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The Effect of Architectural Form of Building on Optimization of Electricity Energy Consumption

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Abstract

In the contemporary age, an issue about human community is the issue of favorable housing, since home is a place that affects people during the day. Therefore, the house and living place should be efficient from two perspectives: 1) physical aspect 2) spiritual need aspect. However, today with excessive use of fossil fuels in buildings, especially residential buildings and due to increase in population, the crisis of lack of energy is predicted in not too distant future. Therefore, this study has been conducted with the aim of investigating the effect of architectural form of building on optimization of electricity energy consumption. The most important efficiency of solar energy is converting it directly to electricity. One of the systems of direct converting solar energy to electrical energy is photovoltaic system. The advantages of using photovoltaic panels have led to increasing growth of it in different scales from power plant to the building. Moreover, using photovoltaic panels as structural elements in architecture has led to some innovations in construction industry and has given new meaning to architecture. Using photovoltaic in buildings is an intellectual method that could make contemporary architecture going ahead with new concept toward green architecture. Finally, it could be mentioned that photovoltaic modulations have doubled performance in the building; meaning that photovoltaic modulations could be an alternative for conventional building materials and generate electricity in addition. Through replacing photovoltaic, the material cost is subtracted from total construction costs and the additional cost caused by using photovoltaic system is compensated to some extent such as combination of photovoltaic with floor, which could be the best mode to gain maximum system efficiency, so that the sun could have direct radiation on it.

Keywords: housing, residential complex, Harmony with the climate, the architectural form of the building, Energy intake

1- Introduction

Today, with excessive use of fossil fuels in buildings, especially residential buildings and due to increase in population, the crisis of lack of energy is predicted in not too distant future. According to the estimations of energy balance sheet (2007) in Iran during 2001-2007, the maximum use of oil products was in transport industry and then in construction industry (residential, commercial and public). However, Iranian architecture with its thousand year history has gained valuable experiences in field of harmony with the climate and nature and has implemented them. However, unfortunately over the decades, deep gap is created in continuity of the harmony and Iranian people have gone away from their past, have ignored past experiences and are establishing new scientific findings for energy optimization. Nowadays, through using orders existed under the title of climatic design in past days of Iranian architecture, people could help saying energy in buildings in designation of modern residential complexes. Hence, the aim by climatic design is energy saving with reduction of consumptive energy in building's body on one hand, which is close to local architecture and uses construction methods of native people and on the other hand; using renewable energies, the conditions could be provided for comfort inside the building like heating, cooling, air conditioning and natural lighting. Inactive solar systems, designing based on use of south lights, controlling disturbing regional winds

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and location of form of site and house are close to traditional concepts of harmony with the climate called today under the titles of green architecture, sustainable architecture and so on.
Along the inactive systems, active systems like using photovoltaic cells, cooling systems could be used efficiently in summer and solar energy could be also applied efficiently in winter and cold winds could be controlled, use of heating equipment could be limited to a few hours at night or it could be minimized during the day. Hence, the thought of harmony with climate is applied to design a complex with regard to reduction of energy consumption in Dorud City. The designer has considered functional needs and physical aspects (temperature, humidity, pressure and light) and aesthetic aspects to design these complexes.

Role of architectural design in reducing energy consumption in building Compatibility of native housing with various environments:
In cold regions: in these areas, forms are used with less lateral surface and with limited number of openings. Moreover, such materials are used that are thermal insulation. For example in Polar Regions, houses are made using pieces of ice with drainage of snow. Inside the home, skin of animals such as bear is used as the second wall between ice walls and human body. Hence, the direction of internal conditions, compared to the temp of 40-50ºC of outside, could be appropriate to considerable level. From this design, many points could be learnt to adapt the building with environmental conditions and the most important point includes controlling thermal exchange; meaning that thermal exchange between inside and outside should be controlled in very cold regions.

