Asia-Pacific
Economic Cooperation

Output 03 - Technical Solution Package for Renewable Energy Supply for Green Buildings (EWG 03 2016A)

APEC Energy Working Group

April 2018

APEC Project: [EWG 03 2016A]

Produced by

Yong Sun (Dr.)
School of Architecture, Tianjin University; APEC Sustainable Energy Center (APSEC)
216 Yifu Building, 92 Weijin Road, Nankai District, Tianjin 300072, P. R. CHINA
Tel: + (86) 022-2740 0847
Email: sunyong-1984@163.com

Yang Yang (phD)
School of Architecture, Tianjin University; APEC Sustainable Energy Center (APSEC)
216 Yifu Building, 92 Weijin Road, Nankai District, Tianjin 300072, P. R. CHINA
Tel: + (86) 022-2740 0847
Email: doublesunrise@126.com

For
Asia-Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace
Singapore 119616
Tel: (65) 68919 600
Fax: (65) 68919 690
Email: info@apec.org
Website: www.apec.org

****

Technical Solution Package for Renewable Energy Supply for Green Buildings (EWG 03 2016A)

Contents

Technical Solution Package for Renewable Energy Supply for Green Buildings (EWG 03 2016A)

Executive Summary

As we all know, energy consumption from building sector accounts for a considerable proportion in the total energy consumption of both APEC region and other areas. This APEC project (e.g. EWG 03/2016A) aims to develop recommendations for application of innovative solar technologies in green buildings to Asia Pacific's various climatic regions, share information on relevant technologies, and promote energy efficiency of APEC region. Green building is one of the measures put forward to mitigate significant impacts of the building stock on the environment, society and economy. The theory of green buildings includes a lower environment load, higher energy efficiency and resource saving throughout a building's whole life cycle. At the same time, green buildings should provide comfortable, safe and healthy environments for people. Renewable energy utilization (REU) is one of the most important aspects of green buildings. Technical solution package for renewable energy supply for green buildings funded by EWG 03 2016A is important to promoting green building with cost-effective renewable energy supply solutions in APEC region. This technical solution package will be divided into five main sessions, including session 1 passive solar design; session 2 active solar design; session 3 application of solar technologies in building; session 4 solar building computer aided design software; and session 5 case study of solar building.

From preliminary workshop and research, our team think that there exists an exciting opportunity for the development of cost-effective renewable energy supply solutions based on innovative solar technologies to promote green buildings in APEC region. Our team hope the final recommendations including this promotion plan could make contributions to the sustainability development of all 21 member economies of APEC.

Technical Solution Package for Renewable Energy Supply for Green Buildings (EWG 03 2016A)

Project Description and Background

Buildings account for about 40% of global energy consumption; therefore renewable energy-supply solutions for buildings will greatly contribute to energy efficiency and energy security of Asia-Pacific region. Responding to 2015 APEC Energy Ministers' instruction for the EWG to "explore strategies to drive the shift towards green buildings including zero energy buildings", this project seeks to foster APEC members' collaborative efforts in developing cost-effective renewable energy-supply solutions based on innovative solar technologies for green buildings in APEC region.

This project aims to develop recommendations for application of innovative solar technologies in green buildings to Asia Pacific's various climatic regions, share information on relevant technologies, and promote energy efficiency of APEC region. A workshop with experts and attendance from renewable energy and green buildings field will be held in China in April 2017. A final research report on RE solutions for green buildings in APEC Region will be submitted.

Project Objectives

The Project Objectives of EWG 03/2016A are:

- To develop recommendations on technical solutions for promoting advanced solar applications in green buildings to Asia Pacific's various climatic regions.
- To make all partners clear about possible sustainable building energy-supply solutions and to enhance understanding of the innovative solar technologies by sharing results and experiences.
- To build interest of governments, investors, architect, manufacturers of building cladding products and photovoltaic companies in the innovative solar technologies and their applications for green buildings including zero energy buildings.

Aim and Objectives of Research Report on Innovative Solar Technologies (EWG 03/2016A)

Recently, the economic growth in most of APEC member economies has significantly increased pressure on both the infrastructure and environment, particularly pressure of increasing demand for buildings, energy consumption, and waste and pollution management. Studies have shown that the greening technologies and design applied in GB can increase the efficiency of buildings by up to ten times in terms of resource utilisation. This research report aims to provide a technical solution package about renewable energy-supply for green buildings, which can help the related stakeholders to deploy the advanced technologies.

Session I: Passive solar design

Solar energy is the primary light and heat resource of the Earth. It can provide eternal energy to maintain the atmosphere temperature and germinate plants. With technological developments, solar energy can be utilized more and more efficiently and economically.

Passive solar design strategies comprise important ways of reducing the heating, cooling and lighting energy consumption of buildings. In this chapter, the passive solar heating and cooling system is introduced. This chapter mainly refers to the relevant literatures published by Ruzhu Wang et al [1].

1. Passive solar heating systems

Passive houses, which emerged in response to the need to reduce space heating demands in residential buildings, are generally characterized by the combination of a highly insulated envelope and a properly dimensioned passive solar heating system, together with an efficient energy system. Their architecture represents the results of an effort, initiated in the early 20th century and strengthened by the energy crisis of the 1970s, to develop environmentally friendly building concepts.

Solar houses, developed throughout the 20th century, aimed at taking maximum advantage of solar heat gains for covering most of their heating demand. Natural heat transfer phenomena such as conduction, convection, and radiation, were extensively used in these buildings to distribute the heat in accordance with the internal space's environmental requirements. Solar houses were usually characterized by an extensive use of solar systems such as greenhouses or glazed balconies, whose diffusion was made possible by industrial developments in the production of cheaper and higher performing glasses.

Experimental buildings developed throughout the 20th century played a fundamental pioneering role in the analysis and quantification of potential energy savings deriving from the use of passive solar systems. Data extracted from pilot experimental buildings often became the basis for the definition of new energy targets and national standards (Fig. 1.1).

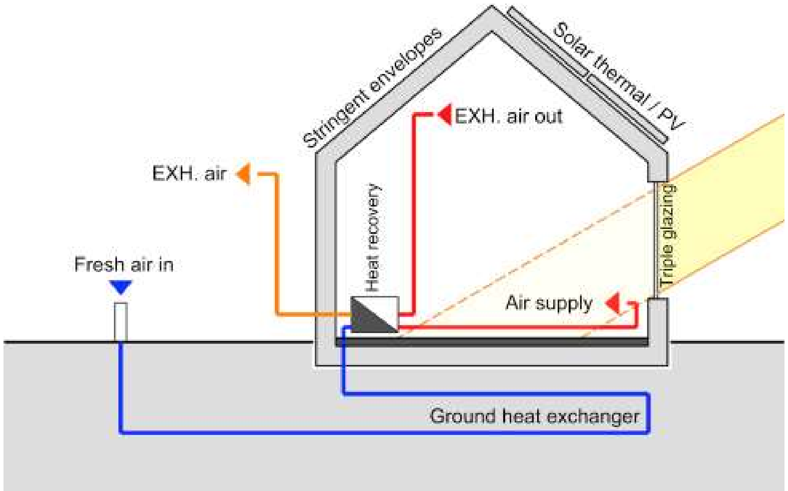


Figure 1.1. Passive house building elements and components. EXH, exhaust; PV, photovoltaic panels.

Despite their simple aesthetics, the architectural design of a solar house is often characterized by a high degree of complexity. Passive solar heating systems adopted in these houses need to be conceived as an integral part of the whole building architectural system, taking into account construction, morphology, internal program environmental requirements, and their distribution within the building form [2]. Light construction ensures that solar heat gains are quickly transferred into the space without being stored in the thermal mass of the inner envelope. An unbalanced dimensioning of solar capture and building heat capacity may still result in an inhomogeneous temperature distribution, creating discomfort.

Passive solar heating systems (PSHSs) are often nowadays optimized through the use of advanced simulation software able to predict environmental performance already during the early stages of the architectural design process. The use of small electrical devices, such as fans, automated shades, or insulated shutters is often justified by the significantly increased performance of the PSHS. The architectural design of buildings requiring the optimization of advanced PSHSs, typically powered by active systems based on renewable energy use, often requires a symbiotic collaboration between architects and engineers.

Figure 1.2. Solar house

1.1 Passive solar heating systems materials and components

The amount of solar radiation that is effectively absorbed within the building form depends on specific characteristics of the building envelope such as the distribution of glazed areas, overall transmittance, and eventually the use of additional components such as shading devices, insulated shutters, or solar reflectors.

1.1.1 Solar capture systems

Solar capture systems aim at collecting most of the solar radiation available during the under heated season. The solar heat transmittance (*g* value) of a window determines the amount of solar energy effectively absorbed through the glazed area, whereas the thermal conductivity (*u* value) determines the possible heat transfer through conduction. A state-of-the-art window is nowadays generally characterized by a *g* value of 0.5, corresponding to around 50%, and a *u* value of 0.8 W/m2K.

