CE (kgCO2)
Jan	0.0172	1.7539	0.3853	2.1565	2.4501	-0.2936	1111
Feb	0.2911	1.6002	0.3517	2.243	2.501	-0.258	1157
Mar	0.9467	1.785	0.3924	3.124	3.3102	-0.1862	1613
Apr	1.9585	1.6923	0.3717	4.0226	4.1451	-0.1225	2078
May	3.0615	1.785	0.3924	5.2389	5.3265	-0.0876	2707
Jun	3.5799	1.7234	0.3788	5.6821	5.7593	-0.0773	2937
Jul	3.9748	1.7539	0.3853	6.1141	6.2008	-0.0867	3160
Aug	4.2693	1.785	0.3924	6.4466	6.5477	-0.101	3332
Sep	3.6294	1.7234	0.3788	5.7316	5.8883	-0.1567	2961
Oct	2.7254	1.7539	0.3853	4.8646	5.11	-0.2454	2512
Nov	1.6034	1.7234	0.3788	3.7056	3.9843	-0.2787	1912
Dec	0.5231	1.7539	0.3853	2.6624	2.9528	-0.2904	1373
Total	26.5804	20.8333	4.5782	51.9919	54.1761	-2.1841	26854

5.3 Selection of Proper Approach

Figure 5.10 summarizes the power production of all proposals based on the parameters described in table 5.9 such as PV area, PV type, inclination angle, location and weather characteristics plugged-in as weather file to IES-VE simulation software.

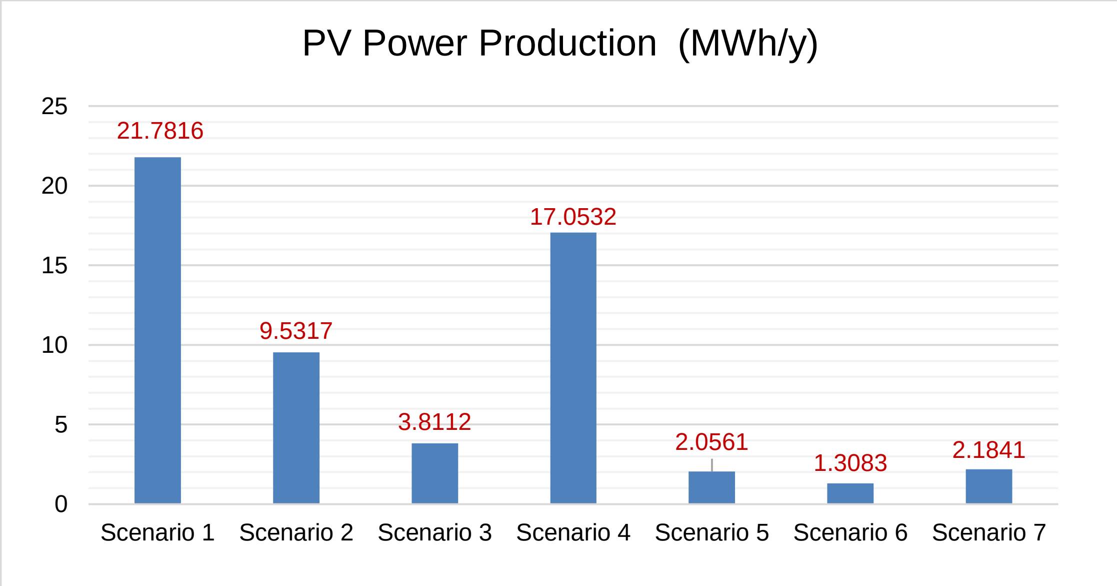


Figure 5.10 Power productions of all proposals (Author)

Table 5.9 Power production and parameters of all proposals (Author)

Scenario No.	Location	PV type	Available Area (m²)	PV area (m²)	PV efficiency **@ STD**	Inclination angle	PV Power Production (MWh/y)	Consumed energy from grid (MWh/y)	Total Annual Consumption (MWh)	Energy Saving %
1	Courtyard	CIGS flexible sheet	380	122	10.5%	5°	21.7816	32.0952	53.8768	40.4%
2	Northern Wing's Roof	CIGS flexible sheet	140	51	10.5%	25°	9.5317	44.4072	53.9389	17.7%
3	External area (West)	CIGS flexible sheet	50	22	10.5%	0°	3.8112	50.3648	54.1761	7.0%
4	Northern Wing's Roof	Monocrystalline	110	51	20.1%	25°	17.0532	37.0529	54.1062	31.5%
5	Arish	CIGS flexible sheet	20	11	10.5%	25°	2.0561	52.1202	54.1761	3.8%
6	staircase	CIGS flexible sheet	12	7	10.5%	25°	1.3083	52.8678	54.1761	2.4%
7	Northern Wing's handrail	Monocrystalline (semi - transparent)	23	13.5	19%	90°	2.1841	51.9919	54.1761	4.0%

Table 5.10 shows the total power consumption of the building under the effect of the proposed scenarios comparing with the basic power consumption as a result of enhancing the thermal performance of the roofs where these proposals to be installed.

In addition, the table demonstrates the contribution of each proposal on the CO_2 emission as a result of the energy saving gained from the PVs' generated power and the enhancement of the roofs' thermal performance.

Table 5.10 Proposals' impact on the power consumption and CO_2 emission (Author)

Scenario No.	Location	PV type	Total Annual Consumption (MWh)	Basic Annual Consumption (MWh)	Proposal impact on Annual Consumption (KWh/y)	Basic Annual CE ($kgCO_2$)	Revised Annual CE ($kgCO_2$)	CE Reduction ($kgCO_2$) %
1	Courtyard	CIGS flexible sheet	53.8768	54.1761	-299.300	28009	16332	41.7%
2	Northern Wing's Roof	CIGS flexible sheet	53.9389	54.1761	-237.200	28009	22844	18.4%
3	External area (West)	CIGS flexible sheet	54.1761	54.1761	N/A	28009	25993	7.2%
4	Northern Wing's Roof	Monocrystalline	54.1062	54.1761	-69.900	28009	18952	32.3%
5	Arish	CIGS flexible sheet	54.1761	54.1761	N/A	28009	26921	3.9%
6	staircase	CIGS flexible sheet	54.1761	54.1761	N/A	28009	27317	2.5%
7	Northern Wing's handrail	Monocrystalline (semi - transparent)	54.1761	54.1761	N/A	28009	26854	4.1%

As stated before, scenarios 5, 6 & 7 are worthless due to the limited power production and do not enhance the thermal performance of the building, therefore these scenarios are not viable for more study / analysis.

On other hand and In spite of the considerable power generation can be gained from scenario 4 (about 17 MWh/y), this proposal is significantly impacted by the proposed shade at the same place (scenario 2) which shades 70% of the terrace area and consequently reduces the power generation of scenario 4. In addition to this conflict, scenario 4 is invisible therefore, it will be overlooked as there is no visual impact to be studied in this regards.

Accordingly, the first three scenarios are more viable for further study due to their power production and the visual impact of these proposals on the overall fort's scene. Therefore, these proposals will be engaged in on-site and online surveys to explore the public acceptance about the idea of integrating PV systems in such heritage building and to determine the most suitable proposal that harmonizes with the architectural features where to be installed.

