E3S Web of Conferences **550**, 01002 (2024) https://doi.org/10.1051/e3sconf/202455001002
*Young Scientist 2024*

# Solar architecture: Significance and integration of technologies

*Zuzana* Dicka[1*], *Erika* Dolnikova[1], and *Dusan* Katunsky[1]

[1]Institute of Architectural Engineering, Faculty of Civil Engineering, Technical University of Kosice, 042 00 Kosice, Vysokoskolska 4, Slovakia

**Abstract.** Solar architecture is an innovative approach to building design and construction that focuses on integrating solar technology with architectural design. Solar-integrated architecture includes both passive and active use of solar energy. Due to the impact of global warming, today's energy environment is changing significantly from the usage of fossil fuels to the production of clean energy on-site. Buildings and the construction sector are responsible for almost a third of the world's total energy consumption and are the primary source of greenhouse gas emissions. Solar energy as a source of inexhaustible energy represents the future of modern sustainable buildings. This article deals with the basic principles and overview of solar architecture and analyses its impact on the environment. The paper includes the advantages of solar architecture, influencing factors, the latest technological innovations, practical aspects of implementing solar solutions, and examples of successful world projects. The paper aims to provide a comprehensive and informed overview of solar architecture and available solar technologies and solutions. Last but foremost, emphasize the importance of this issue in existing but especially in future designs of energy-efficient buildings.

## 1 Introduction

In the era of global warming and growing awareness of climate change, the energy efficiency of buildings becomes a crucial issue. The construction sector is responsible for more than 40% of global energy consumption. The problem of reducing carbon emissions is a necessary and increasingly discussed topic in the construction sector. Relating to sustainability, passive building design takes centre stage, driving increased attention toward utilizing renewable energy sources [1]. The primary and inexhaustible source of energy for our planet is the Sun. Optimal use of solar radiation contributes not only to energy sustainability but also has a fundamental impact on the comfort of the indoor environment of buildings [2]. With the increasing environmental challenges, solar architecture is becoming a powerful tool in reducing emissions and transitioning to sustainable energy sources. Solar architecture offers an innovative solution that integrates solar technologies into the design of buildings and thus enables the use of clean and renewable energy from the Sun [3].

* Corresponding author: zuzana.dicka@tuke.sk

## 2 Solar architecture

The term solar architecture represents an architectural approach that focuses on integrating solar technologies into the design of buildings to effectively harness solar energy. This concept combines architectural elements with advanced technologies to maximize energy gains [4]. Solar architecture includes integrating active solar systems, various intelligent control mechanisms to optimize solar radiation, and passive solar designs that utilize solar radiation without active technologies. The goal of solar architecture is to create sustainable and energy-efficient structures that will contribute to reducing energy consumption and greenhouse gas emissions while providing optimal comfort for building occupants [5].

### 2.1 Historical evolution of solar architecture

The historical development of solar architecture reaches far back into the past when people began to use sunlight and heat to improve the indoor comfort of their dwellings. This issue was closely linked to architecture, technological progress, and culture. From the earliest settlements to modern cities, we have witnessed the evolution of solar energy use in buildings. In ancient civilizations, such as ancient Greece and Rome, architects considered the optimal use of sunlight, specifically through the proper orientation of buildings. They used atrium courtyards, appropriate placement of window openings, and various cutout details on the facade to provide sufficient daylighting for buildings [6]. The idea of passive design first appeared in Greece. It is the principle of Socrates' solar house, which represents the idea of using solar energy throughout the year and ensuring optimal indoor thermal comfort. Socrates designed a higher south-facing facade for better use of sunlight in winter. In contrast, the north facade is lower to protect against strong winds. The shape and slope of the roof depend on the latitude and location. The roof overhang prevents summer sunlight from entering the interior of the house [7].