In the Northern Hemisphere a typical solar capture system (Fig. 1.3) is represented by a south-oriented glazed area, unshaded during the wintertime. Solar capture systems in orientations other than south are possible but should take into account a possibly negative heat balance during the cold season and the higher energy contribution of the sun when it is lower at the horizon during summer. East and west-oriented PSHSs are for this reason generally double-glazed and equipped with adjustable shading devices.

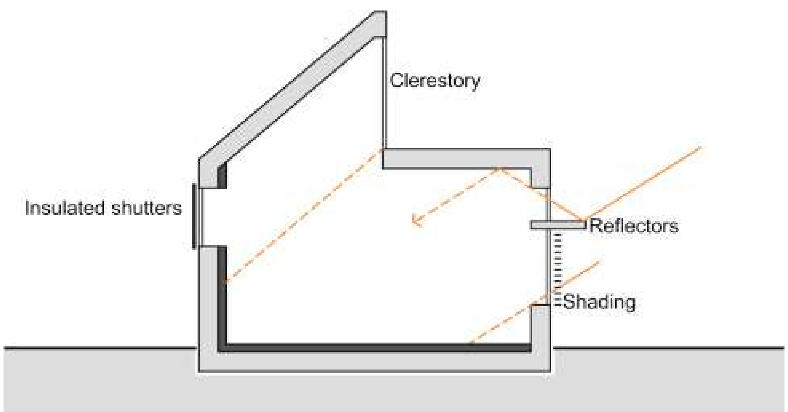


Figure 1.3. Solar capture systems and regulating devices.

The environmental adaptability of solar capture systems is generally enhanced through the use of additional devices, such as shading systems, reflectors, or insulated shutters, able to better tune the access of solar radiation to the internal environmental requirements, increasing the overall performance of the PSHS throughout the whole year.

Fixed shading devices such as roof overhangs or pergolas, commonly adopted in the south facade, are optimized to be able to effectively shade the glass during the summer while still giving access to the sun's rays during the winter when the sun is lower in the sky. Because of the low angle of the sun, on facades facing east and west it is more effective to use vertical devices such as sliding shutters to more effectively block the access of the sun's rays.

1.1.2 Heat storage systems

The heat storage capacity of a building ensures that indoor temperature fluctuations are not affected by the solar contribution, but that energy is first stored in the building internal surfaces and then released with a convenient time lag for thermal comfort. Inside passive houses in central European climates, temperatures generally do not drop below 10°C even without heating [3]. The question is to what point it is possible to enlarge the heat capacity of the building in such a way that the temperature would not fall below the comfort zone by simply relying on the contributions of solar energy and internal heat loads.

The heat storage system is generally composed of a dark-colored surface, working as an absorber, and a high-capacity thermal mass located in the direct path of the sun's rays. As a general principle, the higher the heat capacity of the material used, the better. Storage mediums must also be good heat conductors to easily release the absorbed heat when needed. Thermal lag, determined by heat capacity and thermal conductivity of the material used, represents a fundamental parameter for determining if the dynamic response of the adopted material would fit the climatic contexts in which we are working. Materials such as masonry or stone, characterized by a high heat capacity and high conductivity, are generally unable to quickly store the heat captured by the absorber. For this reason increasing the thickness of the storage system beyond 20 cm generally has no beneficial effect. It is, on the other hand, convenient to extend the storage surface area to large parts of the living area if we want to avoid overheating risks. If water is used as the thermal storage medium, heat is conveyed by natural convection throughout the mass, in which case it is possible to use thicknesses of the heat absorber beyond 20 cm. There is no perfect storage medium in terms of volume, heat capacity, and conductivity, but all these qualities need to be tuned to the PSHS dimensioning in relation to climatic context and building environmental requirements.

1.2 Passive solar heating systems technologies

PSHSs are commonly classified on the basis of the disposal of the capture and storage systems components within the space to heat. Direct, indirect, and isolated PSHSs are thus defined depending on whether the heat is stored directly inside, in-between, or outside the space (Fig. 1.4). Direct systems are generally characterized by an absorbance of 60-75% of the solar energy, whereas only 30-45% of the solar radiation striking an indirect system is actually stored in the space.

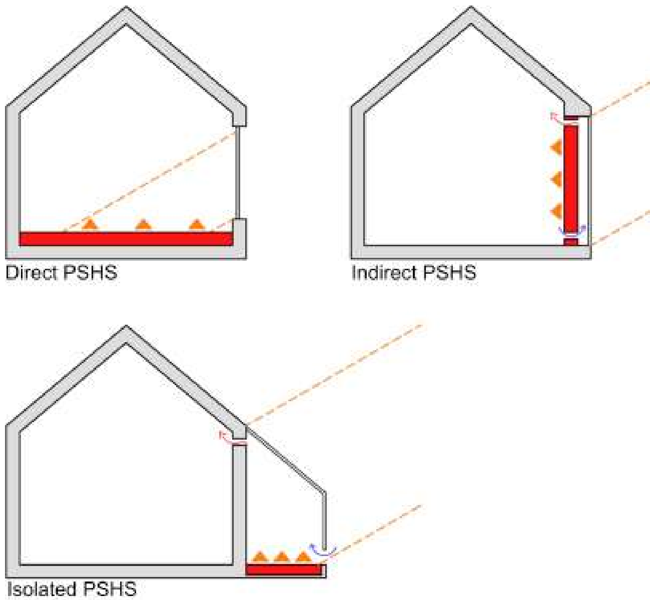


Figure 1.4. Passive solar heating system types

Generally no one PSHS is the most advantageous in all climatic contexts, but specific climatic conditions will suggest the most effective solution to employ in a specific building typology. In vernacular architecture, materials available on site determined which system was most convenient to adopt. Nowadays advanced materials and components, commercially available on a globalized market, have made it possible to adopt passive strategies once intimately connected to different climatic contexts.

1.2.1 Direct passive solar heating systems

Direct systems represent the simplest PSHS technology, in which the sun's rays are admitted and stored directly into the space to be heated. The storage system generally detains the heat as long as the room temperature is high, to then slowly release it when the temperature drops. This usually happens during the night because of the combination of higher thermal losses and lower heat gains related to space occupancy. Heat radiation can even last several days after the heat has actually been stored. Material to be used for the heat storage medium must be defined in accordance with an accurate comparison between climatic data and environmental space requirements with the aim of stabilizing temperature fluctuations within the comfort zone.

A slightly increased area of the solar capture system would make it possible to let a direct PSHS work properly under cloudy sky conditions with the only contribution being diffused solar radiation. In climatic contexts in which indirect solar radiation is dominant, it is advisable to use the minimum necessary thickness of the absorbance system to let the mass respond as quickly as possible when the sun is available.

1.2.2 Indirect systems

Indirect PSHSs are characterized by a storage mass placed in-between the solar absorber and the space to be heated. Solar energy is in this case indirectly transported through convection or irradiation into the space.

Trombe walls are the most common indirect PSHS and are characterized by an opaque wall exposed to direct solar radiation and interposed between the glass and the space to be heated. Solar radiation passing through the glazed area is converted straight into heat inside the cavity, but not all of this is quickly absorbed into the thermal mass. Because of this the air temperature in the cavity can easily pass 50°C in summer. Regulating devices should therefore be used in this period to avoid overheating risks. Vents placed at the bottom and at the top of the thermal mass spontaneously activate a natural convective loop, pouring hot air from the cavity into the space. This process will be active until there is a difference of temperature between the bottom and the top of the wall. To avoid thermal losses that could reduce the efficiency of the system or even reverse the heat transfer process, air vents should be closed in the night when heat stored into the wall can still be slowly released into the space through irradiation.

A thickness of 20–30 cm of concrete roughly corresponds to a time lag of 6–8 h, optimal for transferring heat gains on a daily basis from day to night. In the house in Pullach, Germany, designed by Thomas Herzog, a 30-cm-wide zone where installation, heat recirculation, and water flow are concentrated determines the whole layout of the building. An external envelope made of translucent insulation or glass modules covers a concrete unit painted in black working as the heat storage system

1.2.3 Isolated passive solar heating systems

Isolated PSHSs are heating devices detached from the living area and are typically constituted by a flat panel placed over a storage mass such as a rock bed or a water pond. Heat is transferred into the living area through convection by a water- or air-based siphon system, until an equilibrium in the temperature distribution in the medium is reached. Typical examples of isolated PSHSs are the Barra-Costantini wall or greenhouses. The Barra-Costantini is a variation of the Trombe wall, in which the only difference is the interposition of an insulation layer between the thermal mass and the space to be heated. This limits heat transfers through irradiation but makes it possible to better control the heat transfer from the PSHS into the space to be heated. This system is therefore more suitable in colder climatic contexts where extreme climatic conditions may result in significant heat losses through the system.

