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Using Photovoltaic Systems in Famagusta Residential Buildings as Electric Power

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Abstract
Solar energy is an influential sort of renewable energy which is also richly available in North Cyprus. Contrariwise, there are no natural oil resources in Cyprus; over 90% of the country's main energy is imported to the island which needs high financial government credit [1]. Indeed, high CO2 emissions and their side effects on the global environment as well as destruction role on the ozone layer are among major problems of using non-renewable energy. Considering the geographic location of North Cyprus, it has over 300 sunny days out of 365 days of a year; therefore, there is a considerable potential to integrate solar tracking systems into various parts of industrials or residential portions in the country. In a time when using more renewable sources of energy is important to decline obvious environmental problems, it seems to be beneficial to use photovoltaic systems such as "Building Integrated Photovoltaic". As housing consumes over 40 percent of the produced energy, local sustainable properties deal with enhancing the quality of dwellers life. Based on what has been discussed, the objective of this study is to achieve a high degree of efficient local energy through BIPV so to supply a proportion of buildings' heating and electricity power consumptions. The main concern is considering cultural patterns and local climate aspects in the design process so to reach to a suitable energy solution in each individual case. Accordingly, some criteria which directly affect the produced power ability of photovoltaic systems would be discussed, in particular, determining the direction, the slope of photovoltaic panels, shading, its integration with active solar systems, and buildings' form and facades. Additionally, as the case study, Coloured Building would be presented to show that how those mentioned solutions can integrate to the building in order to refine its energy consumption. Consequently, architects and designers, looking for buildings' self-efficiency and sustainability, should know how to incorporate photovoltaic systems to the building and to consider which criteria in this case. Indeed, the corporation between architects and other engineers who work on a common project is the key role in developing a construction toward a sustainable environment.
Keywords: Building Integrated Photovoltaic (BIPV); Cost Benefit; Energy Efficient; Renewable Energy; Solar Energy.

1. Introduction
Thomas in his book has asserted that "if the 19th century was the age of coal and the 20th of oil, the 21st will be the age of the sun" [2]. The 1973 oil crisis and incredible growth of oil production cost caused economists and scholars of developing countries to carry on their attention towards the significant and widespread renewable energy source called solar technologies. The new subject that called economic of solar energy was born by the commencement of studies on solar energy from the economic viewpoint. Using solar energy as a sustainable source of has created a great motivation among designers and architects to convince the regulatory authorities, and investors to add solar systems in their buildings. The main basic of this motivation is the ability to decline the use of produced energy through this nonrenewable energy source. Hence, concentrating on the efficiently of solar tracking system design has been highlighted considerably.

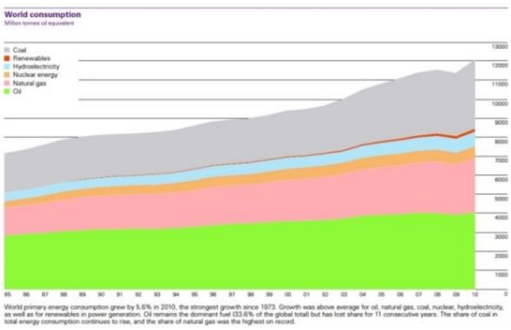

Figure 1. World primary energy consumption from 1985 to 2010 in million tones oil equivalent, BP statistical report [19]

Nowadays, buildings should be constructed and operated with minimum energy consumption. Considering appropriate recycled materials, proper orientation, and use of endless solar source are the primary principles in a sustainable approach (Figure2). Solar energy technology is not only utilized as passive heating tools but also is used as an active technology to feed electrical buildings' appliances. In this case, photovoltaic system is recognized as the best cost-efficient and a new source of energy for local communities. These solar panels transfer solar radiation through photovoltaic modules and thermal collectors to produce clean and dependable heat and electricity energies respectively.