In temperate regions: in these regions, the situation is more appropriate than cold regions, since the weather is temperate in half of the year and the other half is also divided to two relatively cold groups. The decisions made for the two parts like controlling wind in cold seasons and supplying shade in hot seasons are relatively simple. In the summer, the lower edge of tent is removed, so that wind could enter to the tent and the hot airflow could be exit in the hole in the ceiling. The smoke of cooking food could also go out from same hole. In the winter, in addition to close the tenet, the tent is also covered and surrounded by fences made of plant fibers, so that the tent is protected against winter winds (in the winter, the hole in the ceiling remains open to push smoke out).

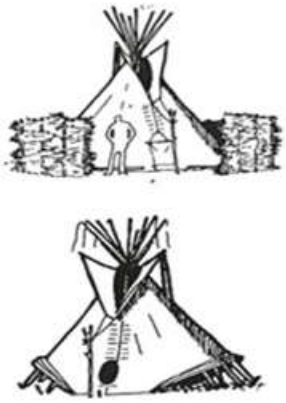

Figure 1: shelter compatible with temperate regions (North America)

The figure is an example of tenet used by native people and similar tents are existed in Turkmensahra, Iran. The tents are made by plant fibers, skin of animals and felt woven cloths and have similar function to the example.
In warm and dry regions, the most important issue is providing shadow. Predicting some holes is essential for proper air conditioning. The example presented in this section is related to desert areas. The skeleton of this structure is made of wood and its entrance is covered by woven of camel or goat wool. This coverage is an insulator by itself and is suitable for nights and other cold times.

In hot and humid regions: in these regions, the main problem is rainfall and sunlight. Hence, the buildings are designed in umbrella form and protect people against direct sun radiation and rainfall. At the same time, these buildings are built on the heights to escape from humidity and warmness of ground surface and have wooden structure and coating of plant fibers. An important principle observed in these structures is acceleration of airflow through opening or making holes in walls in height. These spaces are designed sometimes in different geographical directions (in north direction in winter and in south direction in summer) and sometimes in two different floors (winter in lower

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floor and in adjacency of the ground and summer in upper floor exposed to airflow) and the exchange between the two spaces are done depending on seasons. Another solution is daily migration inside the building.

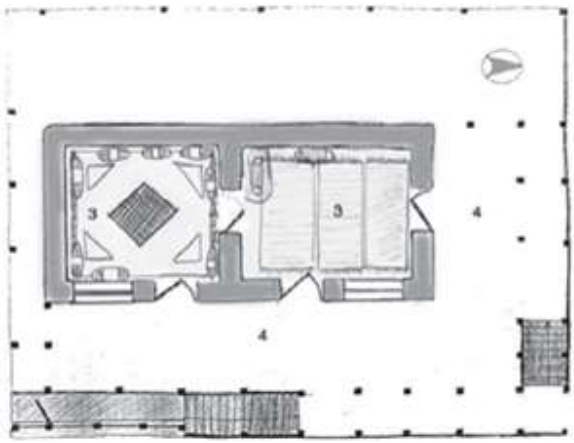

Figure 2: floor 1 in winter

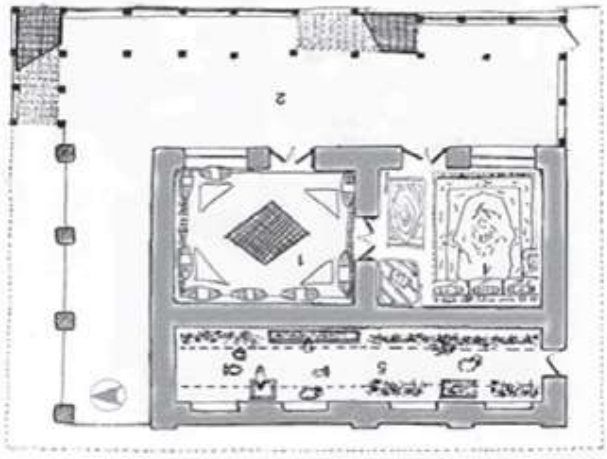

Figure 3: floor 2 in summer

Role of harmonized architecture with the environment in reducing fossil fuel consumption

The main purpose of climatic designation is saving energy with reduced energy consumption in building's body to go close to native architecture and use construction methods used by native people on one hand and supplying comfort inside the building like heating and cooling system, air conditioning and natural light using renewable and natural energy resources. Hence, two main goals are existed in design in harmony with the environment: first, familiarity with native designation methods and using them and second, using renewable energies instead of fossil fuels for heating and cooling purposes, lighting and air conditioning.