Attached greenhouses are the most common among isolated PSHSs, serving the double purpose of heat reservoir and functional space used to extend the living area when environmental conditions are favorable. These types of isolated PSHS are generally elongated along the south side of the building to maximize thermal exchange to the living area while minimizing exposure to the east and west. Because of their dual nature, the architectural design of buffer spaces such as greenhouses is generally slightly more difficult. In their dimensioning a correct balance between the space as a living area and as a heat reservoir should be aimed for. To optimize their environmental performance throughout the whole year, greenhouses are generally equipped with a complex system of valves that make it possible to adjust thermal exchange according to a wider set of boundary conditions.

In an experimental house built in Greve, Italy, by Aude, Lundgaard, Sorensen, and Rotne in 1985, the energy consumption of the building is reduced by dividing the building into three different zones matching the solar radiation contribution (Fig. 1.5) [4].

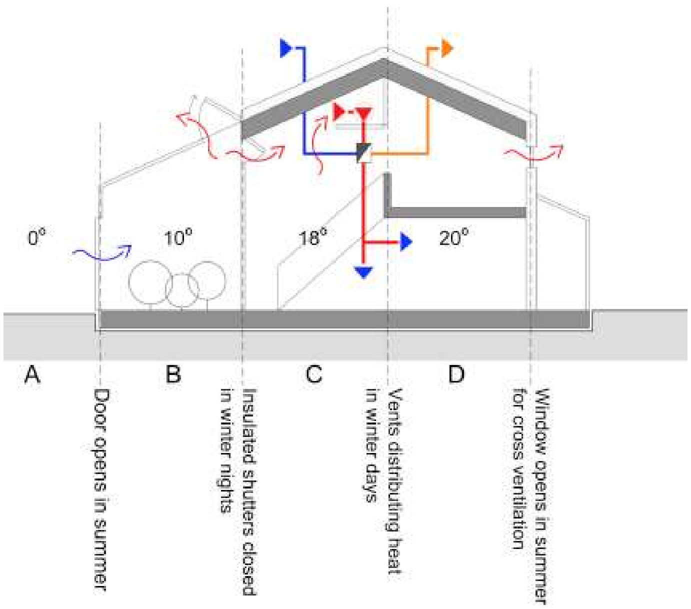


Figure 1.5. Aude, Lundgaard, Sorensen, and Rotne, experimental house, Greve, Italy, 1985.

1.3 Conclusions and future trends

Passive house buildings, which emerged in response to the need to reduce space heating demands in residential buildings, are generally characterized by the combination of a highly stringent envelope and a properly dimensioned PSHS. Because of the light construction often characterizing these buildings, a critical difference between heat absorbance and heat capacity of the building can potentially result in overheating problems.

2. Photovoltaic-powered solar cooling systems

The energy used in buildings accounts for 30% of the total primary energy used. With the use of heating, ventilating, and air-conditioning (HVAC) systems for indoor environments, air conditioning has become a very common practice around the world. Approximately 70% of the energy used in buildings is for heating and cooling. With the economic development in developing countries, more energy is used for buildings, especially use of cooling for air conditioning and refrigeration. The carbon dioxide emissions related to buildings has also steadily increased in recent decades.

To meet the challenge of an energy resource shortage and to solve the environmental problems, solar-assisted cooling technologies have been extensively studied in recent decades. Solar cooling offers a wide variety of cooling techniques powered by solar collector–based thermally driven cycles and PV-based electrical cooling systems [5].

There is not a large difference between PV cooling systems and other PV systems. A PV cooling system usually consists of a PV array, a vapor compression refrigeration system, and other necessary equipment. Compared with a thermal-driven cooling system, the advantages of a vapor compression refrigeration system include being compact, easy control, mature technology, and easy maintenance. The vapor compression refrigeration system is usually driven by an electrical motor.

There are four parts in a PV cooling system: the PV array, control unit, storage unit, and compressive refrigeration unit. For the stand-alone system, the control unit regulates the electricity from the PV array to the appropriate voltage to charge the DC electrical energy into the storage unit or drive the compressor of the refrigeration unit. For the grid-connected system, an inverter is included in the control unit, which converts the DC electricity from the PV array to AC with appropriate voltage to drive the compressor of the refrigeration unit or charge into the grid. In the DC side, different types of batteries have been used as the storage unit, with a lead-acid battery being the most used type. By now almost all conventional compressive refrigeration machines can be used for PV cooling. However, to increase the energy efficiency and reduce the system initial and operation cost, research and development are still needed on refrigeration systems dedicated for PV cooling.

The PV cooling system has become more and more attractive in recent years for the following reasons:

1. Simple structure: The PV cooling system consists of several important components that are mature and widely available in the market. Compared with a thermal-driven system for which the power system must be connected through a metal pipeline, the connections between the components of a PV system are mainly electrical wire and can be easily installed.

2. Easy control and short response time: The electrified system can be easily controlled and incorporated with information technology, which means optimal and remote control and remote monitoring can be easily achieved. The use of a vapor compression refrigeration system can achieve a quick change of output cooling power and quickly respond to the variation of cooling load.

3. Green energy and lower environmental pollution: The system can consume less electricity from the grid and make full use of local produced power. This feature will be more meaningful in the hot summer, when the peak power puts great strain on the power network.

4. High energy efficiency and potential reducing cost: The cost of a PV system will continue to decrease in the following years. The price of PV electricity might be even lower than the price of electricity generated from fossil fuel. Furthermore, the cost of components such as the inverter, battery, vapor compression refrigeration system, and grid connection will continue to decrease.

5. Working as a distributed energy system with more flexibility for energy transition and conversion: The system can be grid connected and reduce the influence of the intermittence of solar radiation. The off-grid system can be used to provide heating, cooling, and electrical power, which is of great significance in improving the living standard of a remote area where grid connection is not economical.

The objective of this chapter is to survey the progress of current researches on solar cooling system. The review is divided into two sections: the first is the solar refrigeration system and the second is the solar air-conditioning system. （Figure 1.6）

Figure 1.6. The solar refrigeration and the solar air-conditioning

2.1 Photovoltaic-powered refrigeration system

Cooling is always needed in daily life. In remote and undeveloped areas where electricity is not available, the storage of perishable food, vaccines, and medicine have always been big problems [6] because of the lack of appropriate reliable and cost-effective technologies. It is expected that solar PV refrigeration technology would provide a more reliable, safer, and cleaner form of refrigeration for perishable foods and improve the cold chain for vaccines. Various solar PV-powered refrigeration systems in small capacity have been proposed and investigated from the beginning of this century . Studies on solar PV refrigeration have been focused on the performance of different components, energy storage, and the overall performance of the system. The study methods include theoretical analysis, modeling, and experiments.

2.1.1Studies on photovoltaic-powered refrigerators

To maintain the properties of vaccines, they need to be kept in a lower temperature container ranging between −3°C and 8°C [6]. The earliest PV-powered refrigerator was mainly used for vaccine storage in remote, underdeveloped villages. In the earlier investigation, the commercial refrigerators were modified to be powered by a PV system to solve the problem of shortage in electricity . Different components of a PV refrigerator have been investigated. Kattakayam et al. [7] used commercial inverters that produce a quasisquare wave output and proved that conventional domestic refrigerators can be operated on nonsinusoidal AC inputs without any degradation of the thermal performance. However, a slight additional heating of the hermetic compressor was observed. Thermal mapping of the temperatures at various points on the refrigerator is provided for steady state, cool down, warm up, periodic opening of the door, and ice-making. An energy flow diagram was given for a steady-state sunny day operation. Major sources of losses are identified.

2.1.2Innovative application in photovoltaic-powered refrigerators

To enhance the autonomy and expand the application of PV refrigerators, some innovative strategies have been proposed. A novel PV DC refrigerator that uses hydrogen as the energy storage material has been proposed. The system consisted of a PV panel, electrolyzer, hydrogen storage tank, fuel cell, and DC refrigerator. When the PV-produced electricity is more than that needed from the refrigerator, the electricity is used to produce hydrogen by an electrolyzer and stored in the hydrogen storage tank. When the solar radiation is not available, such as in the evening or on rainy days, the hydrogen in the storage tank is discharged into the fuel cell to produce the hydrogen and drive the refrigerator .

A monitoring architecture for stand-alone PV systems was proposed with a web application being adopted, thus allowing for online monitoring and control of remote installations [8]. An Ethernet-based real-time remote monitoring system, specifically developed for stand-alone PV-powered appliances, was capable of monitoring the main electrical parameters of the device under test, which were stored on a database together with ambient parameters (Fig. 1.7).

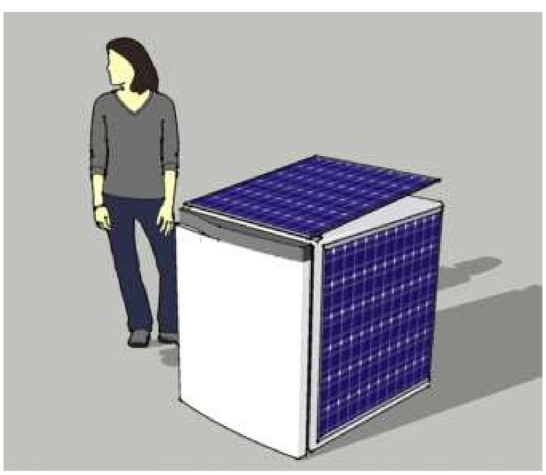


Figure 1.7. Conceptual model of the refrigerator with horizontal and vertical integrated photovoltaic modules [8].