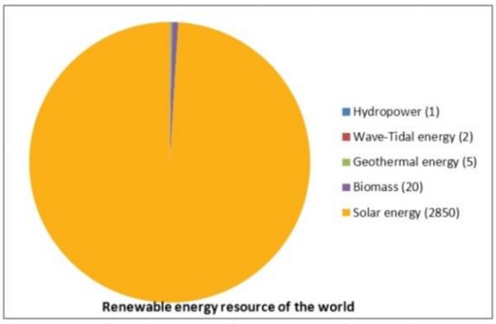

Figure 2. Abundance of the availability of solar energy, [19]

Interconnected photovoltaic system can also be a part of the buildings' components [3]. The term building integrated photovoltaic (BIPV) was derived from the idea to assimilate PV elements into a building cover, in order to generate a symbiotic relationship between economic energy conversion, the architectural form and functional properties [4]. In the world of PV systems, buildings have no permission to use public sources; they should be self-healing to produce over half of their energy demand as well as semi-conductors to combat the dangerous influence of radiation [5]. The favorable common PV devices, which have over 28% efficiency, are based on silicon material. Researches have proved that PV lifetime is over 20 years, in the line which the PV companies predicted. Sometimes this range can increase to 30 years. It depends on its used material and the way it is conserved besides the climatic conditions. Moreover, the extent to which building-integrated photovoltaic systems are reliable can be explained as follows [2, 6 &7]:

- The long lifetime (operating more than 15 years)
- Having the sizable share of energy to supply from a few watts for a solar watch or over 20 kw for powerhouse
- Independent from fossil fuels and having no pollutant emissions
- Reducing the total cost of the project
- A part of the building ca be considered for the installation of PV and there is no need to consider a separate land
- Decreasing the transmitting power losses because power is generated on site
- Warranty of energy storage
- Make giving elegancy to the appearance of the building which dramatically rises its market acceptance.

In line with the mentioned studies, the researcher has tried to point out that the primary criteria through cultural patterns and local climate features for having an efficient BIPV as well as the way to integrate this system properly to the constructed building. Concerning the case study, Coloured Building is known as a part of the architecture department at Eastern Mediterranean University in Famagusta, North Cyprus. This building was chosen as a field study to represent how poor architecture can affect directly human thermal comfort while subsequently increasing the energy consumption of the building. Furthermore, the researcher has aimed to contribute in offering some suitable solutions to make the current situation of Coloured Building better than.

I. Literature Review

In 1880s, Fritts invented solar cells for the first time, and later German engineers acknowledged the importance of his invention, trying to work on it. It can be asserted that in late 1953, Chapin, one of Bell scientists had begun to work on the efficiencies of photovoltaics cells. During his investigations, Chapin put silicon solar cell under good strong sun radiation, and after hard work he finally could reach efficiencies of 4.5-6 % [8], which now the rate has reached 30%. Generally, the application of photovoltaics in buildings is different from one country to another. The application mostly depends on the building type, culture, local site potential, financing type, scale and design of the building project [2]. A wide variety of BIPV systems that exist in the marketplaces can integrate basically into the building in common three locations; roof, façade or above the impermeable layer in the construction [6].

Voss highlighted that external building surfaces must not make a barrier in regulating heat loss and water incoming while it must provide a sound barrier, control the incoming sunlight, and offer proper technical maintenance besides satisfying human visual through architecturally and aesthetically design features [7]. One of the effective aspects of integrating photovoltaic panel systems is its flexibility in integration, not only to a new building but also to the whole expression of built construction elements. PV systems have many multifunctional potential features such as waterproofing, shading, fire protection, external isolation, wind protection and acoustic controlling [9]. Obtained date and suggestions reveal that PVs can integrate into various sorts of roof including flat, inclined, saw-toothed, skylight or even curved ones. PVs can install as the external building's skin or as a part of the roof structure which is called 'retrofits' [10]. The positive point in using PVs as a roof covering is to reduce used materials in the construction process and is more favorable for a building built in a sustainable approach. Likewise, when PVs are laid horizontally on top of a building, they can clearly receive more solar radiation while affecting the building's aesthetic less. Even the PV system can equally be installed on atrium roof for multifunctional features to control sunlight penetrate into the building alongside the production of electricity by solar radiation. Using PV glazing is a beneficial substitute for a transparent roof. Based on Wolter's research, open air PV atriums are economically advantageous because there is no need for doing extra ventilation [11]. For instance, Bejar Traditional Market retrofits is one of the successful examples that can be mentioned. It is suited in Bejar city center, Salamanca, Spain. The area of atrium is around 175m^2 which is fully furnished by photovoltaic glazing elements. By using PVs in Bejar Traditional Market, more than 8500 kW electricity is produced in a year besides 2.95 tons of CO_2 which is saved during the year.

