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Research Article

Comparative Evaluation of Solar Houses Applied in Turkey

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Abstract

The construction sector consumes a significant portion of the energy resources irreversibly and harms the environment. Limited resources and emerging environmental problems have made it necessary to search for new energy resources in the world and in our country, and to use renewable energy sources, environmentally friendly and energy efficient building designs in the building sector. In this context, the issues of solar energy, which is one of the clean and renewable sources and the use of solar energy in buildings, have gained importance. Although Turkey is in advantageous position compared to European countries in terms of potential solar energy, solar energy is not sufficiently utilized in buildings and studies are limited to academic studies. Solar houses, which are built in Turkey in order to benefit from solar energy with active and passive methods in heating, cooling, lighting and ventilation of buildings, consist of single examples designed with different functions. The aim of this study is to emphasize the importance of the use of solar energy in buildings within the scope of renewable energy sources, to examine the solar houses applied in Turkey comparatively and to make suggestions for solar house design.

Keywords: Renewable energy sources, solar energy use in buildings, solar house, active and passive systems, environmentally friendly energy source

Türkiye'de Uygulanan Güneş Evlerinin Karşılaştırmalı Olarak Analizi

Öz

Yapı sektörü enerji kaynaklarının önemli bir bölümünü geri dönüşü olmayacak biçimde tüketmekte ve çevreye zarar vermektedir. Kaynakların sınırlılığı ve ortaya çıkan çevre sorunları dünyada ve ülkemizde yeni enerji kaynaklarının araştırılmasını ve yapı sektöründe de yenilenebilir enerji kaynaklarının, çevreye duyarlı ve enerji etkin yapı tasarımlarının kullanılmasını zorunlu hale getirmiştir. Bu çerçevede temiz ve yenilenebilir enerji kaynaklarından olan güneş enerjisi ve yapıda güneş enerjisinin kullanımı konuları önem kazanmıştır. Türkiye sahip olduğu potansiyel güneş enerjisi açısından Avrupa ülkelerine kıyasla avantajlı konumda olmasına karşın, yapılarda güneş enerjisinden yeterince yararlanılmamakta ve yapılan çalışmalar akademik çalışmalarla sınırlı kalmaktadır. Türkiye'de yapıların ısıtma, soğutma, aydınlatma ve havalandırılmasında güneş enerjisinden aktif ve pasif yöntemlerle yararlanmak amacıyla gerçekleştirilen güneş evleri birbirinden farklı işlevlerle tasarlanmış tekil örneklerden oluşmaktadır. Bu çalışmanın amacı yenilenebilir enerji kaynakları kapsamında yapılarda güneş enerjisinin kullanımının önemini vurgulamak, Türkiye'de uygulanan güneş evlerini karşılaştırmalı olarak irdelemek ve güneş evi tasarımı için önerilerde bulunmaktır.

Anahtar Kelimeler: Yenilenebilir enerji kaynakları, yapılarda güneş enerjisi kullanımı, güneş evi, aktif ve pasif sistemler, çevre dostu enerji kaynağı

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1. Introduction

Population increase and urbanization coupled with industrialization have resulted in the preference of cities over rural areas for settlement. Throughout the world, people spend most of their times within buildings. Consequently, there has been an increase in construction activity and the use of natural resources, causing many environmental and energy problems. Looking at the sectoral distrubition of energy consumption industrilizied counties, the building sector comes in third after industry and transportation (Ministry of Environment and Urban Planning, 2016). Similarly, most of the greenhouse gases that contribute to global warming are generated by the construction industry (Ministry of Energy and Natural Resources MENR, 2001).

The ever-increasing construction activities along with urbanization boost the demand for energy resources which are essential for the continuation of life. The energy crises in the 1970's demonstrated that fossil fuels that are being used heavily since the industrial revolution are not environmentally friendly or renewable, giving rise to discussions on the concepts of environment and energy. The realization that construction activities irrecoverably damage the environment, that the natural resources that take millions of years to form are exhaustible, and that high-cost fossil fuels are not environmentally friendly has heightened the interest in renewable energy resources. Fossil fuels not only cause serious environmental problems (Benli 2006: 100; Dikmen and Gültekin, 2011: 96-100) but also lead to dependence on foreign energy sources. The energy requirement capita in Turkey is increasing in paralel with the increasing population and developing technology. On the other hand, apart from the environmental problems arising from the use of fosil fuels, being dependent on foreign energy makes the use of renewable energy sources and solar energy more important in buildings. Population increase, the rise in construction activities, the ever-growing global energy demand, and the recognition that renewable energy resources are alternatives to fossil fuels all necessitate that energy and environmental problems are dealt with on a local, regional, and global scale. The solutions to these problems need to be sought by developing national and international policies and cooperation. The inexhaustible, environmentally friendly and pollutant-free (Keçel, 2007) renewable energy resources are water energy, wave energy, wind energy, geothermal energy, biomass energy, and solar energy. Solar energy has a potential well above the global energy demand and is used in various sectors such as industry, transportation, agricultural technology, residences and offices, signalization and automation, and electrical energy generation. According to the Ministry of Energy and Natural Resources production forecasts, domestic production of primary energy will level 31,091 ktoe in 2000 and 79,399 ktoe by 2020. The projections foresee domestic generation to top 95,946 ktoe in 2025 and 106,507 ktoe in 2030. Table 1 gives the findings related to primary energy resources and their domestic production planning (Tablo 1) (MENR, 2001; Kaygusuz, 2002). The population increase in Turkey between 1970 and 2020 was 122%; in this period, the energy consumption per capita increased by 148%. This data indicates that the rate of increase in per capita energy consumption in Turkey is above the global average (TUIK Population Growth Rate in Turkey).

Table 1.Primary energy production targets of Turkey from 2005 to 2030 (ktoe) ((Ministry of Energy and Natural Resources MENR, 2001; Kaygusuz, 2002)

Energy Sources	2005	2010	2015	2020	2025	2030
Hardcoal and lignite	21.259	28.522	31.820	39385	42.732	45.954
Oil and natural gas	2.127	1.735	1.516	1.604	1.505	1.465
Central heating	495	884	1.336	2.018	2.427	2.758
Hydro power	5.845	7.520	8.873	9.454	10.002	10.465
Wood and waste	6.760	6.446	6.029	5.681	5.498	5.413
Geothermal	1.380	3.760	4.860	4.860	5.400	5.5430
Nuclear	0	3.657	9.143	18.286	26.988	29.600
Solar	459	907	1.508	2.294	2.845	3.268
Wind	250	620	980	1.440	1.786	2.154

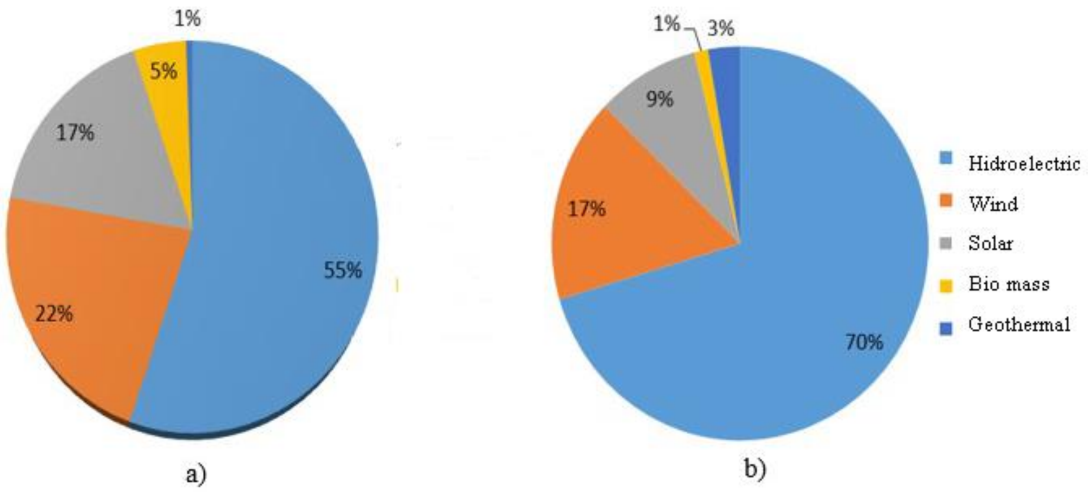


Figure 1. As the end of 2017, a.The distrubition of renewable energy sources in the world according to their installed power b.cumulative installed power sharing ratios of renewable energy sources in Turkey (Delihasanlar, Yaylacı and Dalcalı, 2019).