In the 18th century, the first solar collector was invented by the Swiss scientist Horace Bénédicte de Saussure. It was constructed from several layers of glass placed in a box and functioned like a greenhouse [8]. The rise of the industrial revolution and urbanization in the 19th century brought new technologies, transforming the possibilities of using solar energy in buildings. The MIT Solar House, built in 1939 in the United States, is considered a pioneering project in solar building design. The house was designed by engineer Hottel H. and was the first to use active solar systems for heating and water heating [9]. One of the first passive solar houses is the "Dover Sun House" built in 1948 in the USA. The system was designed by scientist Telkes M. and operated on the principle of accumulating solar energy using salt, which released heat into the environment during phase change [10]. In the 20th century, particularly during the energy crisis of the 1970s, interest in solar technologies for the direct conversion of sunlight into heat and electricity increased. During this period, the first commercial solar water heaters were developed, providing hot water for domestic use [11]. Another significant milestone in solar architecture is the house that rotates to follow the sun. The so-called Heliotrope was designed by German architect Rolf Disch and the first version was built in Germany in 1994. The house was designed to be oriented towards the sun during the heating season and away from the sun during the summer months [12]. With the advent of the 21st century, solar architecture has become an innovative approach to the design and construction of buildings. The first major project in the 21st century to use solar design is the "Druk White Lotus School" educational building, built in 2022 in northern India. Architects from Arup used Trombe walls to maintain optimal indoor comfort and solar panels to generate electricity [13].

Today's solar architecture projects emphasize the integration of solar technologies into the very structure and facades of buildings. With the onset of modern technological innovations, solar architecture is becoming a key element in the global effort to reduce greenhouse gas emissions. The historical development from ancient civilizations to contemporary innovations testifies to the continuous interest in using solar energy in the construction sector to create a more sustainable and energy-efficient future [14].

## 3 Active and passive solar systems

Solar architecture is an approach to building design that emphasizes environmental sensitivity and utilizes climatic factors to achieve indoor comfort. This approach rejects reliance on artificial energy sources, which are not only financially costly but also potentially destructive to the environment. In contrast to the traditional building approach, which views climate as an obstacle to be kept out of buildings, solar architecture strives to integrate buildings into their surroundings. These natural energy sources can be harnessed in two ways: actively and passively. A third option is a combination of the two, known as a hybrid system. Solar systems are ways of using and converting sunlight into energy for the benefit of a building. Solar energy can be used for various purposes such as heating, water heating, air heating, or electricity generation. Active and passive solar systems perform the same function but operate through different mechanisms [15].

### 3.1 Active solar systems

Active solar systems represent a wide range of technological solutions that use mechanical or electrical devices to integrate solar energy into the design and operation of a building. The aim is to reduce the energy consumption of the building and improve the indoor thermal comfort. These systems can be categorized from various perspectives, such as their visual connection to the exterior, geometrical properties, or the materials used [16]. Active solar systems include light chimneys, tubular skylights, solar lamps, heliostats, solar towers, and more. The basic elements and their classification can be considered at two scales. The first is the relationship to the building and the second is to the larger context of urban planning (Figure 1.) [17].

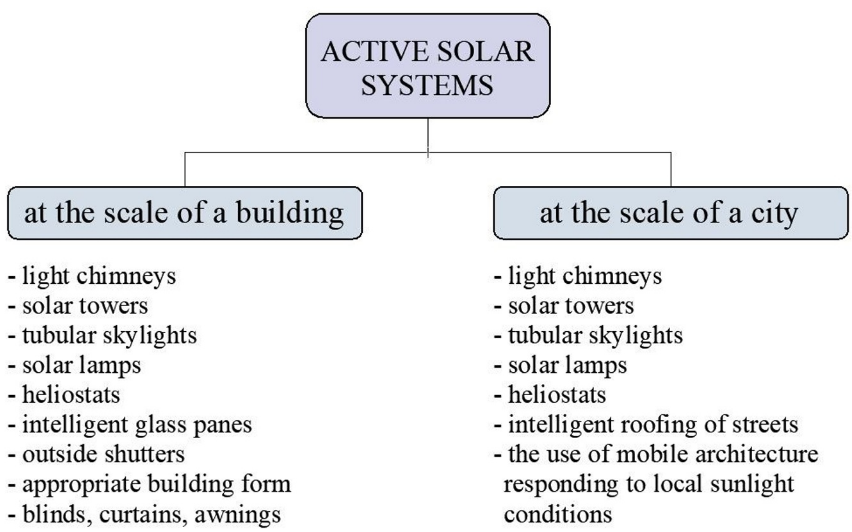


**Fig. 1.** Active solar systems at the scale of a building and city (according to [17]).

### 3.2 Passive solar systems

Passive solar systems use the natural properties of a building and its surroundings to capture and retain solar energy without the use of mechanical or electrical devices. The design principle of passive design is to maximize the benefits of the local climate. When designing passive solar buildings, it is important to consider the size and placement of window openings, shading elements, and the surrounding environment. These factors need to be considered at the early stages of the building design process. In addition, the shape of the building, the use of buffer zones in buildings, and the selection of appropriate glazing are also important factors (Figure 2.) [17, 18].

