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Building integration of solar energy systems in Türkiye and world

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Abstract

Energy is one of the most important issues from the industrial revolution and in the globalizing world. Energy is also a big problem for the Republic of Türkiye, which has made a serious industrial breakthrough in the last 20 years. Because Türkiye, which does not have rich fossil fuels like the Middle Eastern States or Russia, is a foreign-dependent country for its energy needs. It is known that fossil fuels will be depleted in the near future and waste materials generated as a result of energy production pose great threats to the world ecosystem. Therefore, in recent years, developed and developing countries have been developing investment projects for alternative energy sources instead of fossil energy sources. The most efficient and harmless of alternative energy sources is Solar Energy. It should be noted that the use of solar energy, which is so efficient for our world and more attractive than other alternative energy sources in terms of the energy size it produces, requires a certain technical knowledge. Because Türkiye is geographically located in the middle belt and due to its special location, the number of sunny days is much higher than in other countries. In this article, the reality of solar energy in Türkiye and its potential, the solar energy systems used and how they are integrated into buildings, and the advantages and disadvantages of these integrated systems is reviewed. In addition, some examples from some countries of the world will be discussed. Furthermore, projects of integrated solar energy application systems in buildings in Türkiye are reviewed, in addition to some suggestions and recommendations in this field.

1. Introduction

Energy, which is the main agenda item of our world and will remain on the agenda for many years, is also a very important problem for Türkiye [1]. Türkiye is lucky compared to many countries in terms of its solar energy potential due to its geographical location [2]. In most European countries, buildings account for approximately 40% of the total energy use [1]. While nearly half of the energy used in buildings in Europe is produced by solar energy systems, in Türkiye, where the number of sunny days is much higher than in Europe , most of the energy used in buildings is obtained from fossil energy fuels, in addition to non-residential buildings [2].

As observed in Figure 1, Türkiye's sunshine duration is longer than that of many European countries. The developing technology and construction sector in Türkiye and the decrease in the lifespan of fossil fuels make it necessary to use the solar energy system, which is one of the alternative energy sources, in buildings. Most solar components are mounted on building roofs and they are frequently seen as a foreign element on the building structure [3]. This integration process is not accepted by many architects as it is against the design principles and spoils the appearance of the building. For these reasons, when using renewable energy systems (RES) in buildings, it is necessary to integrate the system correctly and not to spoil the form and aesthetic appearance of the building.

There is a lot of discussion by scientific committees about the advantages and disadvantages of RESs used in buildings. The advantages are:

1) Since the energy production is local, the transportation cost is minimized.
2) Since environmentally friendly energy is produced with RESs, very low levels of environmental pollution are obtained at the end of production.
3) Energy consumption expenditures of buildings are reduced.
4) It can be significant income for building owners. (for grid-connected systems)
5) The building can be of a higher class concerning energy performance certificate [3].

The disadvantages are:

1) Increases building construction costs.

2) Creation of RES models according to the design principles of the building.
3) RESs periodic maintenance and costs.
4) RESs disrupt building integrity.
5) The lack of sufficient technical infrastructure as solar energy systems in Türkiye are a new business line.