2.2 Photovoltaic-powered air-conditioning system

HVAC is a necessary equipment in modern buildings, be they residential or public building environments. Normally one-third to half of the annual total electricity consumption is used for air conditioning and refrigeration in buildings worldwide. Solar cooling is considered as the sustainable technology to provide air conditioning and refrigeration because solar energy is the primary energy source and widely available, especially in hot areas where air conditioning is needed. Actually, solar PV air conditioning is a feasible way to replace the conventional electric refrigeration machines for buildings because of the much higher energy efficiency of electric chillers compared with sorption cooling systems.

When the PV price is high, solar PV air conditioning is not economically feasible; hence, study on PV air conditioners has only been conducted in recent years. The initial researches were mainly based on modelling and theoretical analysis.

2.2.1Energy performance of photovoltaic-powered air conditioners

Simulation models were developed to compare five types of solar cooling systems and their performances throughout a year in a subtropical city that commonly features long, hot, and humid summers [9]. The solar cooling systems included solar electric compression refrigeration, solar mechanical compression refrigeration, solar absorption refrigeration, solar adsorption refrigeration, and solar solid desiccant cooling. The solar PV cooling system, the air side system, and the corresponding control provisions were built using TRNSYS and TESS. The schematic diagram of the PV cooling system is shown in Fig. 1.8.

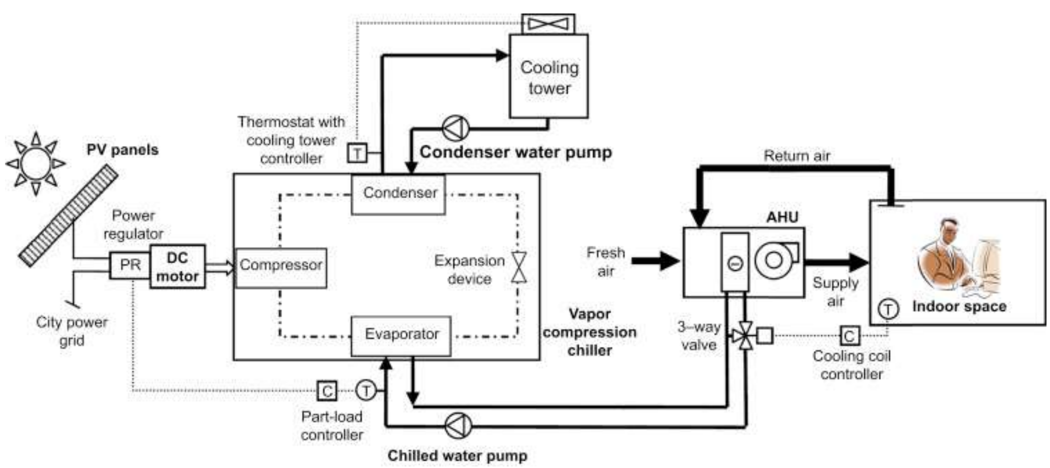


Figure 1.8. Schematic diagram of heating, ventilating, and air-conditioning system designed with PV cooling [9]. PV, photovoltaic; PR power regulator; DC, direct current; AHU, air handling unit; C, controller; T, temperature sensor.

A solar PV air-conditioner system was studied on the heating and cooling performance of the system in a hot summer and cold winter zone such as Shanghai, China . Four working modes have been investigated: cooling in summer and heating in winter, both for daytime and nighttime. Results are reported in terms of COPsolar based on solar radiation, SF, and the solar direct consumption ratio. It was found that the COPsolarfor cooling of the system was approximately 0.32, which is higher than a solar thermal-driven cooling machine, whereas the heating COP solar for heating was approximately 0.37, which is lower than the thermal efficiency of the conventional solar thermal collector. The energy losses in different devices of the system have been evaluated. This work has demonstrated that consistent and reliable air conditioning can be achieved by the present system in winter and in summer and thereby can be used as a good solution to reduce the peak load of the electrical grid in the hot summer and cold winter zone of China or the area with similar weather conditions around the world.

Solar photovoltaics are hampered by the lack of solar radiation during peak energy demand hours of the day and variation of solar radiation. The ability to shift the PV power curve and make the energy accessible during peak hours can be accomplished through pairing solar photovoltaics with energy storage technologies. A system of combining solar photovoltaics and ice thermal storage to operate conventional air-conditioning units has been developed . As shown in Fig. 1.9, the prototype system consists of PV panels, a DC compressor, glycol thermal storage (75-gal freezer filled with Cryogel balls, 1-qt oil containers, 12-oz bottles of water immersed in a weak glycol solution), two air handlers (a conventional 1-T HVAC air handler and a glycol air handler), and a power selector box.

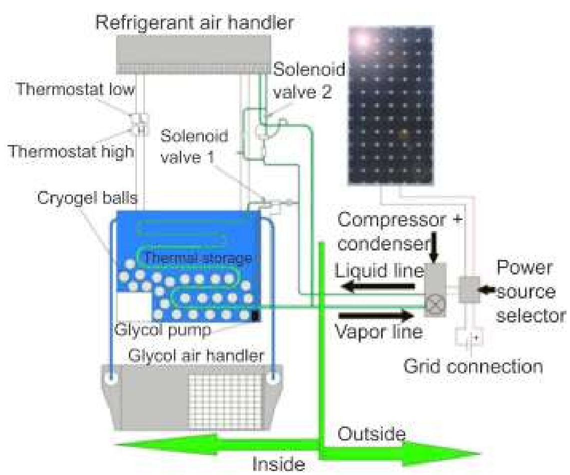


Figure 1.9. Prototype schematic of a solar photovoltaic air-conditioning system and ice thermal storage.

2.2.2 Economic evaluation of photovoltaic-powered air conditioner

To achieve a large-scale application PV air conditioner, the system must be reliable and cost-effective. A modelling comparison was made on a solar thermal-powered absorption chiller and a solar PV-driven cooling system that uses a vapor compression machine [10]. Both solar cooling systems are compared against a standard air-cooled cooling system that uses electricity from the grid. Results are presented in two figures. Each figure has one curve for the solar thermal cooling system and one for the solar PV cooling system. One figure allows estimation of savings calculated based the present value of the discounted energy consumption cost.

The other figure allows estimating primary energy consumption reduction and emissions reduction. Both figures present the result per ton of refrigeration and as a function of area of solar collectors and/or the area of the PV modules. It was declared that the approach to present the result of the simulations of the systems makes these figures general. This means that the results can be used to compare both solar cooling systems independent of the cooling demand (capacity of the system) and allow for the analysis for different sizes of the solar system used to harvest the solar energy (collectors or PV modules).

2.3 Conclusions

The refrigeration system is usually in small capacity and can be used as a cold chain in remote areas. Energy storage can be easily incorporated. The storage method can include cold storage or electricity storage. The control is simple. The system can be grid connected or grid independent.

There are different power capacities for PV-powered air-conditioning systems, from several kilowatts to several thousand kilowatts. For a large-capacity air-conditioning system, grid connection is preferred because of the fluctuation of PV electricity. Commercial products are already available on the market from the window type and split type to the variable refrigerant flow system in small and medium capacity and a central unit in large capacity. The design guides of the PV-powered air-conditioning system in different climate conditions are not available at the time of this writing. Reports on the operation experiences in different climate conditions are rare. More researches and demonstration projects are needed to improve its application and make it more cost-effective.

References

[1] Ruzhu Wang. Advances in Solar Heating and Cooling[C]. Ruzhu Wang and Tianshu Ge, 2016. 95-116

[2] Finocchiaro and Hestnes, 2011 L. Finocchiaro, A.G. Hestnes Symbiosis and mimesis in the built environment, aesthetics of sustainable architecture 010 Publishers, Netherlands (2011)

[3] Woss and Musall, 2011 K.E. Woss, E. Musall Net zero energy buildings Institute for Architectural Documentation, Detail Green Books, Munich (2011)

[4] Dahl, 2010 T. Dahl Climate and architecture Routledge, Oxon (2010), p. 69

[5] H.M. Henning Solar assisted air conditioning of buildings – an overview Appl Therm Eng, 27 (2007), pp. 1734–1749

[6] O. Tom, S.A. Omer, A.Z. Taha, A. Sayigh Performance of a photovoltaic solar refrigerator in tropical climate conditions Renew Energy, 1 (2) (1991), pp. 199–205

[7] T.A. Kattakayam, K. Srinivasan Thermal performance characterization of a photovoltaic driven domestic refrigerator Int J Refrig, 23 (2000), pp. 190–196

[8] G.M. Tina, A.D. Grasso Remote monitoring system for stand-alone photovoltaic power plants: the case study of a PV-powered outdoor refrigerator Energy Convers Manage, 78 (2014), pp. 862–871

[9] K.F. Fong, T.T. Chow, et al. Comparative study of different solar cooling systems for buildings in subtropical city Sol Energy, 84 (2) (2010), pp. 227–244

[10] [10] N. Fumo, V. Bortone, J.C. Zambrano Comparative analysis of solar thermal cooling and solar photovoltaic cooling systems J Sol Energy Eng, 135 (2013) 021002–021011

Session II: Design method of active solar energy technology

1. Roof-integrated PV

A PV system can be integrated into the roof in several ways. One choice is for the integrated system to be part of the external skin and therefore be part of an impermeable layer in the construction. In the early days of BIPV (1990s), several building projects were constructed on the basis of this principle. The other choice for roof mounting the PV system is above the impermeable layer. This is a more secure option but also not without some risk, as the impermeable layer has to be pierced in order to mount the system on the roof. Using PV modules as roof covering reduces the amount of building materials needed, which is very favourable for a sustainable building and can help reduce costs.