Owing to its geographical location, Turkey is among the most fortunate countries with respect to solar energy potential (Philibert, 2005: 9; Öztürk and Yüksel, 2016: 1259-1272; Uğurlu and Gökçöl, 2017). According to the Solar Energy Potential Atlas of Turkey, the total annual duration of insolation is estimated to be 2,737 hours (daily total 7.5 hours) and the total solar radiation as 1,527 kWh/m² per year (daily total 4.2 kWh/m²). The number of solar power plants was 362 by the end of 2015, totalling an installed capacity of 248.8 MW (Ministry of Energy and Natural Resources 2018). In Turkey, solar energy is most commonly used for drying agricultural products and supplying hot water. Despite the existing high potential, solar energy is not sufficiently employed in heating, cooling, ventilation, and air conditioning of buildings, or for generating electrical energy. Compulsory theoretical courses on solar energy are offered in the undergraduate and graduate programs of most universities. Also, some universities carry out solar research projects funded by The Scientific and Technological Research Council of Turkey (TUBITAK), State Planning Organization, European Union (EU), and the Ministry of Science, Industry and Technology. Studies on solar energy are also supported by the Solar Energy Institute established in 1978 within Ege University, the state-funded Marmara Scientific and Industrial Research Institute established in the 1980's within TUBITAK, and the Ankara Electronic Research and Development Institute established in 1986 to conduct studies on solar battery design and production. Other than these establishments, the International Solar Energy Society Turkey Branch has been active, with state consent, since 1992. The State Meteorology Institute, The Electrical Energy Resources Survey Administration (EIEII), and Mechanical and Chemical Industry Corporation of Turkey contribute to solar energy research.

Most of the solar energy research carried out at universities and the projects funded by TUBITAK focus on drying agricultural products and developing water and air heating collectors. Research on the utilization of solar energy for heating-cooling-ventilation and air conditioning of buildings is limited. Similarly, studies on solar engines, solar-powered water pumps, solar-powered refrigerators, solar power plants and solar batteries are sparse. No national research project has been conducted to date on solar power plants or hydrogen production using solar energy, topics that are considered very important for the future of Turkey.

Although Turkey is located more advantageously than most European countries in terms of solar energy potential (Figure 2), the solar house projects implemented in Turkey have remained limited to academic circles; there are only a few projects conducted by the public and private sectors. The aim of this study is to discuss the utilization of solar energy in buildings in Turkey, to review the solar houses implemented in Turkey that have various designs and functions using active and passive systems, to compare these houses with respect to their spatial characteristics, systems used and design criteria considered, and finally, to provide recommendations on solar house projects. The solar house projects evaluated in the scope of this study are, chronologically, Middle East Technical University Solar House (METU SH), Ege University Solar Energy Institute and Solar-Powered Drying House (EU SEI&SPDH), Çukurova University Solar House-Solar Energy Research and Application Centre (CU SH-SER&AC) (UZAYMER), Hacettepe University Solar House-New and Clean Energy Research Centre (HU SH-N&CERC) (YETAM), Erciyes University Solar House (EU SH), The Guesthouse of National Observatory of TUBITAK (GNO TUBITAK), Energy Efficiency Training Facility (EETF), Pamukkale University Clean Energy House (PU CEH), İstanbul Technical University Eco-building (ITU E), and Diyarbakır Solar House (DSH). Other solar houses in Turkey, namely Marmaris Solar Energy Laboratory of the Mineral Research and Exploration Institute, Ankara Metropolitan Municipality's Solar House, and the designed but not-yet-built Gazi University Solar House were not included in this study because of the differences in the spatial characteristics and the systems used in those projects. Out of the 10 solar houses evaluated in this study, 7 were realized by universities, 2 by a public institution that funds TUBITAK, and EIEII of the Ministry of Energy, and 1 by EU funds and the sponsorship of the local administration and many other agencies. Finally, recommendations are provided with respect to the use of clean, inexpensive, and environmentally friendly solar energy in the construction sector and the efficient use of the solar energy potential of Turkey.

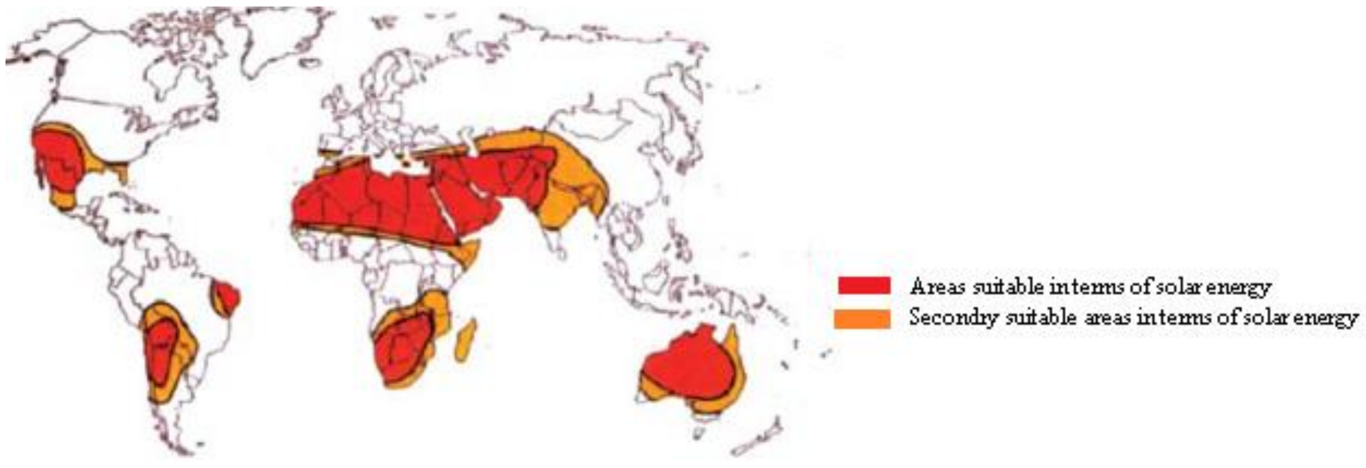


Figure 2. Regions of the world with high solar energy (Philibert, 2005: 9)

2. Materials and Methods

Solar houses aim to reduce energy consumption, maintenance and repair costs, building-related diseases, waste and pollution, increase the efficiency of building materials and increase the level of building comphort. In this study, a method including information gathering, analysis, synthesis and evaluation stages was applied. Within the scope of the study, first of all, studies on the use of solar energy in buildings, direct and indirect gain systems were investigated with a comprehensive literature study. The materials of the study consist of 10 solar houses selected from amaong the solar houses implemented in Turkey. Firstly, solarhouses implemented in Turkey were analyzed according to their construction dates and locations, sizes, architects and constractors and their functions, direct and indirect earnings systems and features. Then, the examined solar houses were evaluatedd comparatively, and the results and recommenations were presented.