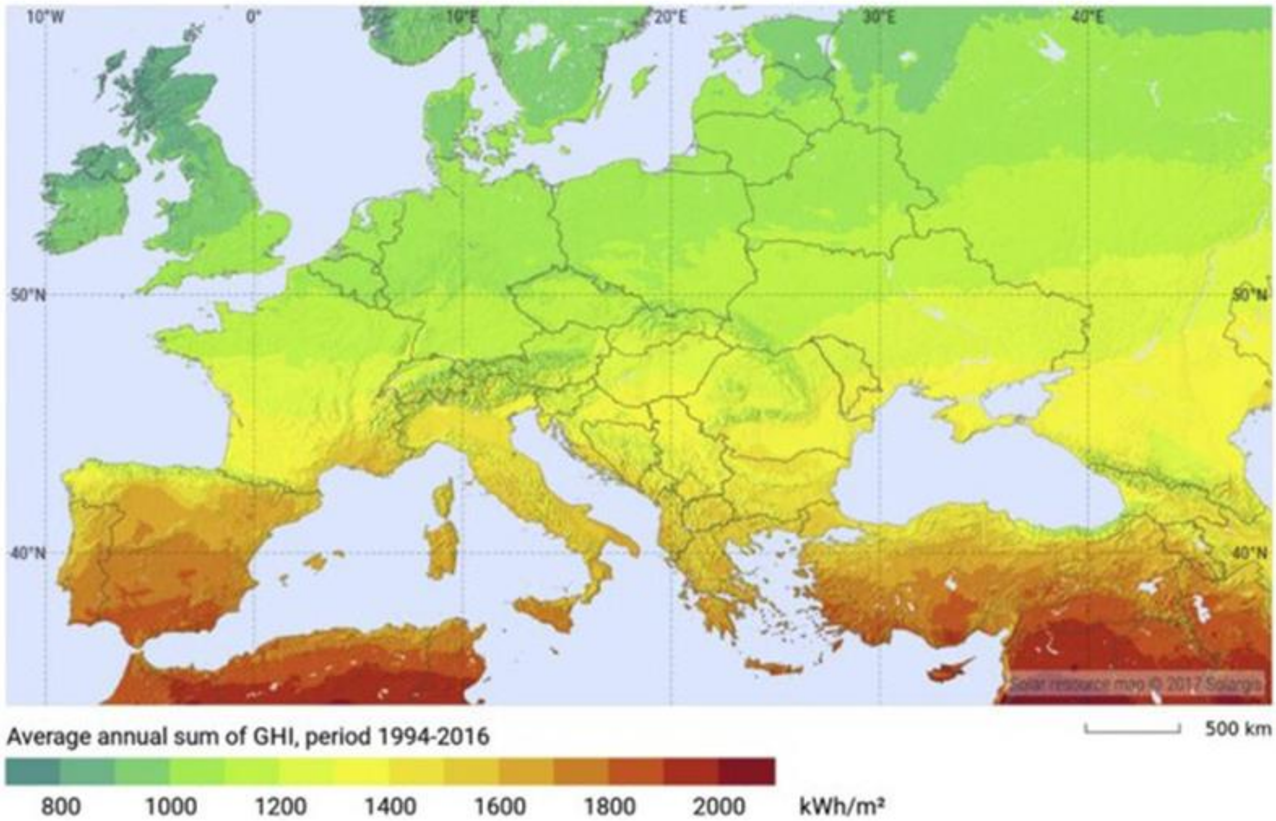


Figure 1. Annual Insolation Radiation in Europe [4].

2. Integration of solar res into buildings in Türkiye

2.1. History of solar energy system

The most important energy source in the world is the Sun. sunlight, earth and it is the main energy source possibility that affects the physical formations in the atmosphere order [5].

Socrates is the philosopher who first revealed the basic principles and principles of benefiting from this energy source [6]. Lavoisier developed a mechanism similar to a solar furnace that has a converging lens with a diameter of 1.30 meters directed to the center. With this mechanism, he achieved a temperature of 1750 °C, and inside the furnace he succeeded in melting the piece of iron that he placed [7]. The first use of solar energy, which has been used since ancient times, in its current sense it coincides with the 18th century [8]. The history of solar photovoltaic cells begins with Edmond Becquerel's discovery of the photovoltaic effect in 1839 [9].

Solar energy systems field activity in Türkiye started between 1980-1990 execution carried out; Establishing a heat pump system as a result of a practical application in the laboratory of Ege University and operating it with solar cells has been one of the first steps taken in this field [10]. Since 2000, the use of solar energy in Türkiye has been increased and the policies related to the use of solar energy have been given importance.

2.2. Solar energy potential in Türkiye

Due to its geographical location, Türkiye has many solar energy potential country is lucky [11]. The annual average solar radiation is 1303 kWh/m and the total annual sunshine duration is 2623 h. energy needed for heating applications sufficient to provide [12].

Although Türkiye is a rich country in terms of solar energy, can be noticed in Figure 2 that not every region or province has the same solar energy. In Türkiye, the smallest and largest values of annual average solar radiation occur in the Black Sea Region with 1120 kW/m^2 and in the Southeastern Anatolia Region with 1460 kW/m^2, respectively [13]. This difference is one of the most important factors in the integration of solar energy systems into buildings. For example, Şanliurfa is the province with the most sunshine duration in Türkiye, and Rize has the least sunshine duration. Solar energy systems to be integrated into buildings in these two provinces should not be designed and manufactured in the same way. Therefore, before a solar energy system is designed, the conditions of the region and even the province should be evaluated and solar energy systems should be produced as a result of these researches. Türkiye's sunshine duration by region is given in the Table 1.