5.4 Survey

The heritage site is one of the community's assets and constitute a cultural value which should be maintained, therefore the public acceptance about any restoration, renovation and modification works might affect the original building's configuration plays significant roles for the designers / architects to proceed further in a specific modification works during the study / design stage and for the dissection makers later on as well.

In this regards On-Site and Online surveys were conducted to explore the public perceptions and to investigate the main parameters behind their acceptance or refusal.

For both surveys, a questionnaire sheet has arranged and divide into two groups, the first group comprises general information to identify the gender, nationality, education level and occupation of the participants. The nationality reveals how the cultural background of various nationalities influences the participant's feedback and evaluation while the education and occupation reflect the participant's professionalism to prove the questionnaire credibility.

The second group comprises 10 questions and adopts three replay methods, scoring system ranging from 1 (low) to 10 (high) to identify the harmony of each proposal with the fort's architecture (Q1) and to evaluate the idea of integrating the PV systems in the heritage building considering three aspects Energy Saving, Aesthetic Value and as New Concept (Q2).

Ranging from Strongly Negative to Strongly Positive is forming the second method for question 3 which asks the participants how these proposals will affect visitors' trip while the third method is adopted for questions 4 to 10 and the answers are ranging from Strongly Disagree to Strongly Agree.

These questions aim to explore the impact of the proposals on the visitors' convenience (Q4 & Q5) and the emulation of utilizing renewable energy sources in such buildings with their adoption (in the past) with the environment (Q6).

Question 7 focuses on the relation between the public acceptance and their awareness about the environmental impact of utilizing renewable energy sources while questions 8 and 9 ask about the visual impact of the proposals on the aesthetic value of the heritage building.

Finally, question 10 aims to explore the applicability of integrating PV panel in the heritage building. The questionnaire sheet template attached in Appendix F (for both English and Arabic versions).

5.4.1 On-Site Survey

To ensure more realistic and actual feedback from wide range of nationality and various cultural backgrounds, the on-site survey was conducted at the case study location, Dubai Museum.

Due to the museum's internal roles, it is prohibited display any poster or graphical portrait inside the display galleries, instead the museum administration proposed two locations to display the 3D visual model of the proposed scenarios either at the entrance lobby or at the exit hall for only 2 hours a day over 1 week.

The survey has targeted the tourist groups, individual visitors (singles and families) and the museum staff. A 3D visual board has prepared to illustrate the proposals configurations. It comprises two pictures for each scenario, first one shows the existing location where the shade to be applied and the second shows the same location after applying the shade to allow the participant compare between the two cases and observe the visual impact of these proposals on the existing scene. Moreover, the board includes a short brief about the concept of this study (in Arabic and English) to explain the environmental benefits of adopting such concept. The 3D Visual Board is presented in Appendix G.

Practically, the exit hall is the best location to present the 3D visual board, at this point, the participants become familiar with the fort's components and perceive the impact of the prevalent climate conditions on their tour (the survey was conducted between 11:00 am and 01:00 pm when the temperature start increases and the sun be plumb). In this manner, the participants are ready to give realistic feedback.

Some of on-site photos are presented in Appendix H showing the interaction between the author and the visitors.

Along one week (10^{th} to 16^{th} May, 2014), 91 persons participated in this survey, 69% male and 31% female from different nationalities (figure 5.11) and various education background (figure 5.12).

Figure 5.11 On-Site Participants' Nationalities (Author)

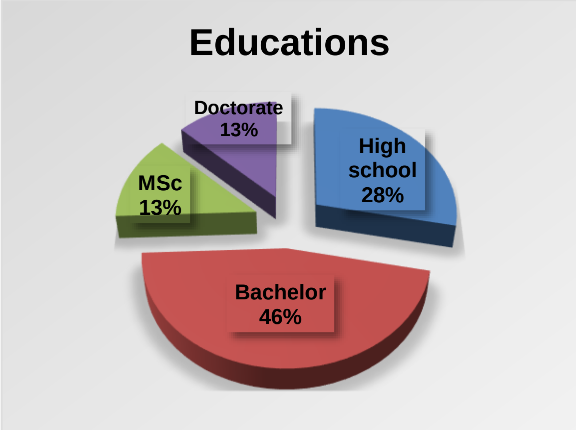


Figure 5.12 On-Site Participants' Education (Author)

The participants' occupations are varied, 18% students, 10% Engineers, 10% Academics, 5% Architects and 57% include accountants, tourist guides, security, ITs, officers, administrators, graphic designer, lawyer, teachers and archaeologist.

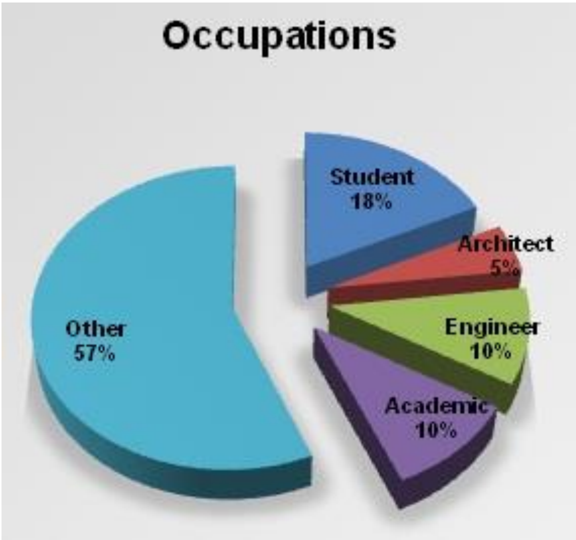


Figure 5.13 On-Site Participants' Occupations (Author)

Several reasons stand behind the relatively limited participants despite the daily considerable number of visitors who come-in such as:

- Most of the tourist groups come from East Asia where English and Arabic are commonly unknown; therefore, the communication was very difficult between the author and the visitors.
- There was no enough time for the group members to have a look and give their feedback as they are normally correlated to a particular schedule of tours.
- The exit hall is quite small with few waiting seats; therefore, most of the visitors go out after their tour.
- The limited time allocated for the survey by the museum administration.

The scoring level to evaluate the proposals harmony with the fort's architecture has categorized into three groups, low score (1 to 4), high score (5 to 9) and full score (10), accordingly, the participants' feedback been tabulated in table 5.11.

More than 70% of the participants believe that all scenarios are in harmony with the building's architecture as all gained higher score, the table reveals that scenarios 1 and 2 gained similar evaluation while scenario 3 achieved maximum full score and minimum low score.

Table 5.11 Proposals' harmony with the fort's architecture (Author)

Score / Proposal	Low Score (below 5)	High Score (above 5)	Full Score
Scenario 1	23.0%	43.6%	33.4%
Scenario 2	23.0%	43.6%	33.4%
Scenario 3	28.2%	43.6%	35.9%

Table 5.12 shows the participants' assessment about the subject of this study concerning three aspects, Energy Saving, Aesthetic Value and as New Concept. Based on these criteria, the study concept achieved higher scores from 75% of the participants and more.

Table 5.12 Proposals assessment (Author)

Score / Criteria	Low Score (below 5)	High Score (above 5)	Full Score
Energy Saving	23.0%	38.5%	38.5%
Aesthetic Value	25.6%	43.6%	30.8%
New Concept	17.9%	43.6%	38.5%

Nearly 57% of the participants' feedback about the impact of the integration idea on the site visit is ranging between slightly positive, positive, and strongly positive (5%, 28.5% & 23% respectively) and 15% believe that the influence will be strongly negative while 29% of the participants are not sure in this matter.