2.1.Utilization of Solar Energy in Buildings

Solar energy has recently become the preferred energy resource in architecture owing to the advantages it provides to the end-user: it is renewable, environmentally friendly, can be implemented locally, does not require complex technology, and allows for the conservation of energy. Solar energy is utilized by two basic systems, passive and active (Özdoğan, 2005). Passive systems consist of the utilization of solar energy for space heating by choosing appropriate materials based on decisions made in the planning phase. The addition of each new technological product to this basic design brings the passive system closer to an active one. To utilize solar energy, passive systems can be employed on their own. Alternatively, mechanical devices can be integrated with the buildings, and active systems can be included in the design (Bekar, 2007; Alparslan, Gültekin and Dikmen, 2009). The principles of utilization of solar energy by passive and active systems are shown in Figure 3 (Esin et all, 2002).

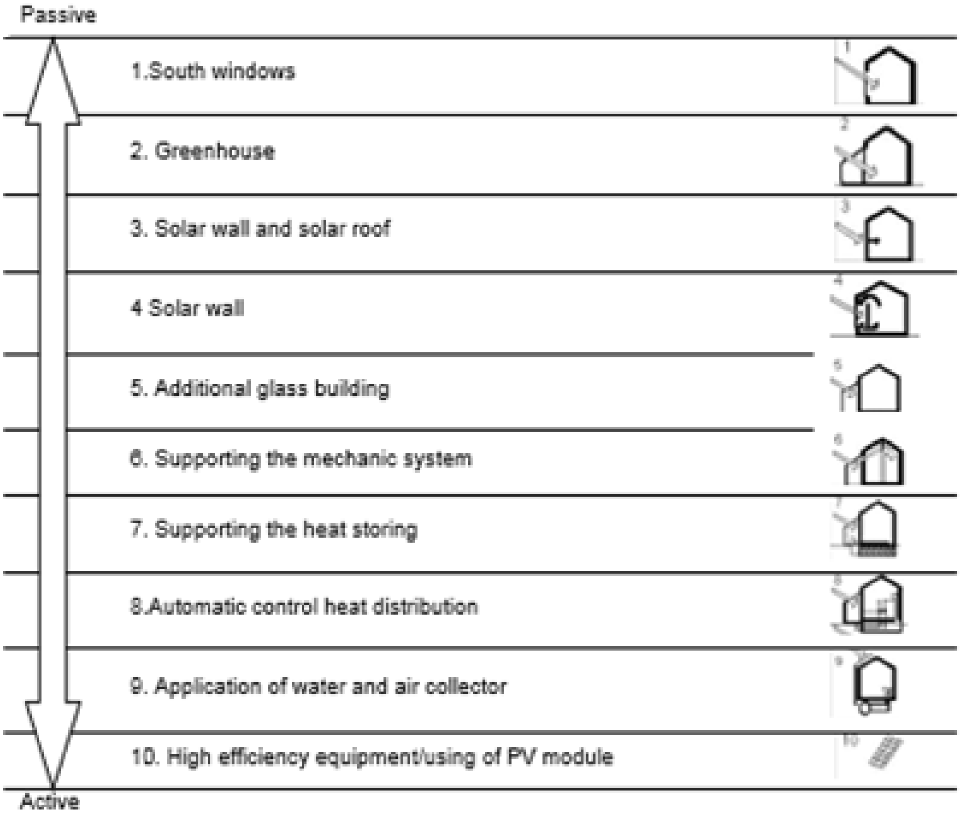


Figure 3. Principles of solar energy utilization by passive and active systems (Esin et all, 2002)

2.2.Direct and Indirect Gain Systems

Utilization of solar energy in buildings by passive systems can be realized by direct and indirect gain systems. In direct gain systems, solar radiation enters the building through glass surfaces or the roof, without an intermediate system, and is absorbed and stored in the interior surfaces and materials, creating a greenhouse effect. Thus, the entire building acts as an energy collector. In such a system, the location and the size of the windows and apertures that allow for heating or cooling, the sunrooms, and the roof apertures are all important. In indirect gain systems, however, solar radiation entering through the glass surfaces is absorbed in a wall placed behind the glass. These walls are usually painted black and made of materials suitable for heat storage, such as concrete, clay bricks, adobe bricks, or stone. The heat absorbed in the walls forms a thermal mass, which then is radiated into the rooms and circulated. Indirect gain systems allow for better control of indoor temperature. Passive systems such as solar walls, water wall, sunroom, roof apertures, and separate apertures are used for indirect gain systems (Tayfun, 2007; Alparslan, Gültekin and Dikmen, 2009; Alparslan, 2010).

The active systems generally used in buildings comprise capturing the solar energy by flat plate collectors, storing the collected energy in water tanks or gravel beds located adjacent to or below the building, and distributing the stored energy by pumps or pipes. In these systems, devices such as solar collectors and photovoltaic panels (PVs) are used for space heating, and the energy captured by the heated and stored water is used for both space heating and a hot water supply.

2.3.Solar Houses Implemented in Turkey

The solar houses implemented in Turkey are presented chronologically by date of construction. They use various systems to utilize solar energy and also use different function.

METU Solar House: METU Solar House, the first solar house implemented in Turkey, was constructed during 1975-1980 by Architecture Department as part their summer practice program. It was originally planned as a greenhouse and solar roof (Eskin, 2006: 78). Studies on the solar house were discontinued and remained unused for a long time. It was repaired by the METU Association of Academic Staff between 1995 and 1996. As part of the repair process, the existing collectors were replaced by an air heater solar roof, and a heat storage system was added to the floors. Today, it is being used as office by the METU Association of Academic Staff (Göksu, 2008).

The passive systems installed during the repair in 1996 are 19 cm. thick exterior walls, heat insulation for the floors and the roof, a windbreak on the northern façade to prevent heat loss, double-glass instead of the former 3 mm. thick glass, a winter garden on the southern façade, and floors and southern apertures designed for heat storage in the winter garden. The active systems installed as part of this repair work are collectors, a cylindrical hot water tank, radiators, air heater solar roof (instead of water-heater), air canals in the floors, and solar panels on the roof (Göksu, 2008; Ecevit and Demirbilek, 1994; Demirbilek et all, 1997a: 3-5) (Photograph 1, 2) (Figure 4). The cylindrical tank that is placed on the roof stores heat and the flat plate liquid-medium solar collectors supply 22.4% of the total thermal energy requirement of the building (Şık, 1994; Altuntop, 2008: 6). The building presently utilizes solar energy for 50% of its power by means of the greenhouse and the passive systems. The use of solar energy is expected to increase to 70% when the solar roof is activated. If funding is available, the solar systems in this first solar house ever built in Turkey are planned to be activated, and the building is intended to be used as a museum.