Role of architectural design in reduced energy consumption in building (wind energy in architecture)

Using wind flow in architecture:

Providing airflow inside the building is called as natural air conditioning. This type of air conditioning could increase oxygen and decrease carbon dioxide and the smells in the building.

Air conditioning using motor deriving force:

Using wind flow for air conditioning inside the building could be done in two ways: first, using same level aperture (transverse or bound ventilation) placed in same height balance.

Received:17 January 2018/Accepted:23 April 2018/Published:1 June 2018

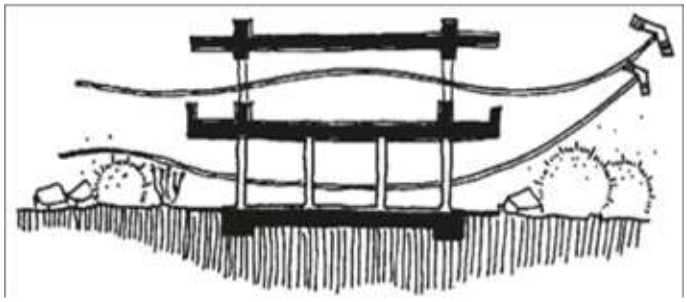

Figure 4: creating air current using two windows

Second method: using non-level air conditioning (feedback and load receptor), in which two different height balances are used for air entrance and exit

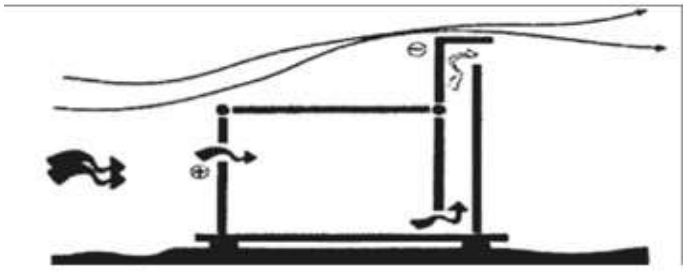

Figure 5: creating air flow using a window and a channel

Unroofed vertical

If the holes are in same level, the best position is possible when openings are placed in front of each other. Air conditioning of second degree happens when the building has two openings in two adjacent fronts. The lowest air conditioning level is belonged to building with two openings on same front; provided that difference of pressure is created between two openings through creating difference between height and vertical blades between two openings.

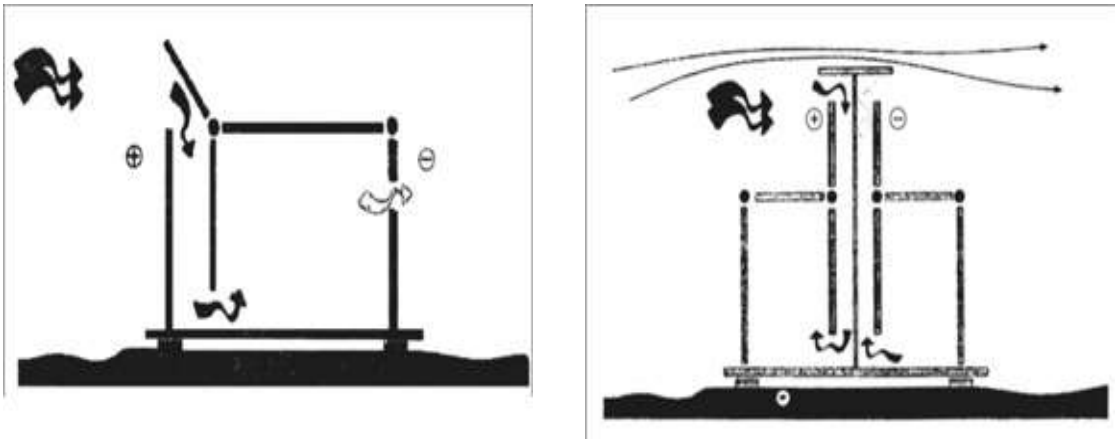

Figure 6: air entrance from top of the building and through vertical channel and its exit from another channel or window