Ranging between strongly agree and agree, 71% of the participants believe that the proposals will enhance the visitors' convenience (23% and 48% respectively) while 29% are not sure.

Consequently, the visitors will get chance to stay more as 72% of the participants feedback ranging between strongly agree and agree (26% and 46% respectively), the hesitant constitute 20% of the participants and the rest believe that there will be no impact in this regard (refer to figure 5.14).

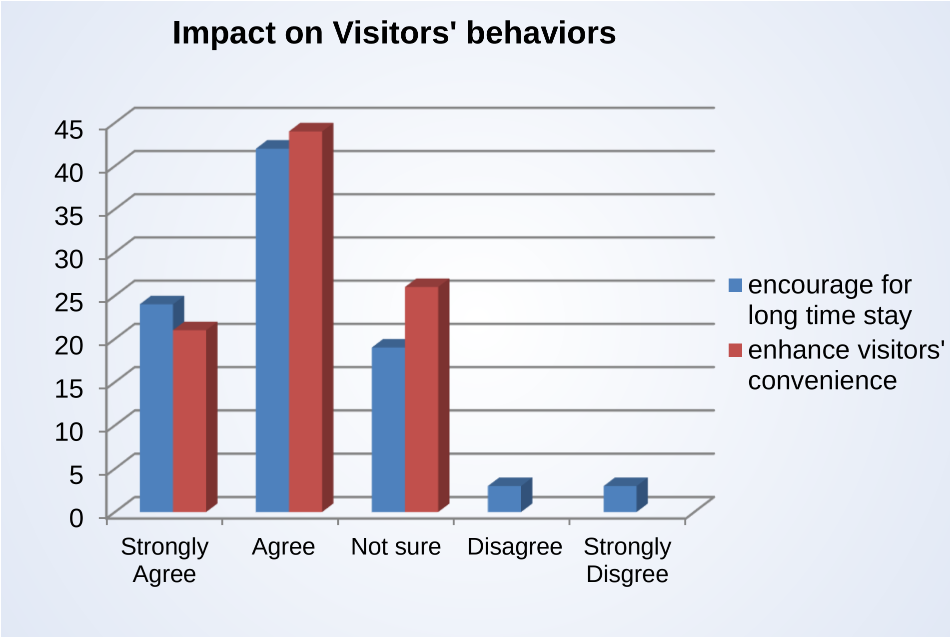


Figure 5.14 Proposals impact on visitors' behaviors – On site (Author)

The society acceptance is vastly correlated with the people awareness about the environmental impact of utilizing the solar power as 84% of the feedback ranging between strongly agree and agree (35% and 42% respectively) while 14% are uncertain. This correlation disagreed by 2% of the participants only.

72% of the participants state that the visual impact of the proposed PV systems is more significant than the anticipated power production while 18% are in doubt about the priority, the rest 10% have an opposite belief.

In spite of the smoothness integration, 38% of the participants strongly agree/ agree that the aesthetic value of the heritage building will be degraded (28% and 10% respectively) but 20% disagree this theory and most of the feedback (42%) reveals that the participants have no clear decision.

The integration concept is applicable as 96% of the participants' feedback ranging between strongly agree and agree (51% and 45% respectively).

Separately, the questionnaire sheet (in Arabic) distributed for the museum staff associated by other three sheets illustrate the proposed scenarios selected for this survey (refer to Appendix F).

Eighteen feedbacks were received from the employees constitute about 20% of the total participants. Two thirds of the employees who participated in the survey are Emiratis while the others are Arabs, therefore the feedback of this group is very important to investigate how the local culture influences people's acceptance about integrating new technology in their heritage sites.

Most of the employees believe that all scenarios are not in harmony with the fort's architecture as 78% scored both scenario 1 & 3 less than 5 while scenario 2 got the same score from 56% of the employees.

From the energy saving point of view, the idea of this study failed in getting any score above 5 and 65% of the employee expressed very low rate for its aesthetic value. On the contrary, 65% stated that the proposals will positively affected the site's visit and 78% believe that the visitors will stay long as the proposals will enhance their convenience during the tour.

In line with the employees' initial assessment, 89% of them think that the visual impact of the proposals is more significant than the anticipated power production and might degrade the aesthetic value of the heritage building.

As per the feedback from 89% of the employees, the idea of integrating PV systems in the heritage building is applicable and the public acceptance is proportionally increasing with their awareness about the environmental impact of utilizing the PVs systems.

5.4.2 Online Survey

In addition to the on-site survey, an online questionnaire has been established utilizing one of the recognized online survey websites called "FreeOnlineSurveys.com" due to its:

- Simplicity: ability of create a survey in minutes regardless user's technical background.
- Flexibility: short URL can be shared via emails and social networking sites such as Facebook and twitter.
- Versatility: videos, images multiple choice and fill-in-blank techniques can be easily added.
- Security: all data and feedback will remain confidential, secured and saved.
- Diversity: various reporting techniques are available such as Excel sheets and different chart styles.
- Availability: available in three versions, free one for 10 days and limited to 50 responses, for student and academic users with storage up to 1000 responses for US$ 9.99/month and standard survey extra account version costs US$ 19.99/month.

Utilizing the mentioned website's advanced features, the questionnaire has been built similar to the paper questionnaire and the 3D visual models were added to illustrate the proposed scenarios and to help the participants identify/mark their choices.

Initially, the free version was utilized and the web link of the survey was sent via emails to 85 persons comprising architects, engineers, academics administrators, accountants and others, but due to the limited period (10 days), only seven responses have been received.

In order to increase the participation opportunities, the student version was utilized and the web link of the survey has resent by emails to 95 persons and posted on a Facebook account.

Along 30 days, the participants' feedback has progressively uploaded and 72 responses were received from 8 countries (figure 5.15) at the end of the allocated period (30 days).

Figure 5.15 Online Participants' location (FreeOnlineSurveys.com)

76.4% of the participants are male and 23.6% female belong to different nationalities (figure 5.16) and from various education backgrounds (figure 5.17). It is obvious that no matching between the participants' location and their nationalities as most of them are living/working in UAE.

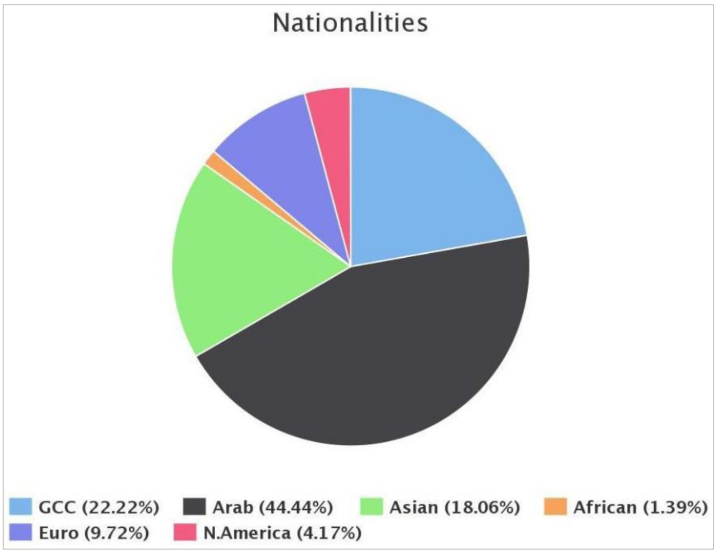


Figure 5.16 Online Participants' Nationalities (FreeOnlineSurveys.com)