Photograph 1. METU Solar House 1995 (Ecevit and Demirbilek, 1994; Demirbilek et all, 1997a: 3-5; Göksu, 2008)

Photograph 2. METU Solar House Winter Garden 1995 (Ecevit and Demirbilek, 1994; Demirbilek et all, 1997a: 3-5)

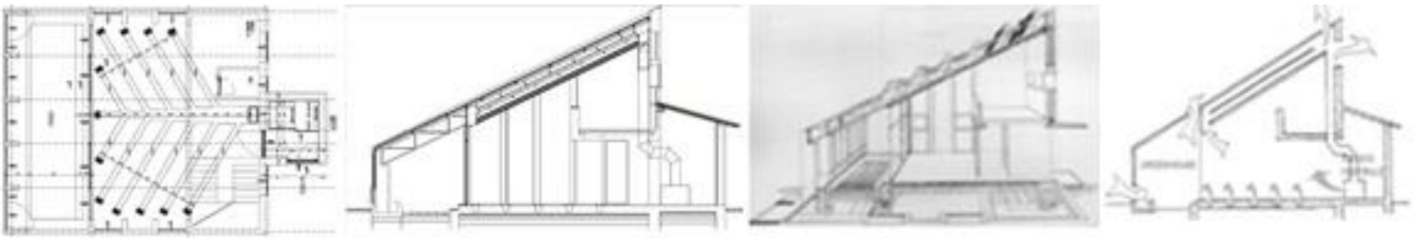


Figure 4. METU Solar House Piping Plan and Section (Ecevit and Demirbilek, 1994; Demirbilek et all, 1997a)

Ege University SEI&SPDH: Built in 1978, it is the first and only institute in Turkey established with this purpose, and it is the largest solar house implemented (Bozdoğan, 2003; Altuntop, 2005). The building was completed and opened for service in 1986 (Akdeniz, 1989). A double-glass wall, sunrooms, a roof inclination of 45° are erected on the southern façade, and solar gardens have been built (Irklı and Demirbilek, 2000). A buffer zone is formed on the northern façade; thick double-layered brick wall with insulation in between was constructed adjacent to the buffer zone. The building is used for training purposes. Among the studies carried out in the building are graduate studies on the utilization of renewable energy resources, including wind and geothermal other than solar. The system employed in the building comprises two ducts allowing fresh air in and letting heated air out. The air ducts located in the wall separating the office and classrooms from the corridor provide natural ventilation, especially in the summer. Movable blinds are used in this building for protection against solar radiation and to prevent overheating of the windows and the greenhouses. In the building, solar energy is concentrated and the resulting high temperature and pressure steam is used to generate electricity. Solar energy is also utilized for heating and cooling, for supply of hot water, and by distillation, drinking water (Photograph 3) (Figure 5, 6).

Photograph 3. Ege University SEI&SPDH (a.Irklı and Demirbilek, 2000; b.Google Images)

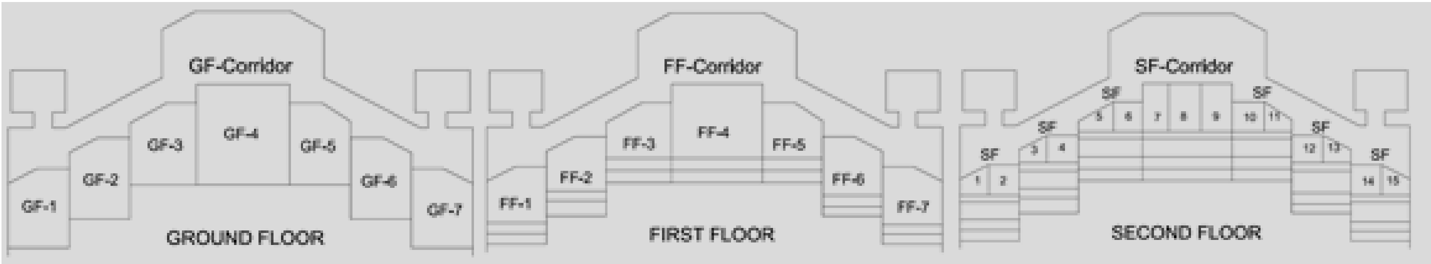


Figure 5. Ege University SEI&SPDH, Plans (Irklı and Demirbilek, 2000)

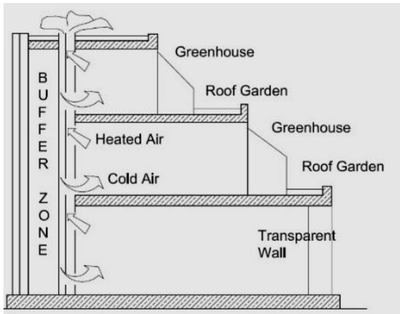


Figure 6. Ege University SEI&SPDH, Section (Irklı and Demirbilek, 2000)

Çukurova University Solar House-UZAYMER: Çukurova University Solar House was constructed in 1981 in Adana. Passive systems are employed in the building where a Trombe wall and a greenhouse are erected on the southern façade. Solar energy and biogas are utilized in the building for air conditioning and a hot water supply. Studies carried out in 1981-1982 indicated that these systems provide a high percentage of the total building's thermal energy requirement even in the winter. The building was repaired in 1991 and renamed the UZAYMER. It is now used for research studies on solar energy, astronomy, and astrophysics and as a training center (Photograph 4) (Irklı and Demirbilek 2000; CU SH-UZAYMER).

Photograph 4. Çukurova University SH-UZAYMER (Çukurova University Solar House-UZAYMER)

Hacettepe University Solar House-YETAM: The Hacettepe University Solar House and garden was constructed in 2003 in Ankara. Solar panels of 1.5 kW_p capacity were installed and the entire electricity requirement of the building is supplied by these panels, with the aid of batteries and convertor (Hacettpe University Solar House). A special glass surface installed on the inclined southern wall collects solar energy, which is stored as heat in the storage unit located in the basement gravel bed and utilized for heating in the building. The studies for the Solar House were initiated in 1993 with funding from Hacettepe University Research Fund, but it was completed in 2003 by individual efforts and initiatives. The building is presently used by YETAM of Hacettepe University as an experimental research center on renewable energy for graduate studies (Photograph 5) (Hacettepe University Solar House; Sugözü and Sarsılmaz, 2006).

Photograph 5. Hacettepe University SH and Garden (a.b.Hacettepe University Solar House)

Erciyes University Solar House: Erciyes University Solar House was constructed between 1993 and 1997 in Kayseri (Bozdoğan, 2003). Scientific studies on clean and renewable energy resources solar being the foremost was initiated in 1993 in Erciyes University, and the Energy Conversion Research and Application Centre was established to coordinate the studies. A hot air collector is installed on the roof. The surplus thermal energy is stored in water and utilized when needed (Altuntop, 2008: 6). Floor heating is provided by plastic pipes placed in a 28 m^2section on the ground floor of this building. In this system, 8 liquid-medium solar collectors, each 12.8 m^2, and a 175 m^2 air collector were used for heating the Solar House. Floor heating is provided in a 30 m^2 section of the building, using the energy captured by the liquid-medium solar collectors (Sugözü and Sarsılmaz, 2006). There are no blinds or other measures in the building; consequently, overheating is a problem in the summer. The building is presently used as a laboratory for research on solar energy and a service building for the Energy Conversion Research and Application Centre (Photograph 6) (Figure 7, 8).