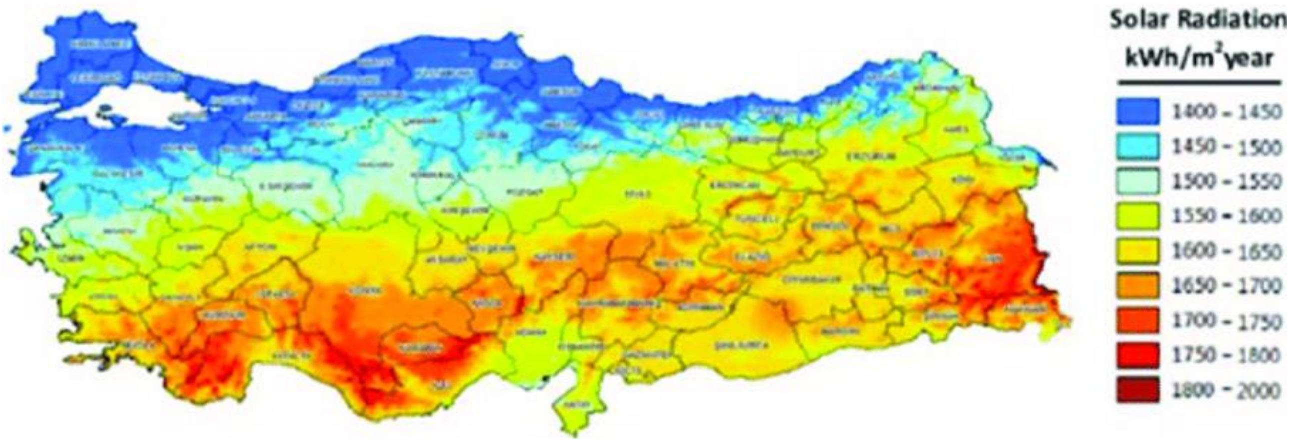


Figure 2. Average sunshine radiation of Türkiye [14].

Table 1. Distribution of solar energy and sunshine duration by regions in Türkiye.

Regions	Annual Total Solar Energy (KWh/m^2) year	Annual Total Sunbathing Time (Hours/year)
Southeast Anatolia Region	1 460	2 993
Mediterranean Regions	1 390	2 956
Aegean Region	1 304	2 738
Central Anatolia Region	1 314	2 628
Eastern Anatolia Region	1 365	2 664
Marmara Region	1 168	2 409
Black Sea Region	1 120	1 971
Türkiye Average	1 311	2 640

2.3. Types of solar energy systems used in buildings in Türkiye

Solar energy systems used in Türkiye are examined under two main headings:
1) Passive Systems
2) Active Systems

2.3.1. Passive systems

Between 470 and 399 BC The house of Megaron, belonging to Socrates, is a house that shows the beginning of passive systems [15]. While designing this house, the relationship of the facades of the house with the sun was taken into consideration. The windows of the rooms of the house were placed on the south facades and were designed according to the terrain conditions. If periods close to the day are examined, in 1940 Architect George Fred Keck designed the provincial passive solar house (Figure 3).

The most important thing about passive systems should be added to the building in the same process as the design phase of the building. Passive systems are not added to the building afterward. Without the need for any mechanical-technical staff, the location of the building, and other architectural features such as location, form, and building envelope relative to buildings made systems.

Passive Systems are examined under two headings among themselves:

Figure 3. George Fred Keck First Modern Passive Solar House, Chicago [16].

2.3.1.1. Passive systems formed by the natural environment

If the factors influencing the negative systems formed by the natural environment are included:
a) Latitude and longitude degrees of the region where the building will be built,
b) The sea level of the area where the building will be built,
c)Air temperature
d)Physical environment
e) Climate, humidity and wind,
can be counted as.

According to these effects in order to make the place comfortable, high indoor air quality and low cost. It is important that the space operates passively with less energy [15].

2.3.1.2. Passive systems formed by artificial environment

The environment created by man, not naturally, is called "Artificial Environment". Natural heating of buildings without the aid of mechanical devices or consciously at the design stage for ventilation of the wind, solar. Planning according to such factors reveals passive systems. The point to be considered with the artificial environment is the absence of any mechanical accents that are subsequently integrated into the building. Therefore, it should not be confused with active systems.