Figure3. PV on coloured skylights at Bejar Market, Salamnca, Spain; Retrieve from: Onyx Solar Website

Studies regarding the location of PVs show that normally photovoltaic systems can lie on the external walls of the building, especially southward, as protective layers. It is interesting to know that photovoltaic panels integrate into both glazing and opaque facades. Reijenha and Kaan have asserted that these panels can even be used as a glass sheet or frameless PV panels. Additionally, to control daylight and generate more electricity power, designers tend to use semi-transparent and transparent PV panels as curtain walls [6]. A notable point of applying PV panels as a curtain wall is to reduce building's cooling loads and glare [12[.

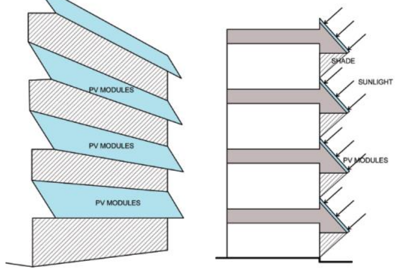

Figure 4. PV facade consisting of overhanging PV shade screens, [11]

Sun shading devices are also able to combine with PVs. However, in sustainable buildings south facades have their own key roles in absorbing more solar energy. The internal space of the building must control against extra heat and subsequently reduce the demand for cooling in summer. Hence, internal or external sun shading could be a wise idea to prevent heat from the inside of a building. Through sustainable approach it is worthy to mix sun shading devices with PVs to provide shade at the same time of producing electricity. There is no limitation in installing shading PVs; it can integrate into the building either horizontally or vertically, or even be fixed to the building or be portable. Moreover, PV shading devices have enough flexibility to be installed as conventional shadings [13].

As mentioned, former, BIPV technology options provide enormous potential to architects and designers but this technology should be installed in a right way from the beginning. In 2001, Thomas has underlined the importance of location, design and usage of the building that should be determined in the primary steps of a project. In order to receive more solar radiation, location of the building needs to have a good access to it, the building type and amount of users should be estimated to install an appropriate photovoltaic system, and also PVs will covers the building and affects both the aesthetics and form, designers, specially clients need to be satisfied with the outcome. Based on the foregoing, figure 5 represents critical steps which are necessary to attention in designing solar house process.

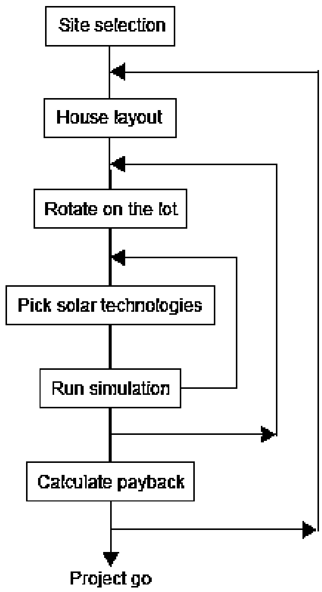

Figure5. Steps for solar construction, [22]

II. Designing BIPV Systems In Coordination With The Building

A. **Determining the efficient direction and slope PV panels -**

Photovoltaic panels collect solar rays straight from the sky, directly from the sun and the reflected sunlight. Solar radiation is composed of direct and diffuse radiation. The percentage of each radiation depends on the location – for instance, in Cyprus direct radiation is high: the total annual direct radiation on the horizontal surface is more than 60% (1199 kWh/m 2) and the remaining one belongs to the diffuse radiation that is around 30.6% (528 kWh/m 2) [14]. By increasing the intensity of solar radiation, the generated electricity of photovoltaic systems would rise subsequently; therefore, there is a direct relation between the power output of PVs and the amount of attracted solar energy (Figure6).