Photograph 6. Erciyes University SH (Arsan Durmuş, 2008)

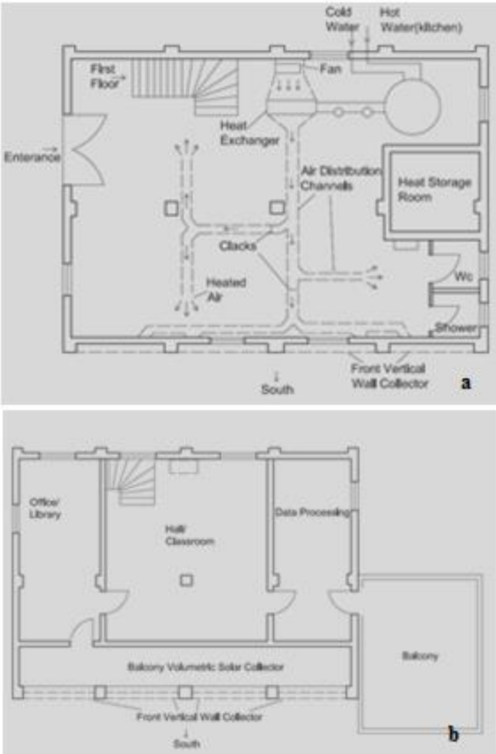


Figure 7. Erciyes University SH Plan (Altuntop, 1996)

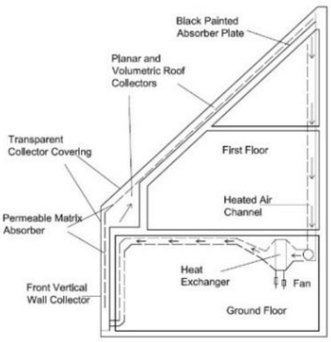


Figure 8. Erciyes University SH Section (Altuntop, 1996)

The Guesthouse and National Observatory of TUBITAK: This building was constructed as a passive solar house in 1996 in Antalya (Altuntop, 2008: 6). The building (Bozdoğan, 2003) is used as a research center, also provides accommodation for the personnel. The building is insulated and buried in the ground on the northern façade, a Trombe wall is built on the southern façade. Windows on the southern wall and a greenhouse at the ground floor on the southern façade are included in the design. To prevent overheating in the summer, air vents placed beneath the greenhouse are used to bring in fresh air, and hot air is let out via the roof hatch. On the southern façade, solar collectors are installed with a total area of 146 m^2; 34 m^2 of which is on the vertical wall surfaces, 19 m^2 is placed at 45° inclinations on the roof, and 93 m^2 is planar. These solar collectors generate hot air that is used for heating in the building. When the heating requirement is low, the surplus heat is stored in the heat storage room that has gravel beds at the ground floor. On the second floor, the wall surfaces are painted black to gain more solar radiation (Bozdoğan, 2003). The building can meet its entire thermal energy requirement (Figure 9, 10) (Photograph 7) (Demirbilek, Şahmalı and İnanıcı, 1997b; Demirbilek et all, 2003).

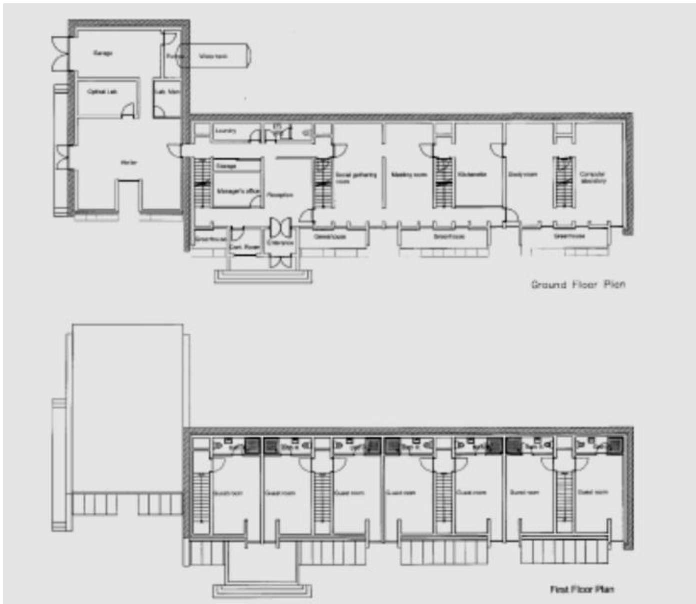


Figure 9. The Guesthouse and of National Observatory of TUBITAK, Plans (Demirbilek et all, 2003)

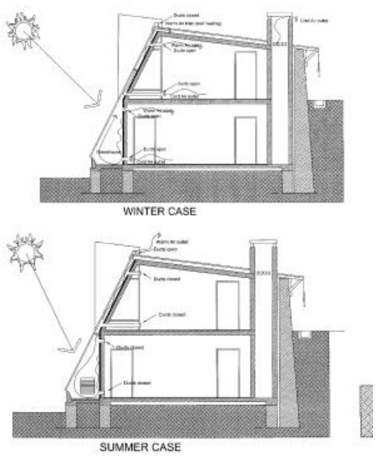


Figure 10. The Guesthouse and of National Observatory of TUBITAK, Sections (Demirbilek et all, 2003)

Photograph 7. The Guesthouse and of National Observatory of the TUBITAK (The Guesthouse and National Observatory of TUBITAK)

Energy Efficiency Training Facility: It was constructed in 2006 in Ankara with the purpose of utilizing renewable energy resources, using energy effectively and efficiently, and exhibiting the implementation in an exemplar building (Energy Efficiency Training Facility a). The systems employed in the building are high-level heat insulation, solar and geothermal (ground source heat pump) energy systems, fiber optic lighting system, daylight control system, natural lighting, and composite wall applications for heating/cooling. On the southern façade, an 84 m^2 solar wall and a sunroom are installed. The air heated by the solar wall and the sunroom is distributed by an induced system via ventilation ducts. Hot water is supplied using solar collectors with vacuum pipes. The building was used for training and research until 2013; presently it is not in active use (Photograph 8) (Energy Efficiency Training Facility).

Photograph 8. Energy Efficiency Training Facility (Energy Efficiency Training Facility)

Pamukkale University Clean Energy House: The project for the Pamukkale University Clean Energy House was initiated in 2006 and was carried out by public-private collaboration and supported by TUBITAK, DPT, Miami University, Nexans Cable, and Bereket Energy. This building within the campus of Pamukkale University was completed in 2007. It was built with a high level of insulation to assure low energy consumption; it is the first solar house in Turkey to generate its own energy and built as a laboratory. Solar energy is utilized for heating, and solar energy and hydrogen are used to meet the electricity requirement. A system comprising 40 m^2 collectors (2.5-kW$_p$ fixed PV panels) provides hot water and floor heating. Electrical energy is generated by the solar panels, and the charge regulators, batteries, and convertor are included in the system that provides electricity to the building. The surplus electrical energy is used to generate hydrogen by electrolysis of water. The hydrogen is stored in 6 metal hydride tanks; it is used to generate electricity when needed (Yılmaz Ulu, 2010). Thus, the energy requirement of the building is supplied in an environmentally-friendly way by using the stored hydrogen. Trombe walls on the southern façade (Altuntop, 2008: 6) provide heating in the winter and natural ventilation in the summer. During the day, electricity is provided directly by the 5 kW solar batteries and by the panels they are installed on. The hot water obtained using the solar collectors are stored in insulated tanks, and the heat exchanger control unit maintains the required temperature. The hot water is used as an auxiliary system for heating in this building (PU CEB). In the Clean Energy House, the sun, water, and earth are utilized for heating and cooling, and the energy generated is used in industry. To date, no articles have been published on the heating, cooling, air conditioning, electricity, and hydrogen generation systems used in the Clean Energy House. Therefore, no data is available on the performance of the building. The building is presently used as an energy research laboratory (Photograph 9) (Yılmaz Ulu, 2010).