2.3.2 Active systems

Systems that convert the energy carried by the sun's rays from the sun into heat, light or electrical energy with mechanical and technical materials are called active systems. These systems are divided into two according to the purpose for which they use solar energy. The first system, the collectors, uses the solar energy to heat the water. The second system, Photovoltaic (PV) systems, converts the solar energy to electrical energy (Figure 4). If these two systems are examined separately:

(a) (b)

Figure 4. Solar Collector (a) and Photovolatic System (b).

2.3.2.1. Photovoltaic Systems

There are various ways to install Photovoltaic (PV) systems in a building. Among them, the most preferred method in Türkiye is the method installed with brackets on a flat or sloping roof (Figure 5).

Figure 5. PV's brackets [17].

Integration of PV systems into the building can be examined and applied under 3 main headings:

(a) Integrating the panels into the building's exoskeleton. In this integration method, PV panels are installed in the empty space by removing the roof tiles and external walls (Figure 6). Although it is a new integration method in Türkiye, it is more advantageous than other methods that are frequently used. Its advantages can be listed as follows:
1) It does not destroy the integrity of the building by removing the add-ons afterwards.
2) It provides high energy efficiency.
3) Since it is compatible with the architectural aesthetics of the buildings, it does not cause architectural deformation.
4) Since it is made of solid materials, it has a longer life than other methods.

Besides its advantages, it also has some disadvantages. These are:

1) It is a very costly method.
2) When there is a new business line in Türkiye, the necessary equipment and technical team are insufficient.
3) Since it is used only in electricity generation, it should be used together with hot water and other methods for heating.

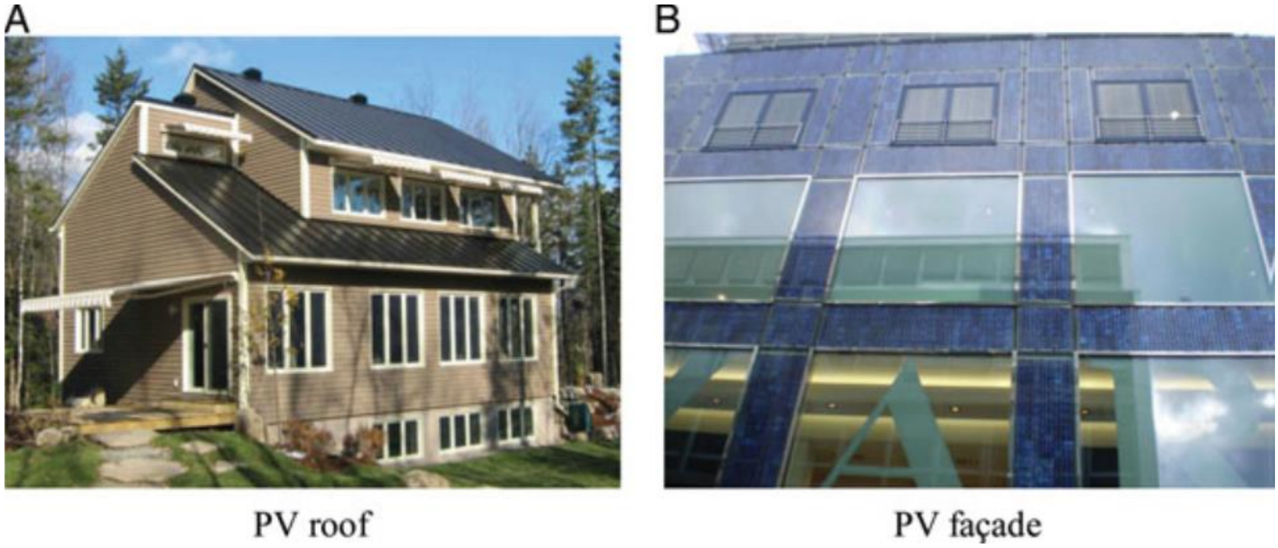


Figure 6. Building integration of PV. (a) PV roof. (b) PV facade [1].