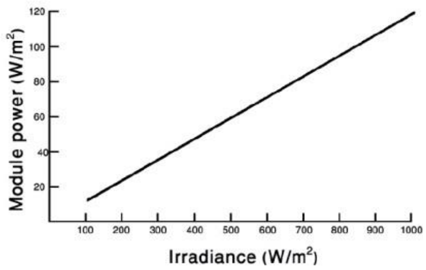

Figure 6. Variation of module power with irradiance, [2]

On the other hand, the shifting in sunlight angle and the amount of radiation during the day can also affect the efficiency of PVs. The photovoltaic systems' output depends mainly on the direction and the tilt of located panels which themselves are related to the amount of incoming sunlight. The amount of received solar energy varies based on the location latitude, the height from the sea, atmospheric phenomena, and etc. Thomas asserted that one of the useful world-known methods to predict the optimal direction and tilt of the photovoltaic panels is using solar disc. In this method, the amount of solar irradiation to horizontal or vertical surfaces should be monitored based on the given meteorological reports (direct and diffuse sunlight) plus getting help from computer programs; then on the solar disc, the various directions and tilt will be drawn during the monthly or yearly period [2]. If the result of solar panels shows that the amount of receiving sunlight in some situations is more than other directions and tilts, it means that the direction and slope of PVs is determined correctly on that location to reach the optimal solar energy. In this regard, it is easily to estimate the suitable direction and slope for a specific location [15]. The maximum point in this solar disc is the place where it receives more solar energy during the year; wherever the sun perpendicularly irritates on photovoltaic panels, the solar energy of those panels reaches the high consequently and the generated electricity is maximized. Based on Thomas experiences in 2001, to achieve the maximum level of solar output, it is needed to orient the solar panels toward south at a tilt of approximately ± 20 degrees from the horizontal, for the efficiency of PVs slightly drops after this amount. Thus, navigating photovoltaic panels is an important issue in determining their angle. If there be a little deviation to the optimal direction, it would not make a significant effect on the final result, considering that a range of tilts and orientations provide over 90% of the maximum solar electricity.

B. **The effect of shading on PV panels -**

Shadow is an unavoidable factor which dramatically affects the access to the sunlight. It is possible that the ground reflection, shadows of surrounding building, even the shadow of the building itself or over-shading of other photovoltaic panels decrease the performance of BIPV. The solar designer's duty is to determine a suitable situation for photovoltaic panels to eliminate any possibility of over-shading. Hence paying attention to the over-shading issue and calculating the shadow location carefully before integrating PVs to the building are critical in solar systems.

B.1**. Shading of the building itself and its surrounding buildings -**

Each type of building, especially dwelling units, requires an unobstructed southern exposure. In the city center, the space between buildings reduces normally, that is why the density of the surrounding buildings critical and should be considered. Another important aspect to pay attention is that the photovoltaic systems integrated to the vertical surface of a building are more sensitive than the ones installed horizontally on the roof. Moreover, architects and designers should predict the shadow of building or its form in BIPV design. It is also essential to consider a space between photovoltaic roof systems with other building fixtures to avoid continuous shading. If there is no way to avoid over-shading, selecting an appropriate element in a suitable location with accurate form would decrease the loss of energy.

Figure 7. Shading effects from building fixtures, [16]

It seems to be fair to say that slope (site topography), spacing between building, sun path (considering Azimuth and Altitude), and height of buildings are four main principles that should be inextricably taken into account.