Photograph 9. Pamukkale University Clean Energy House (Pamukkale University Clean Energy House)

ITU Eco-building: The building is located by a pond within the Ayazağa Campus of ITU; it is part of the Nature-Environment-Science-Society Park Project. The building was designed by HAS Architecture, and the construction was coordinated by the Building Industry Centre. The purpose of the project is to demonstrate that it is possible to construct environmentally friendly buildings and to minimize energy use in constructed environments while improving the quality of life, and to provide a model building for the benefit of future architects and engineers (ITU Eco-building a). In line with this purpose, two laboratories, a multi-purpose hall, library, and offices for researchers are included in the eco-building. Another important feature of the building is that the design allows for visitors to view the functioning systems in the technical spaces. The building is oriented toward the southwest to maximize the use of solar energy, and built on a steep slope to minimize the excavation and the footprint of the building. The orientation and the compact form of the building thus minimize intervention into the natural environment (Figure 11).

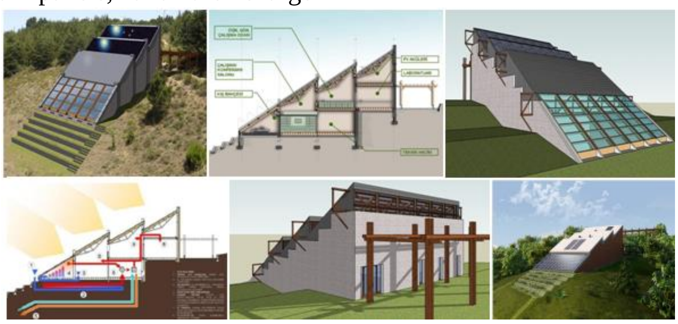


Figure 11. ITU Eco-building (Istanbul Technique University Eco-building a; b)

Natural crushed rock tiles held together by plants were used instead of impervious tiles for landscaping and for walkways and roads to prevent the impairment of natural drainage. Colors and materials chosen to prevent the formation of heat islands that occur due to tiles warming up more than the surrounding natural areas, thereby adversely impacting the microclimate. Light colors were used for the building envelope and in the landscaping, reflective coating was used for the roof, and natural crushed rock tiles were preferred for the floors. In addition, shades were used in front of the building to balance the heat around the building. Alternative means of transport, such as cycling and electric vehicles were considered for commuting between the building and the campus to minimize pollution and adverse impacts arising from vehicle use. Bicycle parking space and vehicle charging stations were planned. Limited parking space, with priority for the handicapped, was provided to discourage vehicle use. The natural vegetation was preserved in the landscaping, and low maintenance plants that do not require irrigating were used in the terraces. Water fixtures with sensors and two-stage reservoirs were used in the eco-building to conserve water. The plan was to store the rainwater collected from the roof in an underground tank near the building to be used in the reservoirs. The collected rainwater and the treated wastewater were planned to be reused. It was decided that the domestic wastewater is disposed of by natural methods by a septic tank located so that the infiltrating wastewater would not contaminate the existing pond. Furthermore, solid wastes are collected separately in the eco-building, considering their potential for recycling. The Eco-building Project was given the 2010 World Architecture Community award. The Eco-building project team adopted the LEED certificate system. This building is probably the first in Turkey to implement these features. The energy strategy for the Eco-building aimed to minimize the dependence on fossil fuels and the emission of greenhouse gases. It was planned to have a low consumption of locally generated energy: no boilers or air conditioners were employed for heating, cooling, or ventilation. Heating, cooling, or ventilation was provided by fresh air inlet and heat pump, and the building envelope was designed to Passivhaus Institut standards (Istanbul Technique University Eco-building b). Alternative heating and cooling is provided, depending on the season, using the heat from the serpentine-tiled pond near the building.

The materials used in the Eco-building were chosen considering their energy requirements and greenhouse gas emissions throughout their life cycle. To the extent possible, locally available, recyclable, environmentally friendly materials were preferred. Woodwork and heat-insulated double-glass were used. Heat build-up in the building envelope was prevented. Both active and passive systems such as PV panels, solar thermal collectors, heat pump, earth-tube, Trombe wall, wind turbines were used. The building was designed to feed the surplus energy generated by the PV panels and wind turbines to the distribution grid of the campus. The purpose was to maintain that the difference between the amount of electrical energy fed to the grid and used from the grid is zero. The Eco-building was also planned to collect the rainwater from the building and to reuse the treated wastewater. Considering the birds near the pond, vertical axis wind turbines were preferred because they are quiet and can operate at low wind speed. The building generates more electricity than it uses from the campus grid, and therefore the grid is used like a storage system. Low-energy lighting fixtures were preferred in the Eco-building to minimize energy consumption, and systems were installed to measure the intensity of natural light and to maintain constant lighting. High-efficiency, grade A electrical appliance were also preferred in the building. The provision of data on the energy systems, their operation, monitoring and reporting were considered because the Eco-building is used as a research center. Software designed specifically for the Eco-building records in-house and makes available via the internet, data such as the building's energy generation and consumption, indoor and outdoor temperature, and humidity. This database is used to evaluate the performance of the building and the installed systems (Istanbul Technique University Eco-building b).

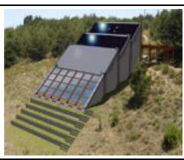
Diyarbakır Solar House: It was designed by architect Çelik ERENGEZGİN and constructed in 2007 by EU funding along with sponsorships from 72 companies and it came into service in 2008. In this building, lighting and electrical appliances such as computers and refrigerators are operated by solar energy. Domestic wastewater is treated by biological treatment with 90% to 95% efficiency and reused for garden irrigation. Rotating biological contactors, which are circular disks on which bacteria attach and grow, are used to treat the domestic wastewater. An advantage of this system is the elimination of odors and noise problems (Diyarbakır Solar House a). In addition, solid waste from the house is utilized as fertilizer. Rainwater is collected from the roofs, stored, and used for garden irrigation (Diyarbakır Solar House b). It is used as a scientific laboratory that publishes information on the energy systems used and the measurement data on a dedicated website 24 hours per day. All energy requirements in the building, including heating, cooling, and lighting, is supplied by solar energy (Altuntop, 2008: 6). A total of 3.88 kW power is generated in the solar house using 24 PV solar panels of 162 W. Two solar collectors on the roof and a special hot water tank in the basement supply hot water to the building (Sugözü and Sarsılmaz, 2006). A sunroom and a solar wall are erected on the southern façade. Subterranean energy is also utilized to provide natural cooling in the building (Photograph 10) Diyarbakır Solar House c).

Photograph 10. Diyarbakır Solar House (Diyarbakır Solar House a, b, c, d)

2.4.Comparison of the Solar Houses in Turkey

Information is provided on their location, size and designer/contractor/sponsor, and each solar house is discussed in terms of their original and present uses and functions in Table 2.