(b) Use of heat collection functions in harmony with PV panels. PV panels typically convert from % 6 to 18 % of the incident solar energy to electrical energy, and the remaining solar energy is available to be captured as useful heat [1]. This heat is lost outdoors in normal applications. In this application, a cooling liquid (air or water) is circulated behind the panel. This liquid helps the panel to cool. This cooling increases the efficiency of the panel because if the temperature of the panel is lowered, the electricity generation life will be extended. This application can be configured in two different ways:

In one open-loop configuration, outdoor air is passed under PV panels and the recovered heat can be used for space heating, preheating of ventilation air or heating domestic hot water—either by direct means or through a heat pump [1]. Such systems produce both electricity and heat energy for the building and eliminate the extra application project load required for the heat in the first application.

It should be noted that in these two applications, PV systems are replaced by building elements. While these applications are economically beneficial, some problems also arise. These are the problems of rain penetration into buildings and heat insulation.

(c) Integrating light transmission functions into the PV panel – building integrated PV/light. In this application, special PV panels are used (translucent PV panels) that transmit some of the sun's rays into the building (Figure 7). In this application, some of the sun rays are absorbed by the panels, but a significant part is directed into the building to illuminate the building. One of the important difficulties of this application is to prevent the windows from overheating. Because this application can cause overheating of the rooms in the building and loss of comfort, since the panels act as windows in the building.

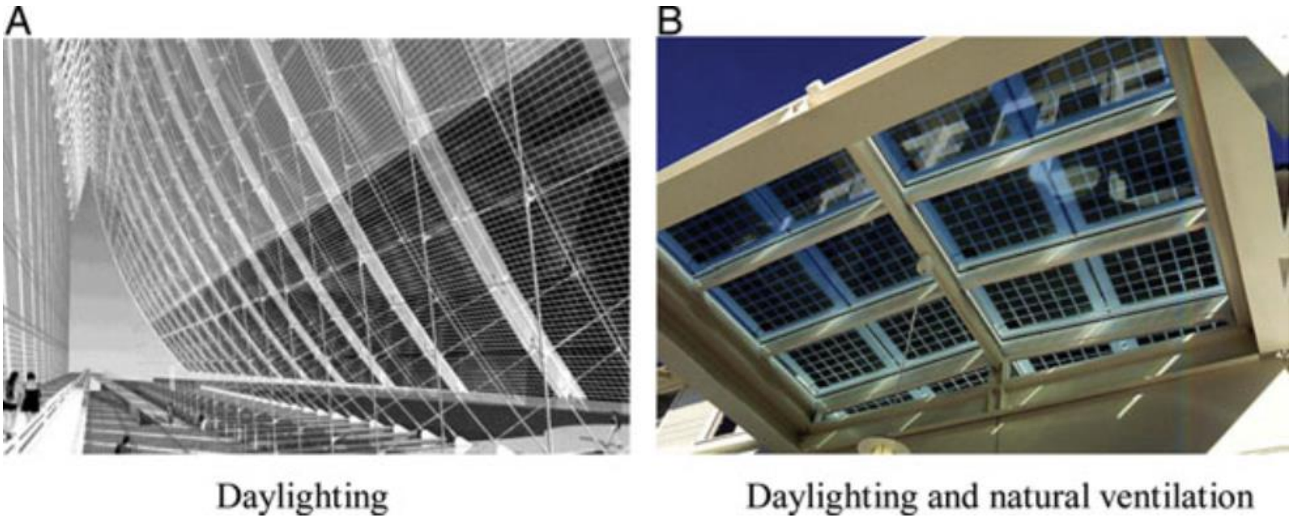


Figure 7. Combination of building integrated PV with daylighting and natural ventilation. (a) Daylighting (b) Daylighting and natural ventilation [1].

2.3.2.1.1. Considerations for the use of PV systems in Türkiye

Although the use of PV systems in Türkiye is a new business line, it can be said that it has progressed rapidly with the incentives made in recent years. There are some issues that need to be considered in the implementation of this developing business line in Türkiye. If these issues are researched, it should be known that photovoltaic systems cannot be used in some areas. To exemplify these areas:

1) Since Türkiye has a rough terrain, PV systems cannot be used on lands with a slope of more than 3 degrees.
2) Large-scale PV systems are not used in residential areas.
3) PV systems are not used in areas within 100 m of highways and railways.
4) PV systems cannot be used in areas within 1 km of airports.
5) It cannot be used in areas within 500 m of environmental protection areas and nature parks.
6) PV systems cannot be used in lakes, dams and rivers.