In addition to covering the complete roof with modules, there are also many products for small-scale use, for example, PV shingles and tiles. The small scale of these products (from 2 cells on a tile to around 20 cells on a look-alike tile) makes them very convenient for use in existing buildings or as do-it-yourself products.

(Semi) Transparent PV modules used as roofing materials serve as water and sun barriers and also transmit daylight. In glass-covered areas, such as sunrooms and atriums, sun protection on the roof is necessary in order to avoid overheating in summer. Transparent PV modules have the solar cells mounted between two transparent layers (mostly glass), while a certain distance has been kept between the different cells. The PV cells absorb 70-80% of the sun radiation. The space between the cells transmits enough diffused daylight to achieve a pleasant lighting level in the area. In order to increase the usage of daylight in the workplaces, transparent PV modules have been used instead of glass.

Of course, PV cells convert sunlight into electricity (with typical efficiencies of 6-20%) with the remainder of the solar energy being converted into heat. This residual heat can also be used to warm the building, for example, by designing an air cavity underneath the PV modules, through which warm air (heated by PV modules) is flowing. This hybrid collector provides warm air to the heating system in the home, which in this case, makes it a cost-effective use of the collector.

A relatively new application of PV combined with a thermal system is PVT: a PV module mounted on a solar thermal module. The residual heat is used to heat the water (or other liquid) in the thermal system. A demonstration project, which was financially supported by the European Commission, can be seen at the head offices of RES UK in Kings Langley, north of London (UK) (see Figure 1).

Fig. 2.1. PVT façade at RES UK in Kings Langley (UK). Photograph © Henk Kaan.

At the Netherlands Energy Research Foundation (ECN) in Petten (NL), Building 42 has a conservatory with 43 kWp BP solar roof-integrated transparent laminates that reduce light and sun transmission by around 70% as compared to glass. The conservatory therefore acts as a big parasol over the offices, protecting them from the sun while still providing enough daylight.

2. Façade-integrated PV

Façades are basically constructed using in situ bricklaying or concrete constructions, prefab elements, or structural metal façades that are mounted in place. Concrete constructions form the structural layer and are covered with insulation and a protective cladding. This cladding can be wood, metal sheets, panels, glass, or PV modules. For luxury office buildings, which often have expensive cladding, cladding with PV modules is not more expensive than other commonly used materials, for example, natural stone and expensive special glass. This cladding costs around \$ 1500 m^{-2}, which is considerably larger than the cost of the PV module today.

Structural glazing or structural façades are constructed using highly developed profile systems, which can be filled with all types of sheeting, such as glass or frameless PV modules.

The development of transparent modules has gone further in the last 10 years. In the semi-transparent modules from the 1990s, the space between cells and the light transmission through the tedlar back foil stipulated the amount of light that came through. Starting with the Sunways cells, a complete new generation of light-through cells have been developed like Schott ASI Glass and Suntech MSK's light-thru and see-thru cells that can be used in roofs and structural façades.

3. PV in building components

Façades are very suitable for all types of sunshading devices, louvres and canopies. There is a logical combination between shading a building in summer and producing electricity at the same time. Architects recognize this and many examples of PV shading systems can be seen around the world. A terrace with a roof on the sunny side of a building is a good place for BIPV systems thus providing shade, protection from rain, as well as electricity.

Session III: Application and analysis of solar energy technology in building

1. solar and building shading design

The core of the solar photovoltaic sun shading system is that the solar energy can be generated by solar radiation and the solar radiation is blocked at the same time, so as to achieve the energy saving effect. In this kind of sun shading system, the photovoltaic module is used directly in the roof and window shading. At the same time, the application of the building glass curtain wall with high energy consumption and poor thermal performance can solve the problem of high energy consumption in many buildings.

Solar thermal shading technology has much cheaper application cost and lower technical threshold than PV technology, so it has been widely applied. The core of solar thermal sun shading technology is to provide sunshade support to the building by absorbing and storing solar radiation through a variety of active or passive heat absorbing and thermal storage components. In the design of architects, the passive form of sun shading is preferred, so that the system can accumulate heat energy while building the sun shading day. Many designers also apply solar thermal storage systems or water heaters to shades of roofs and windows, as well as a case of a heat storage system on the west wall to prevent the sun from being exposed to the sun. It mainly uses the heat storage medium to absorb, store and transfer it to the building shady room or the house hot water system, in order to reduce the extra energy consumption produced by the building heating and heat energy application.

At the same time, with the development of science and technology, more technology in the field of solar energy is also applied to the building shading. In the process of building sun shading, architects are brave to try solar technology including lighting technology, other types of solar energy technology, solar ventilation technology and even the sun stove. The use of these technologies has made solar shading technology develop very well.

The two major components of solar sun shading system are both solar components and sun shading components, which are the most important factors that different geographical location and environment need to design. But in addition to this problem, solar modules also face such problems as the operation of the earth around the sun, the illumination environment and the form of sun shading components. And through the calculation, analysis and comparison of the model of the respective problems, the installation position of the solar sun shading system in different regions and different environment to cope with the unfavourable factors is also obtained.

The main design focuses on the position, inclination and orientation. But in the specific design, we need to combine this model with local conditions for comprehensive calculation and analysis, so as to propose a design strategy suitable for local conditions.

2. Solar energy and building ventilation design

2.1 Introduction of solar chimney

Natural ventilation is one of the significant sustainable building design strategies and has been known to mankind for several hundred years. One of the sustainable strategies for a building to reduce energy consumption is to enhance the natural ventilation in the surrounding spaces based on solar chimney. As a simple and practical strategy, it has been receiving considerable attention to decrease heat gain and induct natural ventilation (cooling or heating) in both residential and commercial buildings because of its potential advantages regarding operation cost, energy requirement and emission of carbon dioxide.

Solar chimney as a reliable renewable energy system has been largely utilized in buildings under the fact of serious environment problem and energy crises with the continued exploitation and overuse of fossil energy. This is because buildings can consume about 42% annual energy usage of the whole world, mainly for heating, cooling, providing electricity and air conditioning. Conventional heating and cooling systems have a great impact on the security of energy supply and greenhouse gas emissions.

Solar chimney is based on natural convective air movement forced by the pressure gradient caused by air density variation between indoor and inside the chimney cavity, acting as a natural ventilation system, passive heating method, or thermal insulation device. It is fundamentally a solar air heater with vertical or horizontal configuration as a part of wall or roof, while the classification of solar chimney can be varied according to different configurations or functions. It generates air movement under buoyancy forces that hot air rises and exits from the top of chimney cavity, drawing cooler air into building with continuous cycle.

A solar chimney house could reduce average daily electrical consumption of an air-conditioner, for example a study stated a reduction rate of about 10–20% in Thailand. The air temperature in a room can also be reduced about 8.5 °C averagely after utilizing solar chimney. Although it could add 0–15% cost to the design and construction of the building, paying this cost in return is a life-long energy saving. Due to the natural ventilation induced by solar chimney, the daily fan shaft requirement in a house located in Tokyo can be reduced by 90% in January and February with a 1 m wide solar chimney, while the reduction throughout the year was obtained of about 50%.

Now the main challenge of designing a solar chimney is to optimize its performance with the lowest cost. However, one can find a large amount of variations in solar chimney design . Therefore, in this study, thirteen key influencing factors were obtained based on literature review which can be classified into four groups, including configuration (height, cavity gap, inlet and outlet areas, and height/gap ratio), installation conditions (inclination angle, opening of the room, and solar collector), material usages (type of glazing, materials of solar absorber, and thermal insulation), and environment (solar radiation, external wind and other climatic conditions).

Besides the solar chimney mentioned above, there is another type of solar chimney, which follows the same principles and is called solar chimney power plant, standing independently as a system for big-scale usage. This literature review will focus on the first type, namely solar chimney attached to a building. The objective of this literature review is to identify key influencing factors and address their influences on the solar chimney performance, and eventually to provide a technical guide for its design in buildings.