Table 2. Solar houses implemented in Turkey

		Date of construction	Place of construction	Total area	Architect/Constructor	Function
METU SH		1975-1980	Ankara	96.6 m^2	METU Dept. of Architecture, METU Faculty Member Society	Solar house METU Faculty Member Society Office (suggestion of museum function)
EU SEI&SPDH		1978-1986	İzmir	9000 m^2	Ege U.	Education and research
CU SH (UZAYMER)		1981	Adana	125 m^2	Çukurova U.	Education and research
HU SH (YETAM)		1993-2003	Ankara	100 m^2	Hacettepe U. Research Fund, New and Clean YETAM	Education and research
EU SH		1994-1995	Kayseri	154 m^2	Prof. Dr. N. ALTUNTOP & Dr. Y. TEKİN, Erciyes U.	Education, research Energy Conversion Research and Application Centre
G&NO TUBITAK		1996	Antalya	720 m^2	TUBITAK, Energy and Building Research &Consulting A.Ş., METU Department of Architecture	Research, accommodation
EETF		2006	Ankara	275 m^2	Ministry of Energy, EIEII and Heating, Water, Sound and Fire Isolation Society, IZODER	Education, research (it is not active now)
PU CEH		2006-2007	Denizli	165 m^2	DPT, Nexans Cable, Siemens and Bereket Energy	Education, Research laboratory
ITU E		2008	İstanbul	500 m^2	HAS Architecture, ITU, YEM	Education, research
DSH		2008	Diyarbakır	120 m^2	Ç. ERENGEZGİN, EU Fund, local government and with 72 institution	Education, research

It shows the active and passive systems employed in the solar houses Table 3. Ege U. SEI&SPDH, Çukurova U. Solar House, and the Guesthouse and National Observatory of TUBITAK employ only passive systems, Erciyes U. Solar House employs only active systems, and the others employ both active and passive systems. It shown the solar houses are compared and evaluated in terms of the design criteria considered such as location, suitability with the physical environment, heating, cooling, ventilation and air conditioning; also lighting, material conservation, etc. in Table 4. It has been stated to what extent the solar houses implemented in Turkey meets these design criteria.

Table 3. Active and passive systems used in the solar houses in Turkey

	Passive Systems Used	Active Systems Used
METU SH	▪ Heat insulation on walls, floors and the roof ▪ Windbreak on the northern façade, double-glass ▪ Winter garden on the southern façade ▪ Heat storage system ▪ Southern apertures ▪ Air heater solar roof	▪ Collectors ▪ Cylindrical hot water tank ▪ Radiators
EU SEI&SPDH	▪ Winter gardens on the southern façade ▪ Double-glass wall ▪ Sunrooms with 45° inclined roofs ▪ Roof gardens ▪ Insulation on the northern façade	-
CU SH-SER&AC (UZAYMER)	▪ Trombe wall on the southern façade ▪ Air conditioning using solar energy and biogas ▪ Greenhouse on the southern façade	-
HU SH-N&CERC (YETAM)	▪ Inclined southern wall	▪ Solar batteries ▪ Parabolic dish (concentrator) ▪ Solar-powered drying closet ▪ Solar-powered water pumping system ▪ Solar-powered distillation apparatus ▪ Solar cookers, solar ovens ▪ Heat storage (gravel bed)
EU SH	-	▪ Hot air collector mounted on the roof ▪ Floor heating ▪ Floor heating with water based solar collectors ▪ Air collector
GNO TUBITAK	▪ Trombe wall on the southern façade ▪ Sunroom on the southern façade ▪ Air vents placed beneath the greenhouse on the southern façade ▪ Black walls for gaining higher radiation	-
EETF	▪ Solar wall and sunroom on the southern façade	▪ Energy systems with solar energy, geothermal ▪ Fibber optic lighting system, ▪ Day light control system ▪ Composite wall applications for heating/cooling purposes ▪ Solar collectors with vacuum pipes
PU CEH	▪ Trombe walls on the southern façade ▪ Floor heating ▪ Hot water supply by solar collectors	▪ Solar batteries and PV panels -
ITU-E	▪ Winter garden on the southwestern façade ▪ High-insulation and air-tight building envelope ▪ Earth-tube ▪ Trombe wall ▪ Access alternatives ▪ Septic tank ▪ Reuse of rainwater and wastewater ▪ Rainwater storage and pumping system ▪ Low-maintenance vegetation cover ▪ Environmentally-friendly materials ▪ Indoor air quality ▪ Insulation on the exterior walls, interior walls, floors and the roof	▪ Heat pump ▪ Wind turbine ▪ Solar thermal collectors ▪ Alternative heating-cooling ▪ PV panels
DSH	▪ Sunroom and solar wall on the southern façade ▪ Biological treatment of domestic wastewater ▪ Reuse of rainwater and wastewater ▪ Rainwater storage and pumping system ▪ Hot water supply by solar collectors and hot water storage	▪ Heat pump ▪ Wind turbine ▪ Solar thermal collectors ▪ Alternative heating-cooling ▪ PV panels

Table 4. *Design criteria considered in the solar houses in Turkey*

-+ Partially considered in the design - Not considered in the design   + Considered in the design   x Not present

		METU SH	EU SEI&SPDH	CU SH-SER&AC	HU SH-N&CERC	EU SH	GNO TUBITAK	EETF	PU CEH	ITU-E	DSH
Location, suitability physical environment data	Location and orientation	+	+	+	+	+	+	+	+	+	+
	Land use	+	+	+	+	+	+	+	+	+	+
	Building form	+	+	-+	+	+	+	+	+	+	+
	Building envelope: choice of colour for the building envelope	+	+	-+	x	+	+	-+	-+	+	-+
	Landscape decisions for the perimeter of the building	+	-+	-+	-+	x	-+	-+	-+	+	-+
	Vegetation cover	+	+	x	x	x	x	x	-+	+	-+
	Floor covering in the perimeter of the building	+	+	-+	-+	x	x	-+	-+	+	+
Heating-Cooling-Ventilation-Air Conditioning-Lighting	Utilization of solar energy for heating	-	+	+	+	+	+	+	+	+	+
	PV panels/hot air collectors	+	+	-	+	+	-	+	+	+	+
	Use of solar thermal collectors	-	-	-	-	-	-	-	-	+	-
	Use of heat pumps	+	-	-	-	-	-	+	-	+	+
	Use of heat storage vessels	-	-	-	+	+	-	+	-	-	-
	Earth-tube	-	-	-	-	-	-	-	-	+	-
	Trombe wall	-	-	+	-	-	+	+	+	+	-
	Double-glass wall (transparent wall)	-	+	-	-	-	-	-	-	-	-
	Winter garden on the southern façade	-	-	-	-	-	-	-	-	+	+
	Greenhouse on the southern façade	-	+	+	-	-	+	-	+		+
	Creating a buffer zone on the northern façade	-	+	-	-	-	-	-	-	-	-
	Air heater solar roof	+	-	-	-	-	-	-	-	-	-
	Floor heating	+	-	-	-	+	-	+	+	-	-
	Wind turbine	-	-	-	-	-	-	-	-	-	-
	Utilization of solar energy for water heating/water tank	+	+	+	-	+	-	+	+	+	+
	Utilization of solar energy for cooling	-	+	-	-	-	-	-+	+	+	+
	Utilization of solar energy for drying	-	-	-	+	-	-	-	-	-	-
	Utilization of solar energy for ventilation-air conditioning	-	-	-	-	-	-	-+	+	+	-+
	Natural ventilation/ air ducts	-	+	-+		-+	+	-+	-+		-+
	Heating-cooling with alternative methods	-	-	-	-	-	-	-	-	+	-
	Wall insulation	+	+	+	+	+	+	+	+	+	+
	Floor insulation	+	+	-	+	-	+	+	+	+	+
	Roof insulation	+	+	+	+	+	+	+	+	+	+
	Use of double-glass/ double glazed glass/ low-e glass	+	+	+	-+	+	+	+	+	+	-+
	Choosing low VOC products for paints, adhesives, finishes and insulation materials	-	-+	-+	-	-+	-+	+	-+	+	-+
	Indoor air quality	-	+	-+	-+	-+	-+	+	-+	+	-+
	Natural lighting	+	+	+	+	+	+	+	+	+	-+
	Utilization of solar energy for lighting	-+	-+	-+	+	-+	+	-+	+	-	+
	Energy-saving lighting fixtures	-	-	-	-	-	-	+	-	+	+
	Use of Class A high efficiency electrical appliances	-	-	-	-	-	-	+	-	+	+
	Use of solar-powered electrical appliances	-	-	-	-	-	-		-	-	+
Access	Alternative means for transportation	-	-	-	-	-	-	-	-	+	-+
	Support for pedestrians instead of car use	-	-	-	+	-	-	-	-	+	-
	Limiting car park capacity	-	-	-	-+	-	-	-	-	+	-
	Use of solar energy in vehicles	-	-	-	+	-	-	-	-	-	-
Material conservation	Use of environmentally-friendly building materials	-+	+	-+	x	-+	+	+	x	+	+
	Use of fire-resistant materials	-	+	x	x	x	+	+	x	+	-+
	Choice of colour for indoor space	-+	+	+	+	+	+	+	+	+	-+
	Use of easily cleanable, low-maintenance materials	+	+	-+	-+	-+	+	+	-+	+	+
	Use of recyclable materials	+	-+	-+	x	x	+	-+	x	+	+
Water conservation, drainage	Sewer system	-	-	-	-	-	-	-	-	+	+
	Sewer system(packaged biological treatment)	-	-	-	-	-	-	-	-	-	+
	Solid waste reuse	-	-	-	-	-	-	-	-	-	+
	Wastewater	-	-	-	-	-	-	-	-	+	+
	Rainwater utilization	-	-	-	-	-	-	-	-	+	+
	Rainwater storage near the building	-	-	-	-	-	-	-	-	+	+
	Utilization of rainwater for garden irrigation	-	-	-	-	-	-	-	-	+	+
	Use of low-maintenance plants in landscaping	+	-+	-+	-+	x	-+	x	+	+	+
	Wastewater/Rainwater use in reservoirs	-	-	-	-	-	-	-	-	+	-+
	Use of double-flow reservoirs	-	-	-	-	-	-	-	-	+	-+
Data collection	Solar/Wind data collection system	-	-	-	+	-	-	-	-	+	+
	Monitoring of data such as the electrical energy used in the building, indoor/outdoor temperature/humidity by software both in-house and over the internet.	-	-	-	-	-	-	-	-	+	-