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Existence of opening in upper part of a space could lead to exit of accumulated warm airflow in beneath of the ceiling and replacement of lower level airflow in this section. The relative vacuum created in lower part of the space could reduce outside air through lower openings.

Figure 7: role of difference in temperature of airflow in adjacency of ceiling and floor in creating breeze

Energy saving in residential buildings

Integrated design

Placement direction: in the preliminary step of designation, the house should be built in such direction that it could use maximum solar energy and the protections could be also created against sun radiation if possible.

Array: to maximize solar energy consumption, the inside space of house should be arrayed in such manner that the sitting spaces are placed in south direction and other spaces are in north direction.

Insulation: insulation should be taken in all building elements in adjacency of outside environment to prevent waste of energy and to ensure that no part is considerably colder than other parts. For example, a non-insulated window or wall in the building without proper insulation system could cause influence of cold weather in some parts.

Heating: heating system should be adjusted with real amount of waste of energy in the house.

Air conditioning: air conditioning should be created from open spaces of the building and should be in control of residents (like adjustable channels with exhaust fans) and not from unintentional paths (like the surrounding area of holes predicted for passage of pipes and cables). In an impenetrable house, the air conditioning holes should be designed in such way that the air could be exchanged for required times.

Form of site and house:

Both climatic conditions and climatic status of adjacent area could affect energy consumption.

Low temperatures in north areas could increase energy consumption.

Wind flow in open sites could decrease temperature and increased heat loss caused by air conditioner.

Sites out of shaded areas could adsorb more amounts of solar energy and need less heat.

Form of house could affect energy consumption:

Minimize the outside heat loss levels.

- Majority of apartments (middle apartments) have least heat loss level.
- Row-based houses (TERRACE) have less outside walls than independent (DETCHED) houses and the floor of the building loses less heat.
- A compacted building form without bumps and dents could minimize heat loss.
- The garage connected to the house could insulate common walls of garage and house.

Inside array of building could affect energy consumption:

- Separate the layers from sitting space. Lack of partitioning these spaces means that the stairs have also same degree of heat of sitting room.
- Avoid layers without keeping warmness inside the house, since they could lead to creation of two cold walls, which have been insulated most of the times.
- In buildings with several apartments, avoid using large entrances and stairs causing wind flow, since they could create cold space in the middle of the house.

Received:17 January 2018/Accepted:23 April 2018/Published:1 June 2018

Implemented Iranian samples:

Ekbatan City:

The city was implemented in 1974 in a land with area of 220ha in west of Azadi Square in Iran. The project with 1400 residential units is one of the largest housing projects at the world and has been predicted for 75000 people. With such area, different uses were considered for it. Although north and south limits of the project end to Tehran-Karaj Highway and Karaj Special Road, perfect vehicle access points are considered for it. Adjacency to Mehrabad Airport and the said roads and nearness to industrial sector of west of Tehran have declined quality of the city.
The city was among marginal cities before overdevelopment of Tehran over the 2 decades.

- Commercial units are placed linearly between blocks. In lower floor, roofed parking lot is placed and the main roads to have access to commercial services are mainly in form of passages. Commercial units in phase 2 are centralized between blocks of this phase in 2 points.
- From the main ring of the road surrounding the area, the access points are branched and end to private parking and open space of each block.
- Lack of using communicative spaces, natural light and air conditioning and lack of access of entrances to each other, lack of terrace or open space, except for the first units of blocks, are the main problems.
- Plots: more than 90% of apartments have 3 bedrooms and most of them have these features.