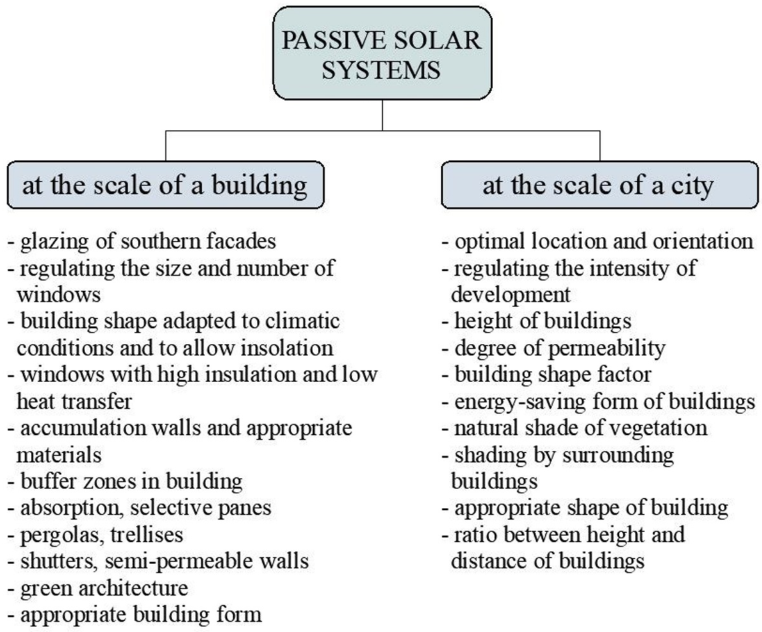


**Fig. 2.** Passive solar systems at the scale of a building and city (according to [17,18]).

### 3.3 Advantages and disadvantages of solar systems

Active and passive solar systems represent two fundamental approaches to utilizing solar energy in architecture. Each of these systems offers benefits to the building, but they also have some disadvantages. The main advantage of active systems is to maximize daylighting in building interiors. It leads to a reduction in the need for artificial lighting and an improvement in indoor comfort. For instance, solar lamps use solar energy to generate electricity. Heliostats and solar towers provide water or air heating in buildings by concentrating solar radiation. In addition to energy benefits, these systems also improve the aesthetics and functionality of buildings, which contributes to their attractiveness and sustainability. Active solar systems thus represent comprehensive solutions for architectural projects that save energy, protect the environment, and increase indoor comfort. The main disadvantage is their higher cost and maintenance requirements [19].

Passive solar systems utilize the natural properties of sunlight to improve thermal and visual comfort in buildings without using active technologies. Their advantages include low cost and easy maintenance, low energy consumption, and long-term benefits in the form of lower energy costs. The combination of these systems allows for comprehensive and energy-efficient solutions in the form of hybrid systems, which combine the advantages of active and passive systems for the benefit of the building. A summary of their advantages and disadvantages is shown in Table 1. [20, 21].

**Table 1.** Advantages and disadvantages of solar systems (according to [20, 21]).

| Solar system | Advantages | Disadvantages |
|---|---|---|
| Active | - reduced carbon footprint<br>- increased system efficiency due to mechanical components<br>- higher capacity than passive systems<br>- installation possible on existing buildings<br>- greater control over energy use | - costs, maintenance<br>- space constraints<br>- need for external resources for operation<br>- unesthetic appearance of the building<br>- risk of frost damage |
| Passive | - environmentally friendly solution<br>- not require external solar equipment<br>- maintenance-free<br>- less expensive than active systems<br>- aesthetic | - lower efficiency than active systems<br>- retrofit not possible<br>- risk of overheating |
| Hybrid | - combines the advantages of both systems<br>- increased energy efficiency<br>- reduced emissions<br>- increased indoor comfort<br>- reduced energy costs | - complexity<br>- higher installation costs |