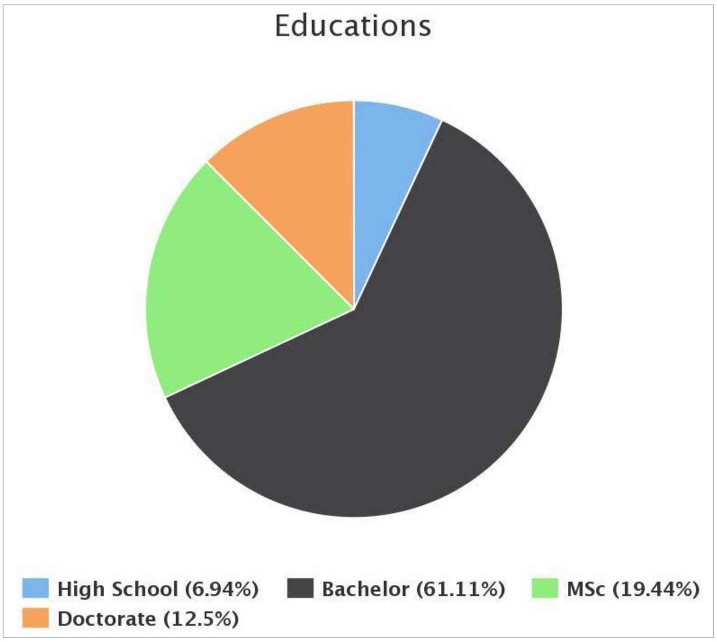


Figure 5.17 Online Participants' Educations (FreeOnlineSurveys.com)

The participants' occupations are varied comprise students, architects, engineers, academics and others which include accountants, administrators, economics and business administrators, figure 5.18 shows the percentage of each category.

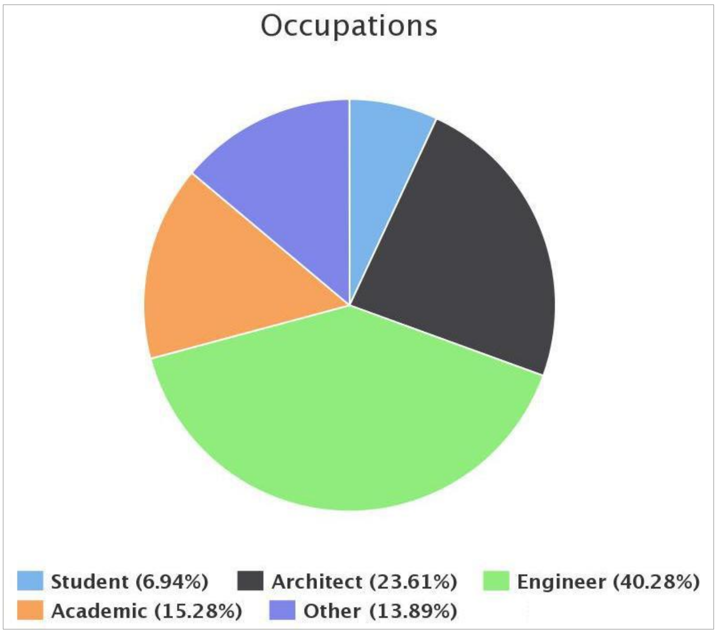


Figure 5.18 Online Participants' Occupations (FreeOnlineSurveys.com)

Regarding the harmony of the proposed scenarios with the fort's architecture, table 5.13 shows the participants' score for each scenario, it is obvious that all proposals gained high score from more than 90% of the participants and scenario 3 gained full score from about 31%.

The results reveal that the proposals are in harmony with the overall fort's scene and smoothly integrated within the places where they proposed for.

Table 5.13 Proposals' harmony with the fort's architecture (Author)

Score / Proposal	Low Score (below 5)	High Score (above 5)	Full Score
Scenario 1	1.4%	81.9%	16.7%
Scenario 2	5.6%	80.6%	13.9%
Scenario 3	5.6%	63.9%	30.6%

The participants' assessment regarding the idea of this study from the energy saving and aesthetic value point of view is shown in table 5.14, the idea gained high score from more than 90% of the participants for both aspects and as new concept, the idea gained high score from 45.8% and full score from 51.4% of the participants.

Table 5.14 Proposals assessment (Author)

Score / Criteria	Low Score (below 5)	High Score (above 5)	Full Score
Energy Saving	4.2%	68.0%	27.8%
Aesthetic Value	8.3%	83.4%	8.3%
New Concept	2.8%	45.8%	51.4%

The integration idea will positively affect the site visit, 58% of the feedback ranging between positive and strongly positive (38% and 21% respectively) and 15% believe that the impact will be slightly positive. 22% of the participants assume that the site visit will not be affected by this integration while 4% of the feedback ranging between strongly negative and negative (1.4 and 2.6 respectively).

Figure 5.19 shows that 85% of the participants believe that the proposals will enhance the visitors' convenience and consequently encourage their stay for long time as 74% of the participants state agree/strongly agree.

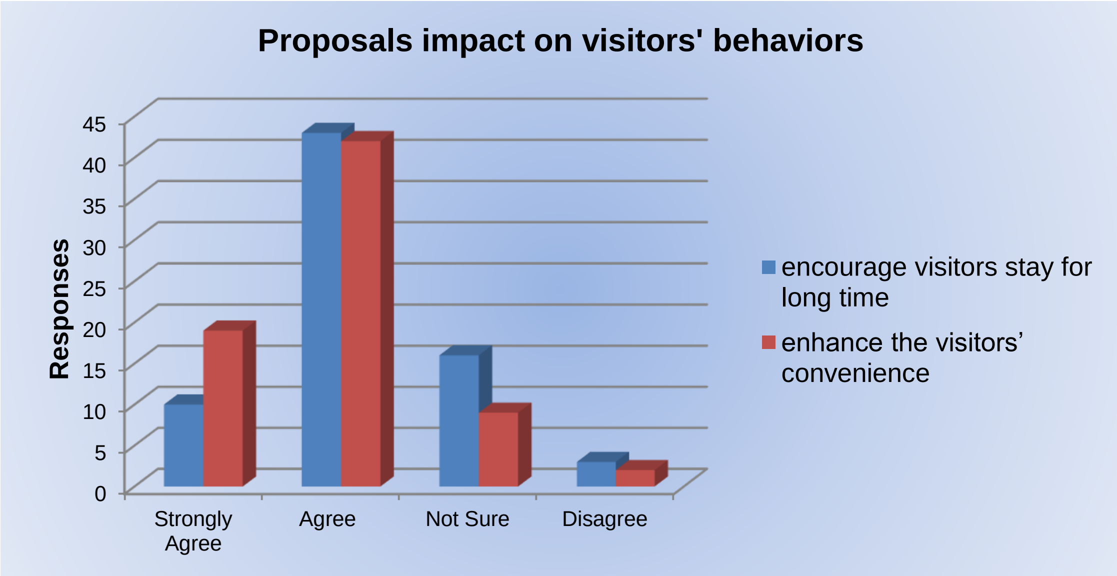


Figure 5.19 Proposals impact on visitors' behaviors - Online (Author)

The heritage buildings have adopted with the environment where they built, 51% of the participants believe that utilizing the solar energy in these buildings emulate the mentioned adoption while 42% are not sure about this emulation and only 7% of the participants disagree this notion.