3. Results and Discussion

Energy is one of the basic elements of life cycle and is necessary for the continuity of life. It has been demonstrated that natural resources, which are essential for sustainability of life and the environment for future generations, are exhaustible and threatened by overuse. Global warming poses a threat for mankind, and natural resources are threatened by pollution. These important problems need to be dealt with on a local, regional, and global scale; the solutions need to be sought by developing national and international policies and cooperation. Environmental conservation and prevention of environmental pollution can be achieved by adopting policies such as utilization of renewable energy resources.

Turkey has the advantage of a favorable geographical location; however, solar energy is not sufficiently employed in Turkey in buildings and its implementation is limited to a few examples. Solar energy is most commonly used for supplying hot water in Turkey; however, the utilization of solar energy for heating, cooling, ventilation, and air conditioning of buildings is not yet widespread. In addition to the existing legislation on efficient use of energy, Turkey has adopted, as part of the harmonization with EU legal framework, the “Law on Energy Efficiency” in 2007 (Law of Energy Efficient, 2007) and the “Regulation on Energy Performance of Buildings” in 2008 (Regulation of Energy Performance in Building, 2008). The newly adopted regulation is comprehensive and aims to improve the energy efficiency of buildings. The implementation, however, has generally been for new housing projects rather than existing buildings. The main reason for this situation is the generally poor quality of insulation in Turkey and the use of inadequate insulation materials and substandard workmanship (Turkish Standardization Institute Standard Number: TSE 825, 2008). This results in high levels of energy loss in existing buildings, which is difficult to make up for using solar energy alone. The high initial investment cost of solar energy also prohibits its widespread use.

The findings from the review of the solar houses are as follows:

- The comparison of the solar houses in Turkey revealed that buildings constructed to date utilize solar energy for heating, cooling, ventilation, and air conditioning, and that the quality of these buildings has improved over time. Among the solar houses for which thermal performance measurements are available, the buildings in Adana, İzmir and Diyarbakır, all of which are in areas with a warm climate, have the highest performance levels.
- Active systems required about 10% to 50% higher initial investment cost than passive systems. The buildings that employ active systems, on the other hand, have 20% to 30% higher thermal performance than those that have passive systems (Altuntop, 2008: 6). Although the initial investment cost is high, active and passive systems should be used together in examples where sı-olar energy is used, and such structures should be encouraged.
- Passive solar systems can be employed directly by the designers during the design, without any installation requirements. However, it has been observed that storage of solar radiation is not very efficient during summer-winter and day–night fluctuations.

4. Conclusions and Recommendations

The recommendations are as follows:

- Since passive energy systems are not very efficient in storing solar radiation in summer-winter and day-night fluctuations, it is recommended to carry out studies to improve the performance of these systems.
- It has been observed that it takes a long time, even in the summer, to store the heat generated by greenhouses, winter gardens, and solar walls in the solar houses that employ passive systems. Therefore, it is recommended that fans are included in these systems to ensure faster heat transfer in the buildings (Altuntop, 2008: 6).
- It is promising that an increasing number of buildings that are in active use, like shopping malls, airports, factories and hospitals, utilize solar energy, even though only a few are constructed as solar houses. Active systems and photovoltaic panel applications are generally used in such structures. Utilization of solar potential is generally limited to the production of hot water. Effort should be made expand applications for ventilation and air conditioning in areas with relatively low solar energy potential.
- Public awareness has been raised by media coverage of topics such as thermal loss from buildings and its consequences with respect to the cost of building maintenance. Engineering and architecture departments of universities offer theoretical and applied courses on the utilization of renewable energy resources and solar energy applications. Considering the importance of the subject, it is very important that the applications are not limited to the applications made by academic circles and that the examples are widespread and reproduced in the building production process. In this context, especially in region with high solar energy potential, applications should be expanded and adapted to current housing practices.
- Studies have been initiated to determine the energy consumption of new buildings and to issue Energy Identity (Performance) Certificates. Exterior thermal sheeting and insulation works have become widespread in existing buildings. These are applications that benefit from applications applied by using solar energy. Programming and design for use in use of solar energy should be developed, can be specially designed and designed in the project.
- Simulation software (BEP-TR, Vaillant) has come into use to calculate energy consumption of buildings and prevent heat loss.
- Although Turkey is a country with high solar energy potential, solar energy can not be utilized effectively and efficiently. In order not to be dependent on foreign energy in terms of energy the use of clean and renewable energy sources such as geothermal and wind energy other than solar energy should be encouraged. Before using solar strategies in the design and redesign process of houses, the subject should be supported with economic feasibility reports and engineering analyzes, and then the house owners should be informed about the suitability of solar technologies (Atiol, Abbasoğlu and Nowzari, 2013).
- In recent years, low-energy or net-zero energy building design, in which on-site solar energy collection and efficiency measures are used together, is one of the issues that is considered and discussed by other actors in construction sector as well as in the discipline of architecture. It is recommended y-that such structures, which will be realized by evaluating building energy simulations by experts, should be increased numerically. It is recommended to develop design tools to provide energy and

clean-energy designs and to draw conceptual and guiding framework for designers. Passive solar energy houses applied with traditional methods cannot provide sufficient feedback to the designer in case of changing design parameters. For this reason, it will prepare the environment for obtaining more accurate results in a shorter time in terms of questioning the performance results ensuring energy efficiency with simulation programmes (Brien, Athienitis and Kesik 2009).

Research and development studies on the utilization of solar energy in buildings must be given priority. Legislation, incentives and funding must be made available for solar architecture.

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