2.3.2.1.2 Building integration applications of PV systems in Türkiye

In Türkiye, PV systems can be integrated into buildings in various ways. If these applications are checked:

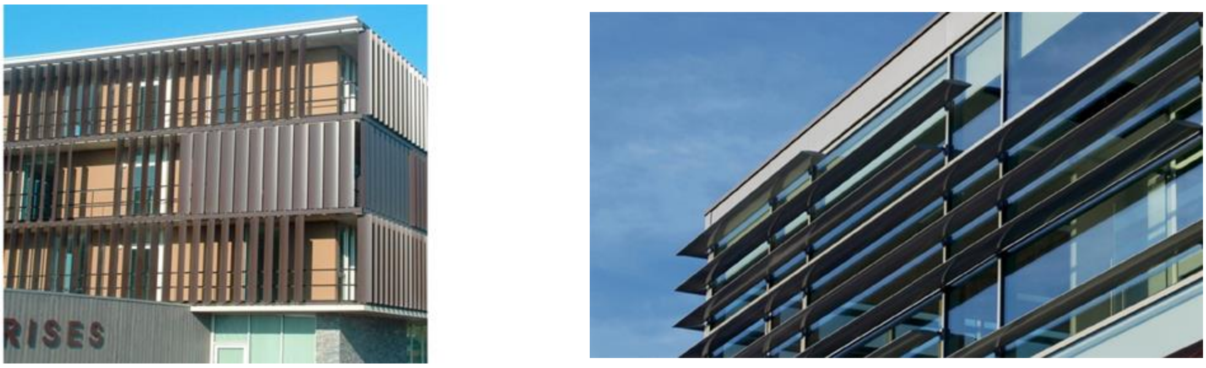
a) Using as a sunshade in buildings

This application, which is the most preferred application in Türkiye, is a useful application method to produce its own energy, to save energy and to protect the building from disturbing sunlight (Figure 8). The use of sunshades in Türkiye is not the same for every building facade. They are used horizontally on south facades. Because with this application, while the high-angle summer sun is prevented from entering the building, the low-angle winter sun is allowed to enter the building.

Vertical sunshades, on the other hand, are preferred on the west and east facades of the building, ensuring that the areas inside the building are protected from harmful sun rays in hot summer months.

b) Using as a coating facade in buildings

Another PV system application used in Türkiye is Coating Facade PV Systems. Facades are one of the most important structural elements in the aesthetic appearance of the building. For this reason, in the application of PV systems used on facades, the design phase of the building and the facade is more important than the installation of mechanical accents. While the coating facade PV systems are being designed, they should be designed together with the building and attention should be paid to the architectural harmony of the PV system and the building (Figure 9).



(a) (b)

Figure 8. Vertical PV sunshades (right photo) and horizontal PV sunshades (left photo) [18].

(a) (b)

Figure 9. Facade PV systems added to buildings later (b), Facade PV systems designed with the building (a) [19].

When examining the application forms in the two photos above, it can be seen that the photovoltaic system of facade cladding made with the building is more aesthetic.

c) Using as a glass in building

The method used as PV glass provides a significant amount of electrical energy to the building, as in other methods. It also contributes to the modern architectural movement by adding a different aesthetic appeal to the building (Figure 10). The most important thing that distinguishes this method from other methods is that thermal insulation elements can be used on glass. With this method, the building both produces its own energy and minimizes heat loss. Studies on this method, which has very little application area in Türkiye, should be intensified and the design and implementation teams should be informed about this method.

Figure 10. Example of Glass PV system used in buildings [18].

d) Use as roof covering in building

The PV system material used in this method is mounted on the roof. Contrary to other methods, in this method, the PV system is integrated into the existing building, not at the design stage of the building. The point to be considered in this application should be the choice of types and colors suitable for the aesthetic appearance of the building of the PV materials added later. These methods are embodied with pictures (Figure 11):

Figure 11. Integration of thin film PV system on roof [20].

The integration of the thin-film PV system on the roof is a method of adaptation to the existing building (Figure 12). The point to be considered in this method is that the aesthetic appearance of the building should not be impaired while the PV system is integrated into the building. This method is generally used in pitched roofs to maintain the existing slope of the roof.