The idea of integrating PV systems in the heritage building will be vastly accepted if the society becomes aware about the environmental impact of utilizing the solar power, about 92% of the feedback ranging between strongly agree and agree (30.6% and 61.1% respectively) and 7% are uncertain. Only one participant assumes that the public awareness makes no change in this matter.

Comparing between the visual impact of the PV system and its power production, 61% of the participants state that the visual impact is more significant than the power production while 15% have an opposite belief and the rest (24%) are in doubt about the priority.

Quarter of participants are not sure that the smooth integration will not degrade the aesthetical value of the heritage building and the rest are evenly divided between agreed and disagreed about this subject matter.

The online questionnaire reveals that 90% of the participants believe that the integration concept is applicable as their feedback is equally ranging between strongly agree and agree.

5.4.3 Total Survey Feedback

The total participants involved in both on-site and online surveys are 163 (72.4% male and 27.6% female) from various nationalities (figure 5.20) with different education backgrounds include high school, bachelor, MSc and doctorate degrees (figure 5.21).

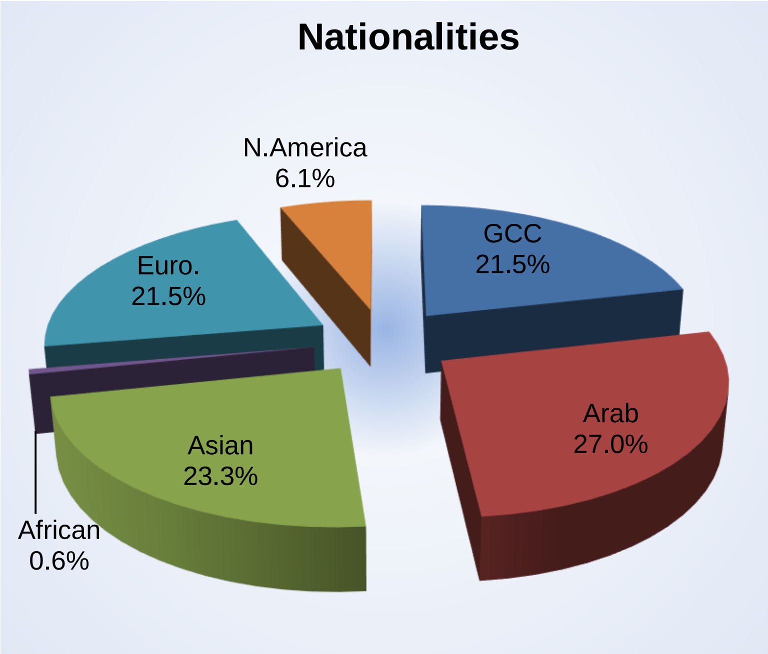


Figure 5.20 Total Participants' Nationalities (Author)

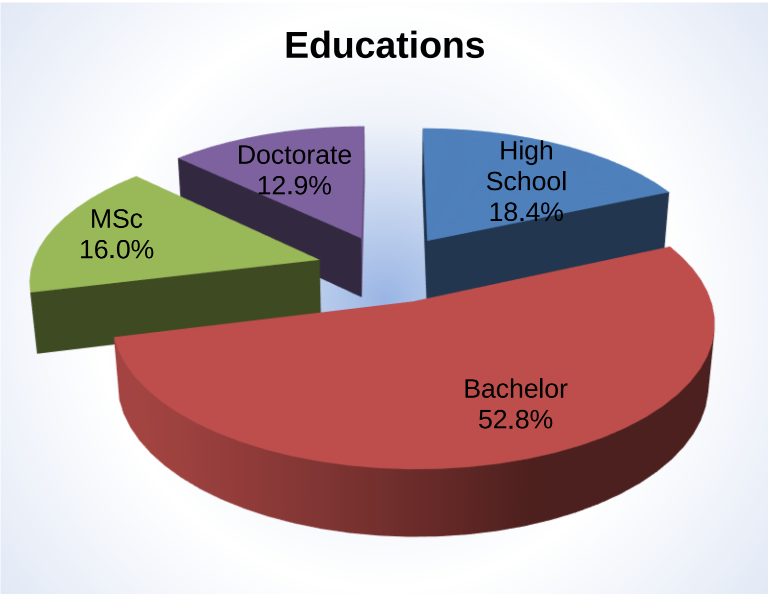


Figure 5.21 Total Participants' Education (Author)

The participants' occupations are varied as explained before and the total percentage of each category shown in figure 5.22. The participant's nationality, education background and occupancy are essential to prove the questionnaire comprehensiveness and emphasize its feedback credibility.

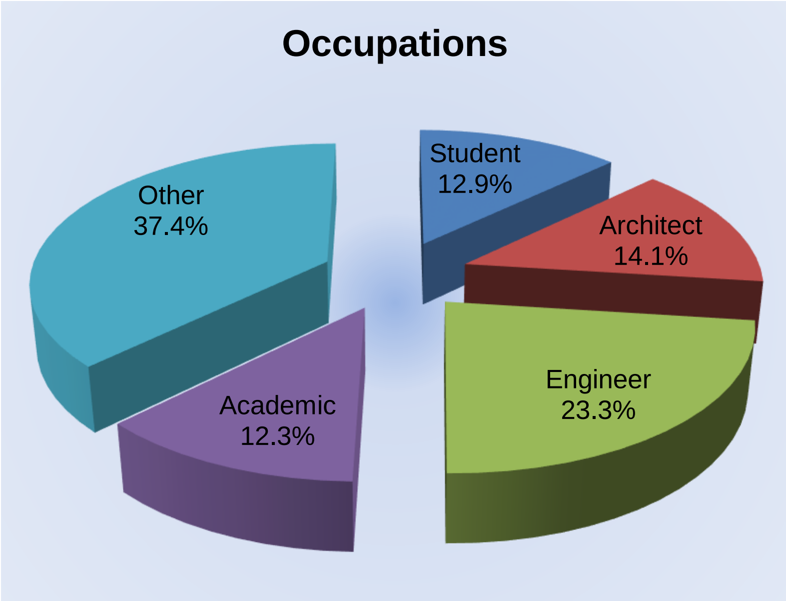


Figure 5.22 Total Participants' Occupations (Author)

Table 5.15 shows the combination of On-Site and Online surveys feedback regarding the harmony of the proposed scenarios with the fort's architecture, the results reveal that the proposals are in harmony with the overall fort's scene and smoothly integrated within the places where they proposed for.

Table 5.15 Proposals' harmony with the fort's architecture (Author)

Score / Proposal	Low Score (below 5)	High Score (above 5)	Full Score
Scenario 1	13.5%	60.7%	25.8%
Scenario 2	16.0%	59.5%	24.5%
Scenario 3	18.4%	47.9%	33.7%

From the energy saving and aesthetic value point of view, the participants' assessment is shown in table 5.16 in addition to their opinion about the idea of this study as a new concept. It is obvious that these three criteria gained the highest score which prove the idea's realism.