B. 2. **Shading of vegetation -**

Shadows of plants and trees are very influential as well. In summer time trees will be very dense while during winter time, they lose their leaves. Trees' branches and bodies can also give too much shade, putting a negative effect on PVs. In order to solve this problem, it is wise to estimate the growth of trees beforehand or to use only short bush and shrubs around the building. It is better to prepare a future plan for vegetation growth to avoid problems that would occur after a few years the PV system has been installed on building. It is suggested that trees be planted on north side of building in northern hemisphere and in the southern hemisphere they be planted on the south side. In 2002, Reijenga & Kaan recommended practical solutions to control a vegetation growth as follows:

- Plant trees on the north side
- The height of the grown tree be less than two stories
- Prune trees regularly to keep them small.

B.3**. Shading of clouds -**

The cloudy sky relatively declines the high intensity of direct solar radiation. If a building is constructed in an environment which is much cloudy in the afternoon and has clear sky in the morning, it is advised to install PVs much facing towards East side.

B.4. **Shading of pollutions -**

Air pollution is another main factor, mostly in city centers, which threats the performance of photovoltaic modules. It can drop solar energy output around 4% or even more. However, the solar panels installed at tilt of over 20 degrees are instinctively clean by rain drops while the special kind of air pollution (like grime) requires cleaning appropriately.

C. **Ventilation of BIPV -**

Photovoltaic panels capture solar rays and convert them to electricity power so to produce higher outputs the PV modules will get heated and ventilation would be an initial demand to remove the heat. As PVs work the same as other electricity appliances, they work better in lower temperatures. Hence, by minimizing the self-heating of PVs while integrating these systems into the building, maximum electricity energy can be achieved. Besides to avoid a decrease in output level, back-ventilation of the PVs is an appropriate solution.

D. **The effect of building form on generating electricity through PVs -**

Based on the previous researches [1, 2 & 16] extension of building form East to West is recommended as solar panels are able to receive more sunlight, and subsequently generate more electricity energy. The more building form is shaping to become parallel to the form of a square, the less solar radiation can be absorbed. Thus, by increasing the external surface area, solar energy production subsequently increases. It should be noted that there is a dramatic difference in producing solar energy while the building is lying from East to West compared to when it lies from South to north.

III. Methodology

As mentioned beforehand, the research firstly included a clarification of the impact of renewable solar energy as a clean energy and then it confined to utilizing photovoltaic systems in buildings. Different aspects of integration have been explained. In addition, to support the theoretical study and to figure out the gaps, the study briefly reviews similar recent investigations which have been done so far. Coloured Building is considered as the case study of the study. This building is a part of the architecture department of EMU in Famagusta, North Cyprus. Followings are recommendations and suggestions to increase the use of solar panels and to decrease nonrenewable energy consumptions.

IV. Field Study: Coloured Building, Emu

Famagusta is a city in North Cyprus where Coloured Building of the Eastern Mediterranean University is suited. Based on Alibaba & Ozdeniz study, Famagusta`s weather is cold with rare rains in winter time and during the summer it becomes hot with a Mediterranean climate [17]. Coloured Building is an atrium that has a rectangular form with three levels in plan, composed of classes, studios, a library, a seminar room, and also a coffee shop.

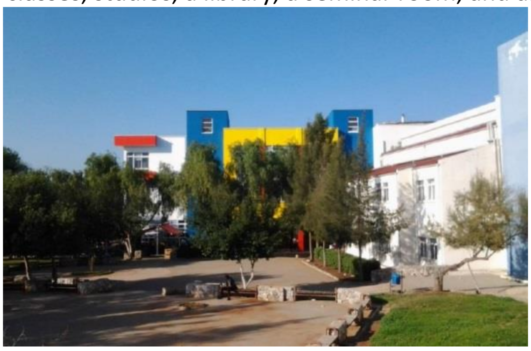

Figure 8. Coloured Building as a part of architecture department (Taken by Author, 2015)

Generally, North Cyprus has a common conventional problem in using electric energy, especially in dwellings. Designing and installing solar panels require more composed knowledge of the average sunlight during a year. Based on the various old metrological reports of Cyprus, the solar radiation is 3 kWh/m^2 in cold times and 7 kWh/m^2 in hot periods (Figure9). These results show the high potential of that Cyprus for installing photovoltaic panel systems. Unfortunately, North Cyprus strongly relies on imported petroleum and oil products for producing electricity. Using these natural fuels generate high sulfur rates which can affect environmental stability directly. However, it seems that this problem is not currently a serious in North Cyprus [18].