2.2 Types of solar chimney

Solar chimney is an approach to enhance the natural ventilation in buildings based on passive solar energy. The basic driving mechanism of the air flow inside chimney cavity is thermal buoyancy, which is caused by air density variation under temperature gradient between the inside room and chimney cavity.(Fig. 3.1)shows the typical solar chimneys used in buildings. It should be noticed that solar chimneys coupled with other systems were not included. It can be seen that three categories can be found, implemented in wall, roof and window. The tree categories are: (1) Trombe wall; (2) roof solar chimney; and (3) combined solar chimney.

Fig. 3.1(a) shows a schematic of Trombe wall (Category 1) for winter heating. It is constructed by external glazing and internal storage wall. The external glazing allows solar radiation penetrating into chimney cavity for heating purpose. Air in the cavity then moves upward under thermal buoyancy. The air enters the room under buoyancy drive through top opening. Opening at bottom left keeps open to benefit air exchange with outside environment, while the one at bottom right is for air exchange with inside room. Trombe wall can also be applied to summer cooling after changing the location of openings, and its structure is similar to that of Fig. 3.1(c). Under this circumstance, hot air in the room can exhaust to outside environment through the chimney. An innovative design of Trombe wall is to use phase change materials (PCM) to keep the latent heat of a storage wall, which require less space and are lighter in weight when comparing to those mass walls .

Based on Trombe wall, a composite Trombe-Michel wall was also developed, shown in Fig. 3.1(b). It was designed to overcome heat losses from the inside room. Due to its structure, it can only be applied for winter cooling. One of its disadvantages is that it cools the building when it actually needs to heat it up during night or winter when the storage wall becomes colder than the indoor air. To overcome the disadvantage, relevant materials such as PCM could be used to keep the heat for later usage during non-sunny days, winters or at nights. Different from the Trombe wall, movable air in the chimney cavity is not heated by direct solar radiation, but the convection processes between the internal air and the massive wall.

A glazed solar chimney wall can be utilized under tropical climatic conditions, as shown in Fig. 3.1(c). It consists of double glass panels with an air layer and openings located at the bottom (room side glass panel) and at the top (ambient side glass panel). The basic mechanism of the glazed solar chimney wall is the same with the Trombe wall. Its performance in tropical area is confirmed by experiment that it can reduce heat gain through glass walls into the house by developing air circulation. However, as the performance of a solar chimney is much dependent on its height and width, its applications under other climatic conditions may be hampered because of weak performance due to limited size.

Fig. 3.1(d) shows a typical roof solar chimney (Category 2). As the performance of a solar chimney is much dependent on the temperature difference, a solar air heater (collector) at the roof is used to maximize the temperature difference. A glazing is used externally to heat the air in the cavity by absorbing solar radiation. A thermal storage layer below the chimney cavity is to extend heating period for late usage such as during cloudy day or night. An insulation layer at the bottom is to minimize the heat loss from storage layer. It should be noticed that this kind of roof solar chimney can be inclined (Fig. 3.1(d)) or vertical (Fig. 3.1(e)), depending on implementations. Comparing to the Trombe wall, air flow in roof solar chimney encounter further resistance because of additional bends of duct.

Fig. 3.1(e) shows a vertical roof solar chimney. Its difference from conventional roof solar chimney is an extra vertical chimney utilized as an inlet. Both inlet and outlet are realized through two chimneys coupled with roof; where one collects solar radiation and the other is a conventional chimney for inlet. Alternatively, the inlet (or opening) of room can be in a form of window, door or the like on the other side. This roof solar chimney may be applicable to some special situations. Its challenge is to circulate the whole room as short circulation (or partial ventilation at the top of the room) may happen when both the inlet and outlet are located at the same height.

Solar chimney shown in Fig. 3.1(f) is a combined solar chimney (Category 3) including both vertical and roof chimneys. Vertical solar collector is located above roof, and ducts are collected along the wall and roof. Air inside the room can exhaust to outside directly through the top vertical solar collector, or through the ducts and then to the solar collector. Opening to supply fresh air from outside is on one side of the wall, shown in the middle of the figure. The performance is dependent on the temperature difference which the vertical solar collector can produce, relying on its size and materials usage. Similar to other roof solar chimney, reducing the resistance caused by the bended duct is still one of the main challenges

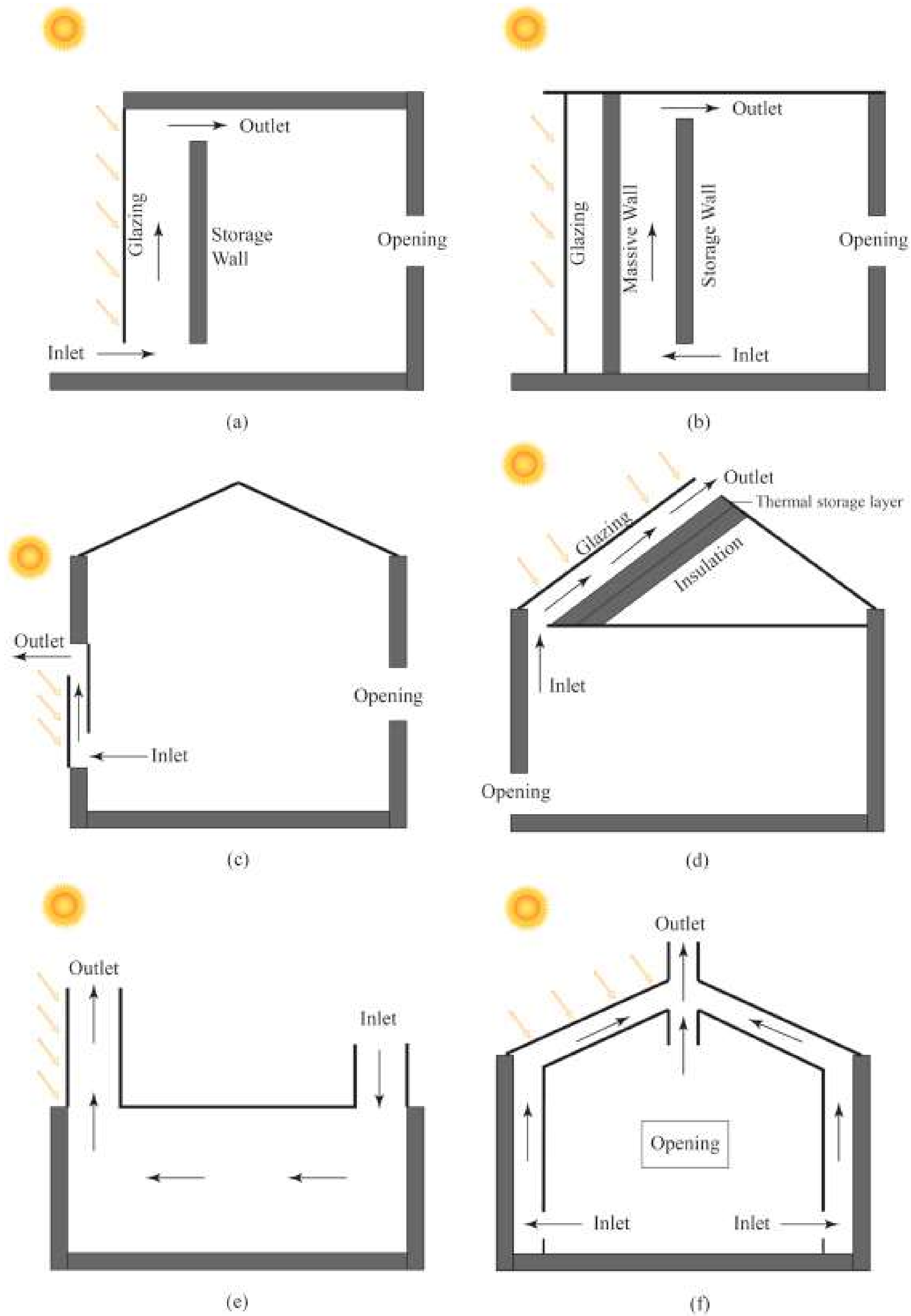


Fig. 3.1. Typical solar chimneys used in building. Category 1 is the Trombe wall which includes (a), (b), and (c); Category 2 is the roof solar chimney shown in (d) and (e); and Category 3 is the combined solar chimney represented by (f).

References

[1] Shi L, Zhang G, Yang W, et al. Determining the influencing factors on the performance of solar chimney in buildings[J]. Renewable & Sustainable Energy Reviews, 2018, 88:223-238.

[2] D.S. Lee, T.C. Hung, J.R. Lin, J. Zhao Experimental investigations on solar chimney for optimal heat collection to be utilized in organic Rankine cycle Appl Energy, 154 (2015), pp. 651-662

[3] Z.B. Liu, L. Zhang, G.C. Gong, H.X. Li, G.F. Tang Review of solar thermoelectric cooling technologies for use in zero energy buildings Energy Build, 102 (2015), pp. 207-216

[4] C.O. Okoye, O. Taylan Performance analysis of a solar chimney power plant for rural areas in Nigeria Renew Energy, 104 (2017), pp. 96-108

[5] A.B. Kasaeian, S. Molana, K. Rahmani, D. Wen A review on solar chimney systems Renew Sustain Energy Rev, 67 (2017), pp. 954-987

Session IV: Solar building computer aided design software

1. Computer aided design software for passive solar room

The design of passive solar houses need to analyse structures around the climate and environment, such as meteorological data analysis, sunshine analysis, the thermal calculation of retaining structure, the indoor thermal environment simulation and analysis of energy consumption, etc.