Table 5.16 Proposals assessment (Author)

Score / Criteria	Low Score (below 5)	High Score (above 5)	Full Score
Energy Saving	14.1%	48.5%	37.4%
Aesthetic Value	17.8%	61.3%	20.9%
New Concept	11.0%	44.8%	44.2%

Figure 5.23 illustrates the impact of adopting the proposed scenarios on the site visit, 54% of the participants' feedback ranging between strong positive and positive in addition to about 10% assume that the impact will be slightly positive. About 26% are not sure if there will be any influence on the site visit.

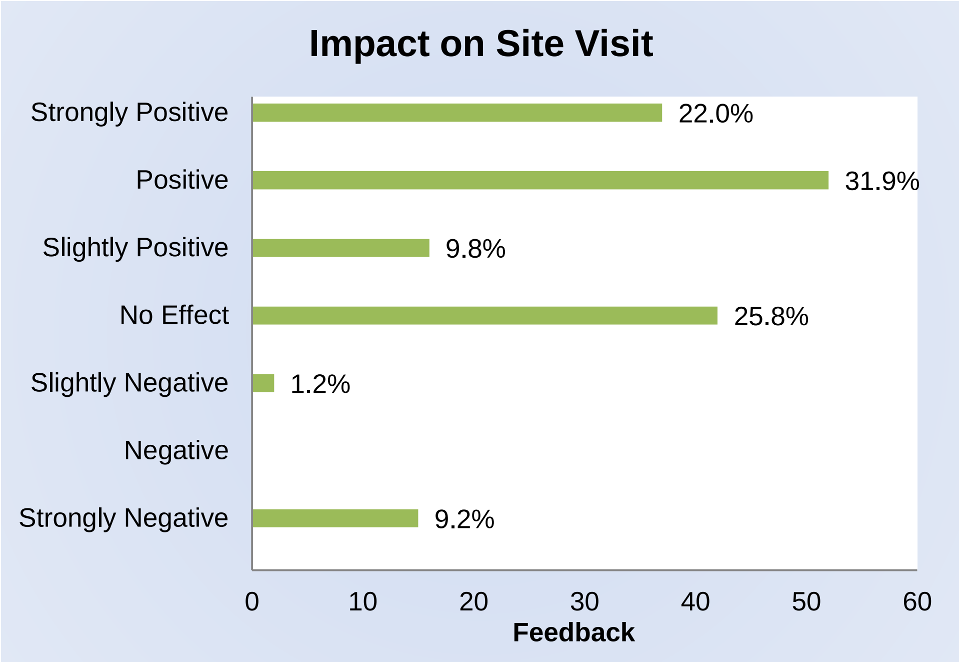


Figure 5.23 Total Participants' Occupations (Author)

Applying the proposals will encourage the visitors to stay longer as their convenience will be enhanced; figure 5.24 shows the participants' feedback about these two aspects. It is clear that more than 70% of the participants believe that the visitors' behavior will be enhanced and about 22% have no clear idea.

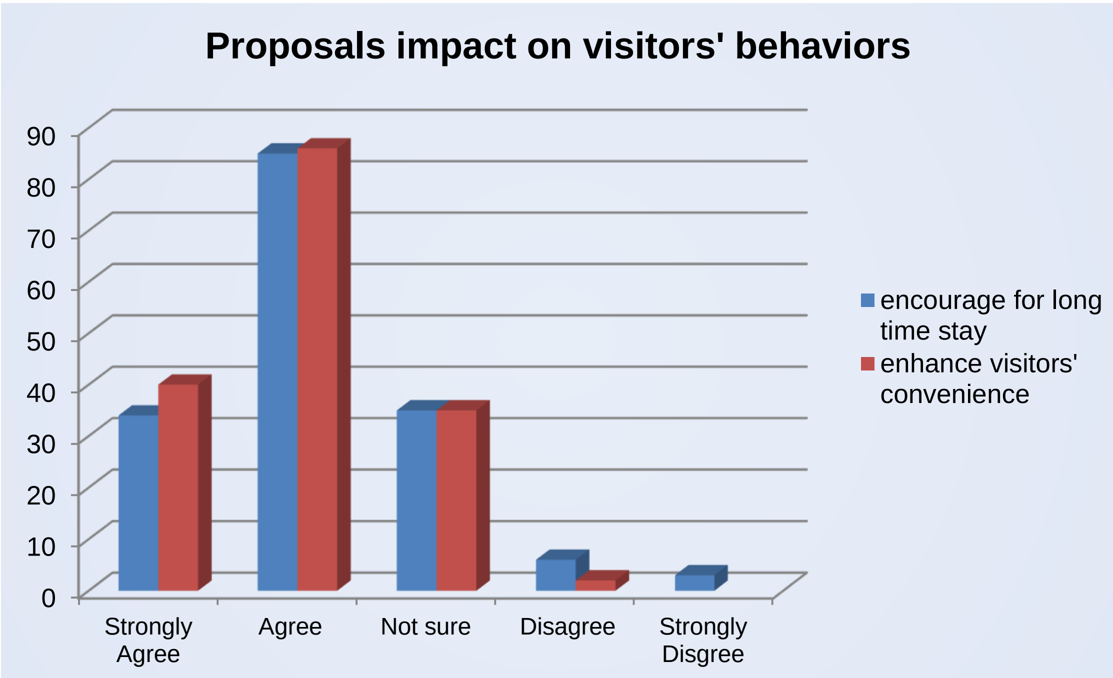


Figure 5.24 Proposals impact on visitors' behaviors - Total (Author)

The survey reveals that the public acceptance about the idea of integrating PV systems in the heritage buildings is extremely affected by their awareness regarding these systems' environmental benefits as about 88% of the feedback ranging between strongly agree and agree (35% and 52.8% respectively) and about 10% are not sure if people awareness and acceptance are correlated.

The visual impact of the proposed integration is more significant than the anticipated power production, this comparison has strongly agreed / agreed by about 68% of the participants and disagreed by 12% while 20% are not sure which aspect is more crucial.

Accordingly, 38% of the participants assume that integrating PV systems in such buildings (even smooth integration) will degrade the aesthetic value of the heritage building and 28% have contrast opinion while the rest participants are not are not sure if the aesthetic value will be affected or not.

Eventually the conclusion of the survey reveals that the concept of integrating PV systems in the heritage building is applicable as the feedback from about 93% of the participants ranging between strongly agree and agree and less than 2% assume it inapplicable.

5.4.4 Interviews

Three interviews have been conducted with heritage buildings specialists for deep investigation about the subject of this study and to discuss the potentials / obstructions of integrating PV systems in the historical building.

Dubai Museum manager (held master degree in the ancient civilization studies) stated that the idea of integrating photovoltaic systems in the heritage buildings is applicable but big attention should be given to the integration technique and the PV types to avoid the visual distortion as a result of the combination between the old-fashioned and modern features.

"In addition to the visual impact and energy saving aspects, there are other aspects should be considered and studied in this regards" she said. Internationally, the proposals have to comply with UNISCO regulations and requirements as the fort is registered as one of the heritage site. Locally, the regulations of historical building reservation are restrict and it does not easy to get approval to integrate / add any new features into the building.

From the visual point of view, she believes that scenarios 1 & 3 look harmony with the fort's architecture (score 6 and 7 from 10 respectively) and would positively affect the site visiting as the proposals provide shaded area which enhance the visitors' convenience and encourage them stay more.

She agreed that the visual impact of the PVs on the heritage building's scene is more significant than the power production and these systems might degrade the aesthetical value of the building if the architects fail in create / adopt the proper integration technique that add aesthetic value and avoid clear contrast.