Separation of day and night spaces, definitely defined communicative spaces, possibility of using natural air conditioner, private warehouse in apartments, lack of access of public communication path to inside the apartments are the main features of this residential complex.

Apadana City:

The city was established in 1975. The complex is located in south of Tehran-Karaj Autobahn and in northwest of Azadi Square. The entrance and exit of the complex have some difficulties because of adjacency to autobahn and defected access of site to urban police. The communication inside the city is provided by external cavalry ring and some branches of it provide access to blocks and possibility of parking car and all parking lots are placed in open space and in the spaces between blocks. Figure 8 has illustrated the access ring and the access point to parking lots in spaces between blocks in Apadana City.

Figure 8: access ring and access point to parking lots in spaces between blocks in Apadana City

Daneshgah Tehran Shahrak:

The complex for professors and personnel of Tehran University is located in a land with area of 94ha in south corner of km12 of Karaj Special Road.
The project was started in 1976 and was established in 1979.
The initial design was in form of separated parts and precast 4-storey apartments in 2 phases and what is implemented is the limit of 4-storey apartments in phases 1 and 2 encompassing 23ha of total area of the site (precast system of the complex is implemented by a French Company). What is implemented is 112 blocks including 677 units and the most

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important feature of residential units is centralization of residential areas, which have access to parking lots and U-turns with a circles cavalry network and link the residential blocks to each other.
Existence of industrial factories around the city and urban link of the complex through heavy transport road (Karaj Special Road) could be negative features of site location.
Establishments: heating is provided by central establishments, cooling is provided by cooler, wastewater system is also provided by septic reservoir complex (all blocks have 4 stories and have no elevator).

Photovoltaic: generating electricity from the sun. The methods of using photovoltaic in building, advantages and limitations:

Using photovoltaic in the building is taken using various methods. Arrangement of photovoltaic panels on the roof, installation of these panels on the building and using them in building façade are the methods of using these panels in the buildings.
Installation of photovoltaic panels on the roof is the first and the simplest method of using these panels in building. In this method, photovoltaic panels are embedded on the roof with suitable spaces from each other and are not practically combined with building architecture. Hence, they play no role in aesthetic and physical appearance of the building.

Figure 9: installing photovoltaic panel on the roof

Installing these panels on the building: in this method, systems formed of photovoltaic panels would be installed on the building with foundation and fastening. This method has some problems such as considerable increase in building weight, increase wind load and destruction of building skin. In business buildings or light structures, increase in applied weight on the ceiling as a result of loading of photovoltaic systems should be calculated, especially if the building is old or has light structure. Moreover, increase in elements installed on a surface, the wind load is also increased on that section. Hence, in systems that photovoltaic panels are installed on the building, the joints of panels should be in such form that could resist against intense wind flows. Destruction of building skin is another disadvantage of attaching photovoltaic to the building, since through making holes in roof to install the panels, water could also penetrate in the building. However, it is currently possible to seal these holes. However, because of increased costs, it has no economic explanation. Integration of photovoltaic panels with building skin is the newest method of using photovoltaic in the building. Integration of photovoltaic with building is called integrated photovoltaic in short form and is discussed in this study.

Integration of photovoltaic with roof

Integrated photovoltaic systems were used for the first time in building roof. In this kind of integration, the best mode to get maximum system efficiency is to consider the slope of integrated roof with photovoltaic to an extent that sun could radiate on it vertically. However, today, it is possible to integrate flat roofs with photovoltaic panels; although the sunlight angle of roof varies due to the geographical location and time. Optimal angle is estimated based on desired time to get maximum energy in different regions. Jagged roofs are preferred to flat roofs. Using photovoltaic roofing shingles in flexible and thin form could be the novel examples of integrated photovoltaic roofs.