In the framed PV system integration method, there is a frame construction, unlike the thin-film PV system. PV panels are not directly integrated into the roof. There are auxiliary structural elements (Figure 13). Just as thin film PV systems are used, framed PV systems are also used on pitched roofs. The difference from thin-film PV systems is higher energy efficiency. However, it is more costly than thin-film PV systems.

Another difference method of framed PV systems on roofs is their integration into flat roofs. Although the PV panel used is the same as the PV panel used in the other method, the additional construction used is different. In this integration method, since the roof is flat, it tends to better use the solar rays of the PV systems with an additional construction.

In the above titles, it has been explained what photovoltaic systems are, what methods they are used in and in which region of Türkiye. In next title, Solar collectors, which are the most widely used solar energy systems in Türkiye, will be included.

Figure 12. Integration of framed PV systems into the building [21,22].

Figure 13. Integration of framed PV systems on flat roofs [23].

2.3.2.2. Solar collectors

Solar collectors have a history dating back almost 120 years. Yet, benefiting new materials and innovative designs, they keep evolving to more effective systems satisfying the necessities of various applications [24]. Solar collectors convert solar energy into heat energy. They differ from PV systems because they convert solar energy into heat energy (PV systems convert solar energy into electrical energy).

Solar collectors consist of a double glass upper surface, the space left between the glass and the absorber layer, a metal or plastic absorber layer, a coating on the back and sides, and a casing that takes place inside all these parts (Figure 14) [15].

The sun's rays fall on the absorbing surface and heat this surface. It provides heating of the liquid inside the pipes connected to the heated surface.

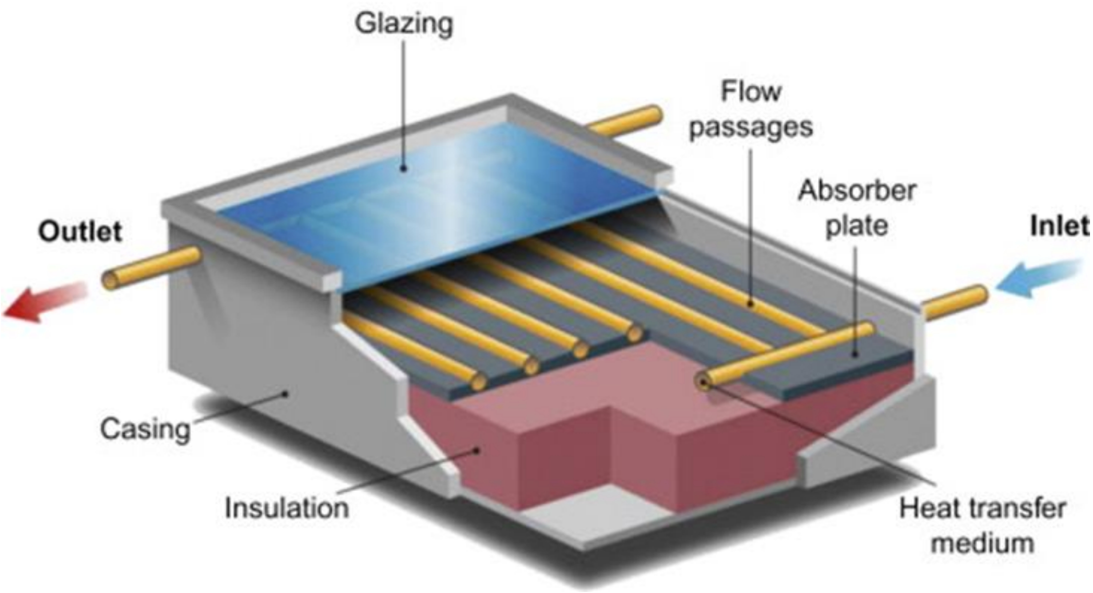


Figure 14. Elements that make up the collector [25].

Solar collectors (Solar Thermal Panel-STP); planar solar collector, vacuum tube solar collector classified as [26] In planar solar collectors (Figure 15), through the glass cover there may be heat losses by convection [26]. However, the vacuum tube solar collector heat losses by vacuuming between the transparent pipe and the black painted pipe inside is avoided [26].

The technical details of the types of solar energy systems and their integration into a building have been reviewed in the above headings. The next topic will review the application projects of solar energy systems to buildings in the world and in Türkiye.

(a) (b)

Figure 15. Planar solar collector (a) and vacuum tube solar collector (b) [25,27].