The process of building physical principle and mathematical calculation is more complicated and the efficiency is lower in the process of commercial operation. With the development of computer simulation technology, it provides designers with easy-to-use data graphs and comparison schemes, thus simplifying the tedious process of passive house optimization design.

At present, the auxiliary design software mainly includes weather analysis software, building thermal environment analysis software, design soft passive solar house special parts.

1.1 PDA（Passive Design Assistant）

Passive Design Assistant Introduction and Getting Started The Passive Design Assistant (PDA) is a software tool designed to elucidate the principles of passive thermal design of buildings to non-specialists. This tool has been developed by Arup in collaboration with The Concrete Centre and AHMM Architects. The target audiences for the tool are architects and other professionals and stakeholders involved in the design process who do not have specialist knowledge of building physics and who would not normally use thermal simulation software. A key objective is that the software has a simple and intuitive user interface that enables the user to understand the influence of the key design parameters. It is intended that the software could be used to inform early design stage decisions and, more generally, as an educative tool to communicate the principles of building physics. The tool could also be used to 'sanity check' the results of more complex thermal simulation models. An additional impact may be to influence the shape of future modelling tools used for Building Regulations compliance, which currently have a fairly crude representation of the building physics important for passive design. The purpose of this manual is to describe how to use the PDA, not to repeat the well-established underlying theory.

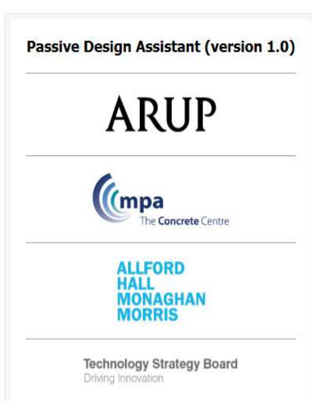


Fig. 4.1.The Passive Design Assistant (version 1.0)

Features specific to the PDA will be described in the following sections. A PDA file is called a project. Project level functions such as creating new, opening, saving and closing are available through the project tab. Projects consists of one or more cases. Clicking the Help button in project tab or pressing the F1 key whilst the PDA application is in use will load this help file. (Fig. 4.2).

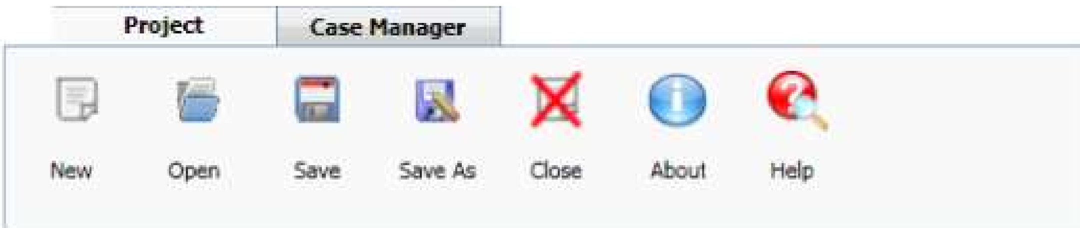


Fig. 4.2.The project table

The PDA allows creation of multiple cases which is useful for running parametric studies. For example, multiple cases can be created to examine the effects of different wall constructions or window shades on the temperatures or heating/cooling loads on a space. The case manager window lists the cases available in the current project. Note that a new project will have no cases defined and the case Manager will be empty. (Fig. 4.3).

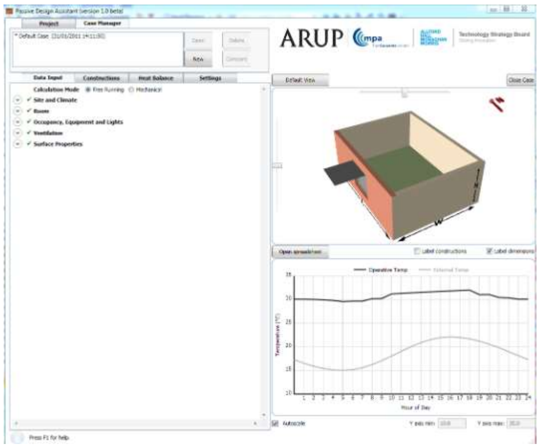
Fig. 4.3.The case manager tab

The case data form consists of several tabbed pages (described below) used to enter or view input data and two viewers which (by default) show a 3D depiction of the geometry and the main results (space temperature or heating/cooling loads). Clicking Close Case will close this case data form. (Fig. 4.4).

The data input tab consists of a number of expanders which can be expanded or collapsed by clicking on the arrow to show or hide various data input fields. (Fig. 4.5).

Passive Design Assistant Constructions that have already been assigned to surfaces may be edited and the effect on the results observed, e.g. the effect of varying the U-Value of the construction that has been assigned to all the external walls can be observed. (Fig. 4.6).

The results of up to four cases can be compared. Use the ctrl button to select multiple cases from the case manager list and click the compare button. (Fig. 4.7).



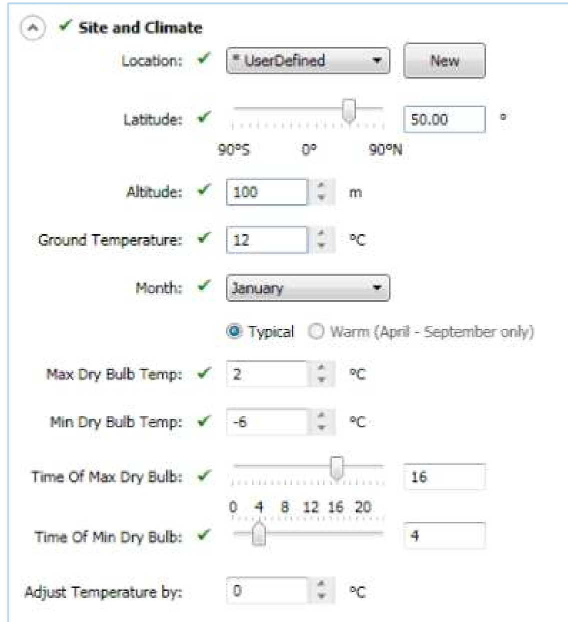
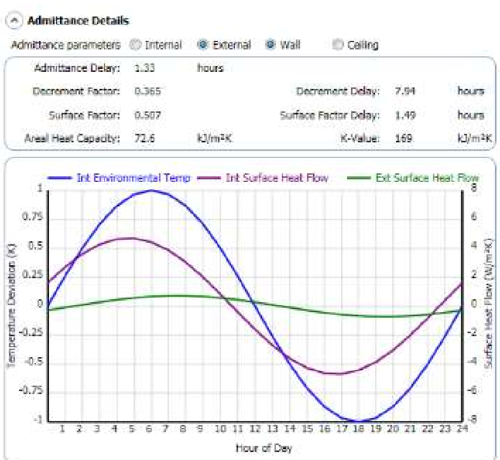


Fig. 4.4.The case data

Fig. 4.5.The data input tab



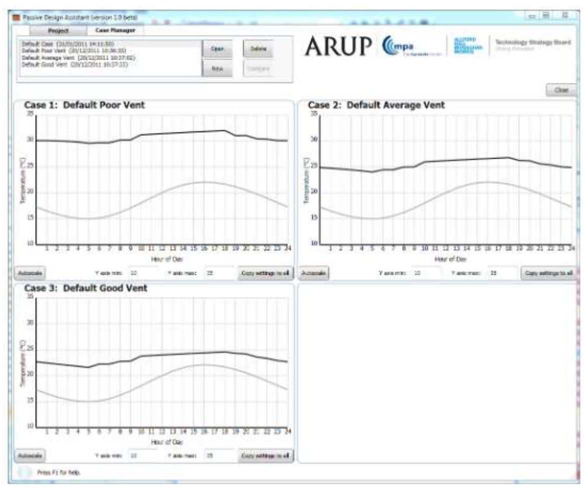


Fig. 4.6.The Constructions

Fig. 4.7.The compare button

1.2 PHPP (Passive House Planning Package)

The PHPP is an easy to use planning tool for energy efficiency for the use of architects and planning experts. PHPP is a software for energy consumption developed in Europe. It was first introduced in 1988 and it has been widely used in the design and calculation of passive solar houses. The core principles of PHPP software are balance the heat gain and loss. As the main calculation and analysis object of the thermal and thermal factors in the building, the software is used to calculate the corresponding detailed control options.