Received:17 January 2018/Accepted:23 April 2018/Published:1 June 2018

Table 1: integrated photovoltaic systems

Integration place	System	Information
1- Flat roof	a)panels a) integrated PV panels on roof	PV panels are integrated with the roof structure
2- Sloped roof	b) integrated PV tiles on roof	PV panels are integrated with the roof structure. Use of these tiles is easy for people and has gained many fans
3- Jagged roof with north skylight	a)PV panels	It enables natural lighting
4- Curved roof	a) opaque and flexible layers of PV or stiff modulations of PV are placed on a curve.	They could enhance designing facilities.

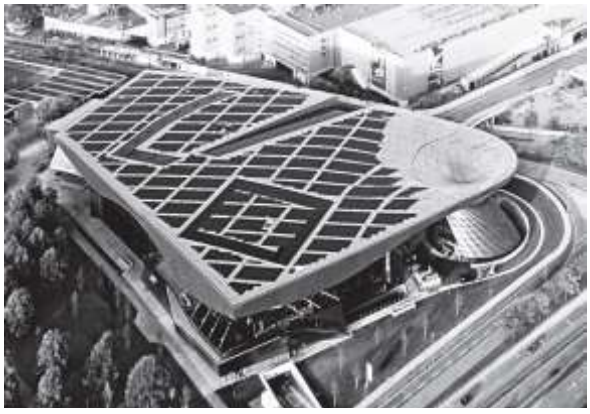

Figure 10: the image of flat roof

Figure 11: the image of sloped roof

Received:17 January 2018/Accepted:23 April 2018/Published:1 June 2018

Figure 12: the image of sloped roof with integration with tiles

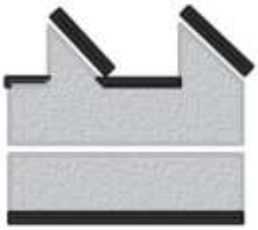

Figure 13: the image of jagged roof with north skylight

Figure 14: curved roof/wall

Designing and estimating photovoltaic system

While designing the photovoltaic system, different factors should be analyzed. These factors include:

Geographical location: latitude and longitude and the height of installation place of PV system to calculate sun radiation power.

Time status: the place and position of installation and its position to sun rotation, shadow, heights and surrounding mountains and hours of the day that shadow could prevent direct sun radiation to panels.

Climate: estimating the number of cloudy days, especially the long cloudy days (in order to store some part of solar power for cloudy days, the capacity of PV system should be estimated based on required power in cloudy days); wind flow and speed to determine strength of metal structure, rainfall and snow height to determine height of panels from ground level, air clarity, dust in the air and its impact on sun radiation, existence of thunder to predict suitable safety equipment.

Received:17 January 2018/Accepted:23 April 2018/Published:1 June 2018

Required electricity: the consumptive power, voltage, direct and periodic current and moment electricity; the consumptive power is entered to the calculations directly. The voltage could determine number of solar panels in line with each other and the moment power value is related to the time that all consumers are on the circuit with each other and devices are entered to the circuit that the required power consumption to start them is different from constant use of the devices. This is very important factor in designation of controller.

Creative combination of PV in architecture:

Photovoltaic canopies

The state of Australia has made an interesting measure to make students and children familiar with importance of renewable energies. In this measure, all primary schools are equipped to canopies generating electricity by means of PV cells. The form of these canopies is similar to the head of Cobra and has the rotating ability to 180º to get maximum sun radiation.