3.Application projects of solar energy systems in the world and Türkiye

Numerous projects in the world where building integrated active and passive solar energy systems are used exists [28]:

3.1. The world's largest solar energy office building shines in China

The world's largest solar building, exhibition halls, scientific research center, special for meetings and educational events, with a building area of 75,000 m^2 in the north-west of China it is a multifunctional project with areas and sections used as a hotel [28] (Figure 16). By encouraging the use of sustainable energy in building construction, solar energy was used instead of fossil fuels. A large number of solar panels are installed on the facade and roof of the building. Thanks to this design approach in the building, an average of 30% per year energy recovery was achieved [29].

Figure 16. World's largest solar Office building (China) [30].

3.2. Salavador Dali Museum

Yan Weymounth, the architect of the Salvador Dali Museum (Figure 17), which welcomes an average of 300 000 visitors a year, was based on the sustainable energy model during the design of the building. Thanks to the active and passive energy systems used on transparent and opaque surfaces, the heating-cooling, ventilation and electrical energy needs of this museum, which has a very intensive use, can be met to a large extent [16].

3.3. Novartis Building, Basel, Switzerland

This building (Figure 18), built in 2009, is perhaps one of the best examples in the world of the integration of solar energy systems into the building. The glass roof covering is equipped with semi-transparent PV panels and the panels are produced in a project-specific color [31]. With this integrated system, all the electrical energy needs of the building throughout the year are met.

3.4. Muğla University Türk Evi'' Student Cafeteria

It can be said that the planned integration of PV systems with the Muğla University student cafeteria is done (Figure 19). The roof of the building is covered with PV panels. With the building-integrated grid-connected system with an installed power of 25.6kWp over 35,000 kWh of electrical energy is produced annually and is connected to the grid is transferred [34].


Figure 17. Salvador Dali Museum [32].


Figure 18. Novartis Building, Basel, Switzerlan [33].

Figure 19. Muğla University Türk Evi'' Student Cafeteria [35].

3.5. Denizli government building

With the BIPV application (Building Integrated Photovoltaics) in the Denizli Government Building (Figure 20), all the energy needs of the building (75 kWp) are met from this system [31]. With the PV systems added to the roof, the building can produce the energy it needs. Since the system is connected to the grid, it can use the electrical energy it produces without storing it.

Figure 20. Denizli Government Building [36].

4. Conclusion and recommendations

Today, with the developing technology and rapidly increasing population, the desire of individuals to have better living standards has increased the energy used by humanity significantly [37]. Considering the future as well as the present, it is a necessity to design new buildings energy-efficiently, to make existing buildings energy-efficient, and not to create ecological environmental problems by choosing the energy needed by the building from renewable energy sources [38]. When examining the distribution of energy use in Türkiye according to sectors, the rate of energy used in buildings is not to be underestimated. In today's developing Türkiye, where fossil fuels seriously increase the foreign dependency of the country's economy, the use of alternative energy sources becomes even more important. At the beginning of these alternative energy sources, of course, is Solar Energy. Photovoltaic panels producing electricity in a country like Türkiye, which is extremely advantageous in terms of solar energy, it is possible to produce an estimated 40 billion kWh of electricity per year only by using it on the roofs of some houses, workplaces and especially in places such as factories with a large roof area [39]. In the light of the above information, studies should be carried out in order to benefit more from solar energy in Türkiye [29]. Here are some suggestions for the work that needs to be done:

4.1. Building legislation regulations:

Although there is the necessary legal infrastructure for legislative arrangements, it is known that there are important deficiencies in the administrative infrastructure. The joint efforts of the Ministry of Environment, Urbanization and Climate Change and the Ministry of Energy and Natural Resources should be increased and necessary arrangements should be made.

4.2. R&D and training studies:

R&D studies of solar energy systems should be made more comprehensive and these researches should be supported by the state and private sector. They should review the course content and make necessary educational reforms on the use of alternative energy sources and their integration into buildings in the Faculty of Architecture and Engineering.

4.3 Dissemination of architectural applications:

The state should build exemplary structures and provide comfortable working spaces for architects and engineers working in the private sector.

Author contributions

Ahmad Aboul Khail: Supervision, Visualization, Editing
Zeynel Polattaş: Methodology, Investigation, Writing, Original draft preparation

Conflicts of interest

The authors declare no conflicts of interest.

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