An Emarati architect works at the Architectural Heritage Department in Dubai Municipality (a formal authority managing the renovation work of the historical building in Dubai) stated that any additional feature to be installed / integrated in the heritage building is prohibited as per the local regulations, his answers on the questionnaire are strongly affected by the roles of the authority where he works.

Accordingly, he scored the harmony of scenarios 1 and 2 with the fort's architecture 4 and 3 of 10 respectively as they are integrating inside the building while scenario 3 gets 7 of 10 as it is outside the building.

Out of the effect of the local roles / regulations, he likes the idea of integrating the PVs in the heritage buildings as new concept (9 of 10) and based on energy saving and aesthetic value, the idea scored 6 and 2 of 10 respectively while his answers for questions 4 to 10 are ranging between agree and strongly agree.

This interview reveals that the local roles / regulations has significant impact on the potential of integrating such systems into the historical building.

To explore the opinions from other cultural background, the third interview hosted a Syrian architect specialist in the ancient building restoration who doubted about the benefits desired from integrating such technology in the heritage buildings as the electricity unit rate in Dubai is less than the same generated from the PV systems.

Deep discussion was conducted to explain the environmental benefits of produce clean energy from renewable energy sources to fulfill the energy demand fully or partially which results in significant reduction in CO_2 emission and consequently protect our environment.

"The local regulations is very restricted and this idea has no chance to get official approval but it can be utilized for in progress project adopted by Dubai Municipality to fix fabric shades for the public sitting areas within selected open spaces of main city's sectors", he stated.

In spite of his doubts, he believes that the proposals are in harmony with the fort's features as these shades emulate the traditional sun breakers and tents commonly used during the same time when the fort was built, accordingly he scored the proposals 6, 8 and 10 of 10 sequentially.

Aesthetically, the idea of integrating PV systems in heritage buildings scores 6 of 10 and from energy saving point of view it scores 8 of 10 and 10 of 10 as it is new concept.

He believes that implementing the proposals will positively affect the site visit, enhance the visitors' convenience during the tour, and encourage them stay for long time. Eventually he stated that this concept, in theory, is applicable but practically there are many obstacles prevent the relevant authorities adopts this concept.

Chapter 6 – CONCLUSIONS AND RECOMMENDATIONS

The heritage buildings constitute an important and vital part of the society's assets and reflect its cultural values, therefore most of the governments all over the world exert significant efforts to preserve and rehabilitate their civilization legacies in order to fulfill the contemporary society's needs without compromising the aesthetic and cultural values of these buildings.

In this regard, the United Arab Emirates, federal and local governments, granted a great attention to all heritage buildings and sites all over the country through establishing the specialized authorities and put active and systematic development programs for this purpose.

Dubai Municipality, for instant, instituted the Architectural Heritage Department to manage and implement a strategic plan to restore, maintain and renovate about 220 heritage sites and buildings by 2016 as the work of 160 sites have been completed and the rest are ongoing.

The construction booming in UAE (particularly in Dubai) last decade has associated by a rapid increase in the power consumption in addition to the increasing in the habitants' energy demand affected by the economic growth and the evolution of life style.

As the United Arab Emirates uses the fossil fuels in generating the required power, the vast power consumption put this country at the top list of the countries that contribute significantly in the global warming due to the millions of tons of CO2 that emitted to the atmosphere.

Recently, several pilot projects lunched in UAE aim to utilize renewable energy sources such as solar and wind to secure some of the growing energy demand, these projects represented in Masdar City in Abu Dhabi and Sheikh Mohammed bin Rashid Al Maktoum Solar Park in Dubai to produce 1000MW by 2030 when all phases be completed.

Nowadays, integrating PV systems in the new construction becomes common in the UAE in line with the government's interests in this regards but integrating these systems in the heritage buildings in this region is not exist yet and will pose a major challenge primarily for the decision makers and the architects/designers as well.

6.1 Conclusions

Various publications in this area include journal articles, books, conference's paper and some of relevant authorities' releases have been reviewed to identify/determine the main objectives of this study.

These objectives include identify the most appropriate PV models to be applied, the optimum integration technique, the influence of climate characteristics on the PV system productivity and the best research methodologies utilized in this area.

Extensive literatures have been published in this field to study the renovation strategies and criteria, integration techniques, selection of proper technology, regulations/policies and more. Major of these researches have conducted for historic sites and buildings in Europe countries such as but not limited to Italy and Greek due to the ancient civilizations and numerous historic sites infested over these countries.

On the other hand, the unstable fossil fuel market (supply and price) compelled most of European countries to utilize various renewable energy sources to compensate the shortage in the fuel supply by a relatively cheap and secured energy sources.

The literature review reveals that the PV integration in the European historical buildings becomes common due to the public awareness about the environment benefits of utilize renewable energy resources, updated building codes, formal incentives to adopt the renewable energy systems and the buildings' architecture/configuration that allow for this integration (patched roof and glazed windows).

In contrast, there is obvious lack in the literatures regarding the same subject in the GCC countries where the building's architecture is totally different and presents vast contrast between the contemporary appearance of the solar systems and the old fashioned scene of the buildings.

There are four main approaches to maintain the heritage buildings include preservation, restoration, rehabilitation and reconstruction, these approaches were defined to specify the rationale of adopt each one.

It was concluded that the PV systems should be naturally integrated in the proposed location and not visibly look as an additional feature. The matching between the building's content and the integrated PV systems is essential to mitigate the visual impact of the new technology appearance on the overall building's scene.

Various methodology approaches utilized by the researches is this area include Experimental methods, Literature review, Survey (on-site and online), Numerical method, Computer simulation, On-site monitoring and 3D modeling & visualization method.

The pros and cons of each approach were discussed to identify the most appropriate methods for this study, accordingly, three methods were selected include:

- 3D modeling and visualization method: to present the visual impact of the proposed integration scenarios on the building's scene.
- Computer simulation: utilizing IES-VE simulation software to build the simulation models and calculate the annual energy consumption with the PV power production of each proposal.
- On-Site and Online survey: to conduct the public acceptance about the integration scenarios and to evaluate the concept of this study.

The selection of these methodologies based on the suitability, usability, practicality and availability of these methodologies in addition to the nearly zero cost and relatively reasonable time frame.

Al Fahidi Fort (Dubai Museum) has selected as case study for this research due to its architecture of design, location, cultural value and function (former and current). The fort's characteristics have been analyzed including its layout, components, façade, construction materials, location, orientation, function and operation time to identify the best and proper PV systems and integration techniques with full consideration to the fort's cultural and aesthetic values.

It was concluded that the fort's facades style and features constitute the main constrains to integrate the PV systems within these facades as these facades are solid, blind, rough and muddy appearance.

Instead of the external fades, seven scenarios are proposed to integrate the PV systems internally at the top of the fort's wings and at the central court yard, Three PV systems were selected include Monocrystalline, semi-transparent monocrystalline and CIGS flexible sheets.

The integration technique has selected based on the PV system type and the location's Properties where the PV to be applied. The CIGS flexible sheet proposed to be integrated within fabric shades in various configurations depends on the location, utilize these shades emulates the traditional sun breakers and tents commonly used in Dubai when the fort was built.

This technique has adopted for scenario 1 (Central shade at the court yard), scenario 2 (shades at Northern wing terrace), scenario 3 (Shade at external open area), scenario 5 (pitched roof of "Areesh" mockup) and scenario 5 (shade at courtyard staircase).