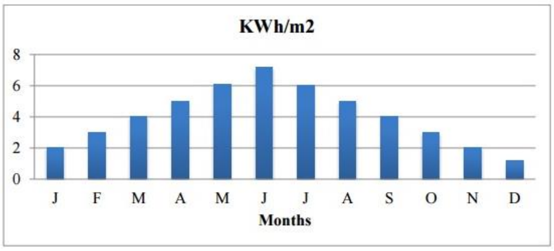

Figure 9. Average daily global solar radiation in Cyprus [20]

Based on what just conferred, Coloured Building has so many glazing panes which have no good insulation for preventing the internal space from external weather changes. So far, users consume a lot of energy to reach the internal space to its comfortable thermal zone, which is not even possible. Coloured building uses great amounts of nonrenewable energy and the cost of electricity power produced by oil fuel is significantly high, around 0.20 €/WH in the Northern Cyprus. In line with this context, it is proven that among other renewable energy sources, photovoltaic technology is the most feasible and the most available for North Cyprus. By investigating surrounding buildings of Coloured building looking at the building in the city, it is obvious that citizens are more familiar with utilizing a solar thermal heating technology than PV systems that generate electricity.

Analyzing the location of Coloured Building, it is approximately situated 30° to the North as shown in figure 10. Because of tall trees which produce over-shading on the building surface and also as a result of having a small space between Coloured Building and the other part of architectural department, it is impossible to use PV panels on the vertical surface of the building.

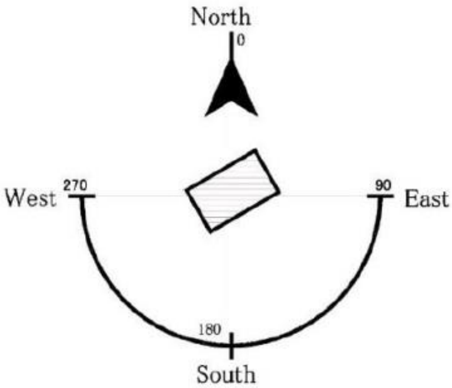

Figure10. Current orientation of Colored Building toward North, [21]

Another point is that the wrong direction toward sun causes most of elevation surfaces to be under the building's shadow or the shadow of the building form. It seems that the most suitable part of the building for integrating photovoltaic panels is its atrium roof which is covered by transparent materials. It is possible to install solar panels as a part of external skin which is a very well choice to renovate a large inclining atrium roof. Among different types of photovoltaic panels, it is suggested to use colored transparent or semitransparent PV modules. This type of PVs serves as sun and water barriers and also controls daylight while increasing the visual quality of the inner side of the Coloured building.

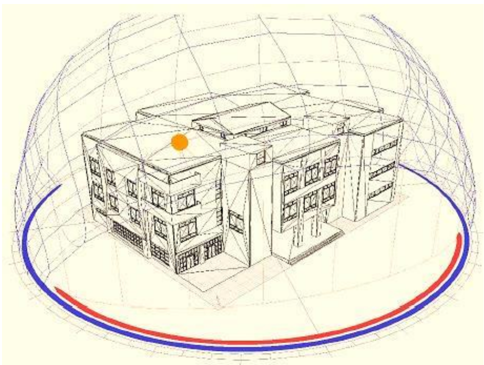

Figure11. South view of Coloured Building, 3D modle by Ecotect Simulation Analysis, [21]