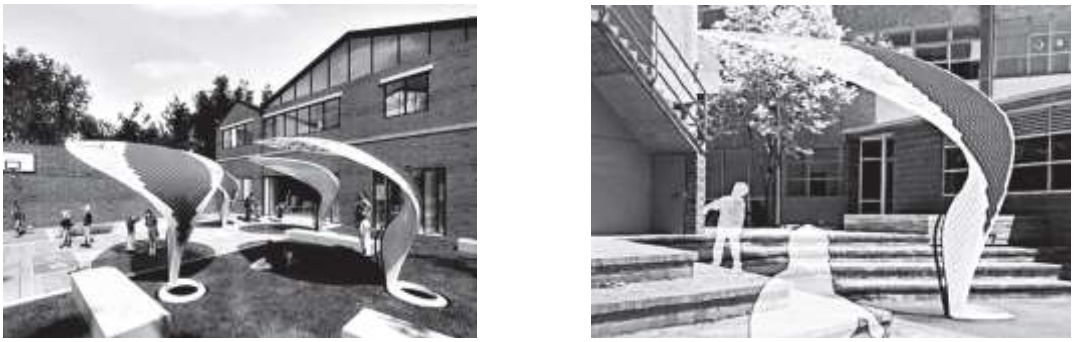

Figure 15: PV canopies

The sunny woods design

The sunny woods design is a complex of tree-like structures in parking lots. The leaves of trees in this wood are made of PV cells and their stem is the power outlet. In addition to generate electricity and charge cars, the trees play the role of canopy. He aim by designation of sunny woods is protecting the natural environment using powered vehicles.

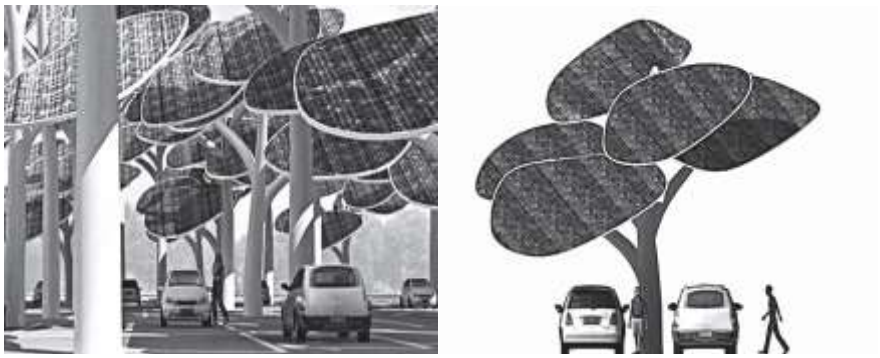

Figure 16: sunny woods design

Integrated photovoltaic in Iran

With the existence of worldwide requirements in field of using renewable energies, abundant advantages of integrated PV and the unique potentials of Iran to use solar energy, this technology is still unknown in Iran unfortunately. In the following, the most important factors affecting underdevelopment of integrated photovoltaic in Iran are referred.

Unreal energy costs in Iran:

In Iran, subside is allocated for the energy generated by fossil fuels and these energies are supplied for the subscribers in low costs. However, energy generation from renewable resources such as solar energy, wind and biomass energy need high costs including research and development costs, preliminary support, economic and technological development of affiliated industries, protective costs and tax discounts. The cost of conventional energies in Iran like

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fossil fuels is not their real cost and other costs should be also considered to estimate them which are always neglected in Iran unfortunately. The most important costs include environmental and social costs imposed on citizens, ecosystems and natural resources.
The cost of saving fossil fuels per kWh of generated power from PV systems is about 410.9 rials per kWh.

Lack of technical knowledge and information in field of integrated PV:
As integration of photovoltaic in a building has no long history and no activity has been taken in this field in Iran to the date, required technical information and sufficient knowledge are not available about this technology in the building. Despite to efforts of author to have access to designers and experts familiar with integrated PV industry in Iran, it seems that serious shortage is existed in this field.

Non-profitability of selling generated power
The tariffs to purchase power generated by renewable energy resources is fixed regardless of existing potentials and its source is wind energy. However, for solar energy, separate tariff should be created to provide the conditions for competition of investors in private sector.
According to article 62 of Drafting Part of State Financial Regulations, the guaranteed cost of each kWh of electricity is determined to 650Rls/hr in peak hours and to 450Rls/hr in low consumption hours. These costs are approved at the beginning of development plan and have not been changed or amended to the date. According to increased costs over the years, investment in this sector has no economic explanation. Moreover, according to the statements of SANA officials, the conditions are not provided to connect to the network by integrated PV systems in Iran.