The monocrystalline and semi-transparent PV panels proposed for scenarios 4 and 7 respectively at the roof of the Northern wing roof. While the roof floor level is applicable for scenario 4, the semi-transparent panels (Scenario 7) have proposed to be installed within the handrail at the internal edge of the same roof.

A base simulation model has built using IES-VE simulation software and based on the architectural layout, wall thickness, thermal conditions and Dubai weather file to identify the annual energy consumption as a comparison baseline.

Utilizing the base simulation model, various simulation process were carried out for all proposed scenarios considering the PV parameters of each proposal such as PV type, area, efficiency, temperature coefficient, azimuth and inclination angles as simulation inputs to calculate the PV system's power production and the annual energy consumption of the building under the effect of each scenario.

It was concluded that the maximum power production can be gained at 25° inclination angel for all proposed PV types. This inclination angle is applicable for scenarios 2, 4, 5 and 6 while for scenario 3 and 7 the inclination angle has adjusted to 0° and 90° respectively to comply with the common setup of similar configuration.

The inclination angle for scenario 1 has adjusted to 5° to keep the proposed shade level below the top buildings' periphery level and avoid the visual impact of the proposed shade on the external building's scene.

The findings of the simulation processes reveal that scenarios 1.2.3 and 4 are the most productive energy proposal (21.7 MWH, 9.53 MWH, 3.81 MWH and 17.05 MWH respectively).

Accordingly, scenarios 1,2 and 3 have been selected to study their impact on the overall building's scene and its aesthetic value. Scenario 4 has excluded from more study due to its discrepancy with scenario 2 as both of them are proposed for the same location (scenario 2 is shading the proposed PV system of scenario 4) and scenario 4 has no visual impact to be studied (to be installed at invisible area).

These three proposals can be jointly installed as there is no conflict between them and the total annual energy production will be about 35 MWh which constitutes 65% of the buildings annual energy demand. This production will contribute in 66.7% reduction in the CO_2 emission comparing with the annual emission of the conventional energy consumption.

Refer to table 5.1; the mentioned PV generated power can be utilized to feed the AC systems and miscellaneous equipment or for internal lighting systems, audio systems, miscellaneous equipment and the rest can be utilized to feed the external lighting.

These proposals can be jointly installed as there is no conflict between them and the total annual energy production will be about 35 MWh which constitutes 65% of the buildings annual energy demand. This production will contribute in 66.7% reduction in the CO_2 emission comparing with the annual emission of the conventional energy consumption.

On-site and online surveys have been conducted to investigate the public acceptance about the concept of this study using the three selected scenarios (1,2 and 3) due to their considerable power productivity and anticipated visual enhancement.

A questionnaire sheet has prepared comprises 10 questions related to the proposals visual impact on the visitors' behaviors, identify the priorities (energy or view) and eventually the applicability of the integration concept.

In addition, the questionnaire requested some personal information about the participant such as gender, nationality, education and occupation.

Along one week, 2 hours per day, the questionnaire sheet has distributed to the visitors of the museum exit hall and a 3D visual model board has presented to illustrate the proposals comparing with their existing scene.

Similarly, an online questionnaire has built utilizing one of the recognized website called “FreeOnlineSurveys.com” associated by the proposals 3D Visual models, and the web link has sent to 95 email addresses and posted on a Facebook account. The feedback has progressively uploaded on the survey link along 30 days.

The feedback received from 163 participants (91 on-site and 72 online) comprises 72.4% male and 27.6% females from various nationalities with different education background. The participants’ occupations are varied.

The results reveal that the proposals are smoothly integrated in the places where they proposed for as all proposals gained high score from more than 80% of the participants.

64% of the participants believe that the proposals will positively impact the site values. The visitors will be encouraged to stay for longer time and their convenience will be enhanced as stated by 73% and 77% of the participants respectively.

It was concluded that the idea of integrating PV system in the heritage buildings will be widely accepted when the society becomes aware about the environment benefits of adopt the renewable energy sources. In this regards the feedback from 88% of the participants’ ranging between strongly agree and agree (35% and 52.3% respectively).

The proposals’ value impact constitutes the top priority comparing with their power productivity, 68% of the participants agree with this comparison, however only 38% believe the aesthetic value of the building will be degraded affected by the PV integration even its smoothness.

The final conclusion of the surveys reveals that 93% of the participants’ believe that the integration concept is applicable in the historical buildings.

The surveys followed by three interviews with heritage buildings specifications include the Museum manager and two architects from the Architecture Heritage Department in Dubai Municipality. It was concluded that the local regulations are restricted against any features to be integrated in the heritage buildings and significantly impact the potential of integrating PV systems in these days.

The museum manager stated that the fort is accredited by the United Nationals Educational, scientific and cultural organization (UNESCO) as one of the world heritage sites and any modifications have to comply with the specific roles in this regards.

Out of the international and local restricted roles, the interviewers believe that the concept of integrative PV systems in such buildings is theoretically applicable but needs deep discussions and argumentations with the relevant authorities and stakeholders.

6.2 Recommendations and Further Research

The findings of the 3D visual models, simulation processes and both on-site and online surveys reveal that there is a good opportunity (at least in theory) to adopt the concept of integrating PV systems in the heritage buildings.

Turning this theoretical potential into practical opportunity, further studies are recommended as following:

- While there are extensive literatures regarding the topic of this paper for European, American and Asian countries, there is obvious gap for the same in the Arab region especially in GCC countries. The unique architectural features of the historic buildings in this region need deep studies to determine the opportunities of utilizing the renewable energy sources in the heritage buildings as part of the renovation, restoration and maintenance strategies.

- The Gulf region climate is characterized by abundant renewable energy sources such as solar, hydro and relatively winds energies. The exploitation of these resources is one of the local governments' duties to produce clean energy and contribute in the global efforts to minimize the global warming by reducing the CO_2 emission as a result of reducing the reliance on the fossil fuel in the conventional energy production.

- Enhance the public awareness about the environmental benefits of utilizing the renewable energy sources via social media, multimedia, scientific conferences, formal incentives and advertisements.

- Develop the universities' curriculum and scientific research tools for deep investigation in this field to promote genius architects and engineers who can present creative and innovative designs and solutions in this regards.

- Update the international and local building regulations towards more flexibility to accept the concept of integrating the renewable energy technologies within the historic building with full consideration to maintain its aesthetic and cultural values.

- Various PV systems are available in the United Arab Emirates market but the flexible PV panels are still unknown. Nowadays, Dubai Municipality is studying to install fabric shades for some public sitting areas within selected open spaces of main city's sectors, there is a real opportunity to integrate proper PV systems within these shades similar to the proposals explained in this study and monitor the public interact with these proposals.

- Implement one or more of the proposed scenarios or similar proposal in the site (Dubai Museum) as an experimental practice to examine the real public interact with this concept, monitoring the visitors' behaviors under the effect of this proposal, calculate the power production of the PV system, compare the unit rate of the PV generated power with the existing grid power rate and investigate the reduction in the energy consumption as a result of installing the shades.

- More investigations are required to develop the PV technology to produce new generation of modules that compatible with the old-fashioned scene of the heritage buildings. This includes various colors and shapes, texture, flexibility, efficiency, price and innovative installation techniques.

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