## 4 Integration of solar architecture in contemporary projects

A modern example of the integration of solar design and sustainable construction is the Masdar City project in Abu Dhabi. It is a project with minimal energy consumption and the use of renewable energy sources, which has the potential to become a model for sustainable future cities. Construction began in 2006 and is to be completed in 2030. The city will cover an area of 6 square kilometres and will accommodate up to 50,000 people. Masdar City uses various technologies and strategies to achieve its carbon-neutral goals. From a solar architecture perspective, the buildings in the city are designed with a southern orientation to maximize sunlight and shading elements that reduce summer overheating. Another element is the use of thermal mass in building structures to reduce the energy needed for heating and cooling. The city will also have a photovoltaic panel system for generating electricity and a system for collecting rainwater and reusing it [22]. Another interesting example is the "The Edge" building in Amsterdam, which is the most energy-efficient and ecological in the world. The administrative building was completed in 2014 and consumes 70% less energy than conventional office buildings. The dominant feature is the glazed facade, which is oriented and shaped to allow for the most optimal use of sunlight. The all-glass north facade reduces the need for heating energy. On the other hand, the south facade is covered with photovoltaic panels, which, in addition to generating electricity, also provide shading and protect the interior from overheating [23]. Another example of solar design is the Bullitt Center, built in Seattle in 2012. It was designed to be the greenest commercial building in the world. It uses passive solar design elements such as orientation and shading elements. An interesting feature of this building is its facade, made of a composite material that can absorb solar energy and release it as heat. The facade also includes photovoltaic panels [24]. The King Abdullah University of Science and Technology in Saudi Arabia, built in 2009, also uses passive solar design. In addition to orientation and shading elements, this building is particularly interesting for its perforated roof, which regulates light and allows air to flow through the building [25]. Another example of solar architecture is the Beddington Zero Energy Development housing complex built in the UK in 2002. This complex is considered one of the first in the world to achieve zero carbon emissions. A striking architectural feature is the winter gardens located in front of the apartments, which are a source of passive cooling and heating. In addition to these iconic buildings, passive solar architecture is also used in many other projects around the world, ranging from single-family homes to large commercial buildings. With the growing interest in sustainability, it can be expected that even more such buildings will be constructed in the future [26].

## 5 Conclusion

Solar architecture has become a fundamental aspect of modern and future architectural practice, focusing on energy-efficient and sustainable solutions in construction. Through active and passive elements, it enables the effective use of solar energy to achieve indoor comfort and optimize the energy balance of buildings. The historical development of solar architecture reflects not only technological advancements but also dynamic changes in environmental awareness and societal priorities [27]. Innovative approaches to solar architecture integrate not only efficient active systems but also sophisticated passive design strategies that maximize natural lighting and thermal comfort in buildings. Implementing these strategies requires a comprehensive approach to architectural design, with an emphasis on analysing solar radiation and local climatic conditions. Through continuous development and innovative approaches, solar architecture has the potential to significantly contribute to solving global energy and environmental challenges.

This paper was elaborated with the financial support of the research project VEGA 1/0626/22 of the Scientific Grant Agency of the Ministry of Education, Research, Development and Youth of the Slovak Republic and the Slovak Academy of Sciences.

## References

1. M. Wall, M. C. M. Probst, C. Roecker, M. C. Dubois, M. Horvat, O. B. Jørgensen, K. Kappel, *Achieving Solar Energy in Architecture-IEA SHC Task 41*, Energy Procedia, **30**, 1250-1260, (2012), ISSN 1876-6102
2. J. A. Duffie, W. A. Beckman, *Solar Engineering for Thermal Processes*, John Wiley & Sons, 909, (2013), ISBN 978-0-470-87366-3
3. A. Htet, S. R. Liana, S. Y. Rani, A. Bhaumik, *The effectiveness of daylight management in building: A review*, in Proceedings of the AIP Conf., 24 August 2023, **2854(1)**, 020005, (2023)
4. Q. Duan, Y. Feng, J. Wang, *Clustering of visible and infrared solar irradiance for solar architecture design and analysis*, Renewable Energy, **165(1)**, 668-677, (2021), ISSN 0960-1481
5. S. O. Raquel, R. Coelho, A. T. Marques, C. Torres, J. A. Simoes, *Design of Active and Passive Solar Elements for Sustainable Contemporary Architecture*, J Archit Eng Tech, **3(4)**, 1000132, (2014), ISSN: 2168-9717
6. F. Nyole, *History of Daylighting: A comparative analysis across the periods*, Wiley & Sons Inc., 8, (2013)