Solar energy in architecture:
- One of the features of a zero energy house is that in peak hours, the power generation in this house is more than other times and in time of rationing and blackouts, this house could provide comfort of residents through generating required electricity.

An example of zero energy houses is constructed in Florida with warm and humid climate:
Widescreen protrusion of old houses in Florida is being used less today with the assumption that artificial air conditioner is the best way to meet cooling needs. Why the air conditioning equipment should be overused and increase costs? 3ft protrusion (90cm) of roof of zero energy house (compared to protrusion of 1.5ft (45cm) of control house) has shadows 2 times more than it, which is especially useful to control warmness of walls and windows.
Another innovative method in zero energy houses is using white and reflecting tiles in ceiling. Instead of using asphalt, gray and brown tiles used in each control house, R-30 fiberglass insulation is used in sloped ceiling of both houses. However, the temperature recorded in the peak consumption day (Jan 18, 1998) could prove the differences of the two houses. In the afternoon, the temperature of control attic is increased rapidly and has reached to 92ºC; although in attic of zero energy house, the temperature has reached just to 38ºC equal to the outside temperature. The advanced windows to control sunlight are carefully installed; meaning that they mostly make visible sun spectrum pass throughout them; although they limit transmit of radiations of spectrum in range of infrared and ultraviolet radiations (leading to high temperature and color decay of furniture).
To gain better results in zero energy houses, underbuilt channels are larger than the desired size in the attic. These channels are embedded in conditioned spaces. The experiments have shown that in warmest hours, the influence of heat to duct could waste one third of cooling capacity of air conditioning, which could lead to more airflow and less friction.

Sample projects in Netherlands:
Hardwick project: Hardwick City project includes 31 houses. Houses are divided to a row of houses with common terrace and two rows of houses for the elderly people. The houses for the elderly people have sitting room, kitchen, bedroom and bathroom in a grand floor and an additional rom in the flooring.

Less energy consumption:
These houses are insulated properly. Solar energy is adsorbed through the greenhouses on the roof. The ceiling of greenhouses includes a sun collector and a PV system with area of 12m2 to supply hot water for each house.
PV system made of several transparent layers has solar transfer coefficient lower than 30%, which could lead to reduction of temperature of greenhouse. The energy generation power of each system is also equal to 0.85kw. The energy efficiency coefficient in these houses is equal to 0.70%.

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Conclusion

- The main component of PV systems is photovoltaic cell. PV cells are also known as solar cells. These cells are made of semiconductor materials and mainly of silicon and could convert light directly to electricity.
- PV systems have other advantages in addition to energy generation and some of them are as follows:
- They are needless of fossil fuels
- Intangible difference of energy generation in the best and the worst location in terms of sun radiation
- Reduction of environmental pollutions
- Unlimited access to solar energy to convert it to electricity
- Facility of installation and being needless to complicated equipment and manpower
- Low probability of dangerous accidents like fire and explosion
- Reduced waste of energy
- Integrated PV in building means using PV with skin building. In this method, PV modulations play additional role in building; it means that PV modulations could be replaced instead of construction materials in addition to generate electricity. Through replacing PV, the costs are subtracted from total costs of building and the additional cost of using PV is compensated to some extent like integration of PV with roof, which is the best mode to get maximum system efficiency with sun radiation. The other one is integration of façade, especially in south facades. Integration with canopies and bars of terrace are also other types of this integrated system.

The components of integrated PV system are as follows:

- Solar panel: solar panel coverts sunlight to direct electricity.
- Junction box: junction box is the mediator of connecting panels to electricity circuits and is also protection for solar panels against thunder.
- Metal structures: metal or constructive structure maintains the panels in special direction and angle.
- Controller: controller is responsible for controlling power generation, power consumption, charging storage batteries and regulating information of generated and consumed power in terms of voltage and ampere
- Connecting cables: connecting cables provide connection of PV system and power circuit
- Storage batteries: storage batteries could store the power required for cloudy hours.

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