Open air PV atrium has a positive side that it does not need extra systems for ventilation as well; Famagusta has a hot climate with more than 60% direct sunlight; therefore, considering sun protection and powerful back-ventilation

for solar panels on roof is compulsory to avoid overheating in warm times. Additionally, the proper slop of solar panels to give optimum annual energy is the angle near horizontal surface within 10° to 15°; more or less than 20° leads to a decrease in capturing solar radiation.
On the other hand, to contribute active solar system, adding external shading devices as a passive solar system to provide shadow for internal space of Coloured Building during the summer time is the most helpful factors. There is a wide range of external shading with various materials like roof eaves, wooden trellis, canopies, light shelf and etc.

V. Conclusion

In future, built environment would be a great potential for BIPV to include as a sustainable energy strategy. BIPV purposes to reduce energy consumption and costs while increasing the architectural elegance. Contributing to the photovoltaic panel technology in North Cyprus will create desired conditions to use the abundance solar radiation appropriately. Unless there is this chance for North Cyprus to put up wind turbines for creating electric energy, the best remedy for this country currently is to get use of solar renewable energy that is more available and much cost-effective than other sustainable energies. Renewable energies are growing presently due to the speedy growth of population, increasing energy demand, high production cost of nonrenewable energy, plus encountering problems because of lack of financial budget, CO_2 emission, public utilities covering all cities in the country and also loss of energy in the transferring process. Based on previous researches, it is clear that over half of total produced energy is consumed in different types of buildings, mainly in the domestic sector either for electricity power or heating water. BIPV technology in North Cyprus would not only cause sustainability of social life to grow, but also it can create a good opportunity for foreign trades which will affect directly the financial budget and increase the construction of building with a sustainable approach.
Undoubtedly, the high implementation cost of integrating photovoltaic panels to the building would pay-back in time period of around 3 to 4 years. But present financial condition of North Cyprus is the major difficulty which this country is facing. Hopefully, with some governmental grants, PV technology will find permit to be used with a lower price and longer durability in buildings. The prospect of using BIPV technology to generate electricity in North Cyprus is bright. From the view point of both economic and technology, installing photovoltaic panels in various types of buildings is feasible.
Additionally, the use of solar energy in generating electricity and heating offers environmental protection. As the results have revealed, consuming solar energy decreases the amounts of greenhouse gasses pollution significantly. Compared to a conventional system, generating electricity with solar system creates about 80% less pollution.
Furthermore, it is the duty of designers and architects to distribute sustainable renewable energy through amazing aesthetical constructions. So far, designers and architects need to enhance their knowledge of BIPV and try to practice integrating photovoltaic systems into their designs. Visibility of solar panels, color and form of panels, their dimensions, frames and back sheet are the recognizable essential issues which designers and architects should pay attention in the initial steps of building any construction.
In the coming years, solar energy and integrating PV panels into building will predominantly grow in many countries. Followings are some recommendations for using Photovoltaic modules to generate electricity:

1. The lack of fossil fuels and the high cost of importing energy in North Cyprus could be solved by supplying power for all demands through in the macro level by power plants or in the micro level by putting PV systems in each living area.
2. Government should collaborate with designers, architects, clients and even investors, encouraging them to incorporate PVs on their building construction, giving them even special offers.
3. In these days, when developed countries are trying to control air pollution through appropriate sustainable policies, it is the duty of other developing and under developed countries to pay attention to this public awareness. In this regard, these countries can implement applicable policies which are tested formerly in developed countries.
4. One other familiar problem that has a fast solution is lack of investigation on availability of other energy sources and educational research on PV panels. Scholars can dramatically help designers and policy makers by their researches to clear up all aspects of power usage by PVs. In this way, the country quickly grows in a desirable way through knowledgeable experts.
5. To reduce the resistance of both public and private sectors to the new sustainable adoption, social public media has the most critical role in increasing public awareness. However, coordination of government with public media in this regard is also compulsory.

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