7. A. I. Dumitraşcu, T. M. Hapurne, I. Bliuc, C. G. Corduban, R. M. Nica, *Waffle structure optimization in terms of energy efficiency and spatial geometry for a single family house*, IOP Conference Series: Materials Science and Engineering, IOP Publishing, **444(8)**, 082013, (2018)
8. S. Barber, M. Behm, *History of Passive Solar Energy*, Environmental Science, History, Engineering, 12, (2012)
9. K. Koehler, *The Solar House: Pioneering Sustainable Design. By Anthony Denzer,* New York: Rizzoli, 2013, Arts, **3(3)**, 303-306, (2014)
10. J. O. Dalenbäck, *Solar Architecture Buildings Pre 1950,* ISES SWC50 - The Century of Solar-Stories and Visions, 12-15, (2018), ISBN: 978-3-9820408-5-1
11. R. Hastings, *A Time Journey Through Solar Architecture — 1900 to the Future*, In: Goswami, D.Y., Zhao, Y. (eds) Proceedings of ISES World Congress 2007 (Vol. I – Vol. V), Springer, Berlin, Heidelberg, (2008)
12. architectuul.com [online] "*Heliotrop Rotating House*", available: https://architectuul.com/architecture/heliotrop-rotating-house, last accessed 2024/3/15
13. J. Fleming, R. McGowan, D. Richter; J. Rose, *Druk White Lotus School, Ladakh, Northern India*, The Arup Journal, (2002)
14. K. Butti, J. Perlin, *A golden Thread, 2500 Years of Solar Architecture and Technology*, Cheshire Books, Pala Alto, California, **514**, (1980), ISBN 0-917352- 08-4
15. G. Cillari, F. Fantozzi, A. Franco, *Passive Solar Solutions for Buildings: Criteria and Guidelines for a Synergistic Design*, Applied Sciences, **11(1)**, 375, (2021)
16. C. Vassiliades, A. Michael, A. Savvides, S. Kalogirou, *Improvement of passive behaviour of existing buildings through the integration of active solar energy systems*, Energy, **163**, 1178-1192, (2018), ISSN 0360-5442
17. A. Zaręba, A. Krzemińska, R. Kozik, M. Adynkiewicz-Piragas, K. Kristiánová, *Passive and Active Solar Systems in Eco-Architecture and Eco-Urban Planning*, Applied Sciences, **12(6)**, 3095, (2022)
18. B. Norton, *Harnessing Solar Heat*, Springer, (2014), ISBN 978-94-007-7275-5
19. N. O. Onubogu, K. K. Chong, M. H. Tan, *Review of active and passive daylighting technologies for sustainable building*, International Journal of Photoenergy, **2021**, 1-29, (2021)
20. H. Taherian, R. W. Peters, *Advanced Active and Passive Methods in Residential Energy Efficiency*, Energies, **16(9)**, 3905, (2023)
21. J. F. Kreider, F. Kreith, *Solar heating and cooling: active and passive design*, CRC Press, 479, (1982)
22. V. Sankaran, A. Chopra, *Creating Global Sustainable Smart Cities (A Case Study of Masdar City)*, Journal of Physics: Conference Series, IOP Publishing, **1706(1)**, 012141, (2020)
23. A. Jalia, R. Bakker, M. Ramage, *The Edge, Amsterdam: Showcasing an exemplary IoT building*, University of Cambridge, 22, (2018)
24. J. H. Crowe, *Architectural advocacy: The Bullitt Center and environmental design*, Environmental Communication, **14(2)**, 236-254, (2020)
25. Y. A. Adenle, H. M. Alshuwaikhat, *Spatial Estimation and Visualization of CO2 Emissions for Campus Sustainability: The Case of King Abdullah University of Science and Technology (KAUST), Saudi Arabia*, Sustainability, **9(11)**, 2124, (2017)

26. T. Chance, *Towards sustainable residential communities; the Beddington Zero Energy Development (BedZED) and beyond*, Environment and urbanization, **21(2)**, 527-544, (2009)
27. J. P. Eberhard, *Solar Architecture: Designing Sensible Solutions to the Energy Crisis*, Research&Design, The Quarterly of The AIA Research Corporation, **1(1)**, 41, (1978)