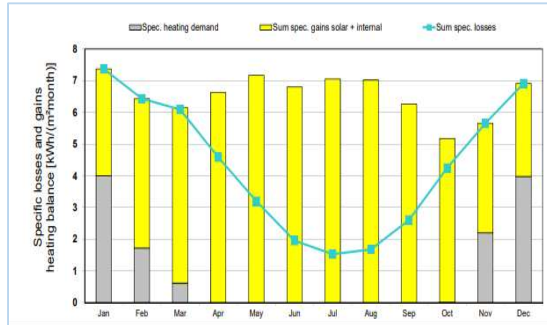


Fig. 4.8.The Passive House Planning Package   Fig. 4.9. The output chart

The main functions are as follows:

1. Verification in accordance with the international EnerPHit criteria for modernisation of buildings

The international EnerPHit criteria make it possible to specify minimum quality standards for the relevant building components in a refurbishment project depending on the location. In addition, the requirements with reference to the cooling and dehumidification demands can be determined depending on the use-related internal loads and the climate prevailing at the location.

2. Management of different design variants or refurbishment steps

The PHPP 9 enables input of efficiency parameters for different variants into a single PHPP file. The results for the variants are entered sorted in columns and are calculated in parallel so that the effects of these parameters can be compared easily.

In this way, different steps of a refurbishment can also be input into a single PHPP file. This makes it possible to depict the improvement in efficiency resulting from each individual refurbishment step and to enter and assess projects with a long-term strategy in a convenient manner.

3. Comparison of economic feasibility between selected planning variants

Economic feasibility comparisons of different variants can be carried out in a separate worksheet. Besides information about the financial boundary conditions, it is also possible to specify whether the economic feasibility comparison should be performed for the entire building or only relating to individual components.

4. Data input assistance by means of error messages, warnings and plausibility checks

The message function for incorrect or missing data input has been systematically reviewed. All messages have now been compiled in a new worksheet prepared for this purpose. In this way users can receive clear information regarding the places where incorrect, or incomplete or implausible data has been entered and needs rechecking or reviewing.

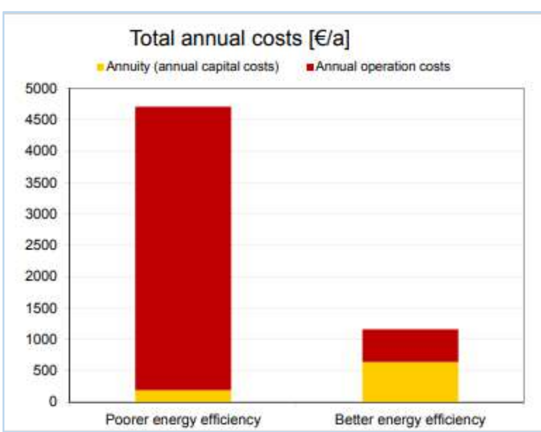
5. Extended input options for losses from heating and hot water distribution networks

The input options for calculation of distribution losses of heating or hot water pipes have been extended considerably. Besides the possibility of entering several pipe systems, it is now also possible to take into account heat recovery systems for shower water. The hot water demand can alternatively be assessed in detail in order to ascertain further potentials for saving energy for example based on the use of flow-optimised fittings.

6. Implementation of evaluation method according to the PER factor classification system

During the course of their service life, buildings being planned today will be supplied with renewable energy to an increasing extent. This fact has already been taken into account in the PHPP 9: as an alternative to the evaluation method used previously, which was based on the non-renewable primary energy factors (PE factors), buildings can now be assessed according to the new system for renewable primary energy (PER / Primary Energy Renewable).

Passive house buildings and energy efficient projects which are carefully planned using the PHPP have proven successful. Whether new builds or retrofits, building projects that achieve the Passive House or EnerPHit Standards meet the level of comfort and the extremely low energy demand being strived for. Moreover, in most cases they can also be realised cost effectively and profitably. Significant deviations of energy consumptions from the planned energy efficiency targets, often described as the "performance gap", do not occur in Passive House buildings and EnerPHit retrofits which have been planned and quality assured, as has been confirmed by numerous measurement monitored projects. The effectiveness of the dimensioning procedure for systems of building services has also proved effective, and enables the use of simple well-coordinated components and thus the implementation of cost effective efficiency products. In addition to the application of the Passive House concept and Passive House technologies, the use of the PHPP as a planning tool remains to be the most important basis for the implementation of sustainable building concepts.



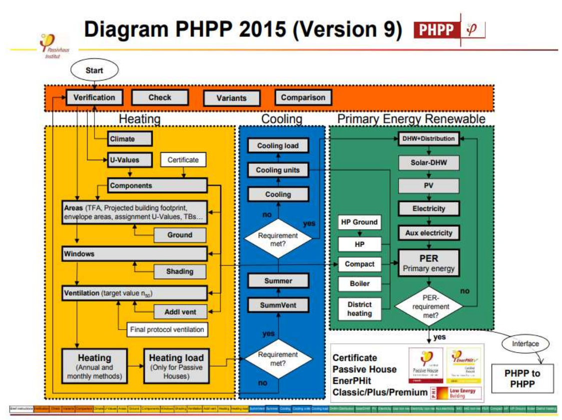


Fig. 4.10.The economic feasibility comparison **Fig. 4.11.The PHPP illustrated**

2. Computer aided design software for solar hot water system

The software with high frequency in the design of solar hot water system has f-chart, RETScreen, TRANSOL and Polysun.

Fig. 4.12.Computer aided design software for solar hot water system

2.1 Polysun

Ploysun is developed by the Swiss solar hot water testing center (SPF), which has a high degree of international recognition. Designers use Polysun solar water heating system to run simulation in solar hot water project scheme design phase, thus improving the specific direction of solar hot water system and completing system optimization step by step.

The version is divided into a simple version, a professional version and a design version, which covers the most comprehensive system templates and allows users to create their own solar water heating system.

The operation is simple, as follows.

1) Create a plan: Polysun recorded every construction project detailed engineering information, including name, location, and site photos, the user can be obtained by map longitude and latitude of the project, and call the meteorological data of 8000 meteorological stations around the world, and match the project site.

2) Select solar hot water system: Polysun's system template library covers the system types commonly used in solar hot water.

3) The editor: solar water heating system of hot water load on the chosen solar hot water system, Polysun requirements for information we will further improve the numerical simulation, such as

people use hot water, hot water temperature, hot water use in demand or demand, and the use of the time characteristics of hot water, etc.

4) Define the parts of the system: Polysun can be set to the parts of the system to further refinement, such as the types of collector, collector towards and obliquity, collector area, solar energy, reliability, water storage tank solvent, auxiliary heat source type, etc., in order to make Polysun solar hot water system model is established more close to the actual project situation, to ensure the accuracy of simulation calculation.

5) Obtained simulation results: Polysun used transient simulation calculation for solar water hot water system to simulate the operation status of solar hot water system in hours and provide effective data support. Polysun uses the climate parameters which are the average value in recent years, so the simulation data is very reliable.

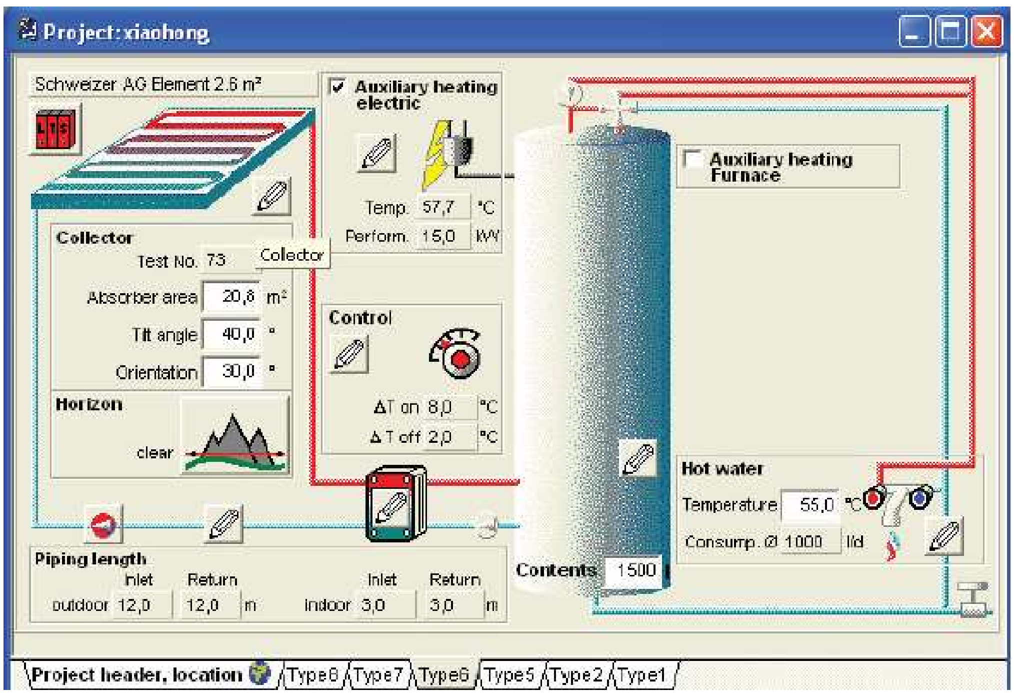


Fig. 4.13. Select solar hot water system

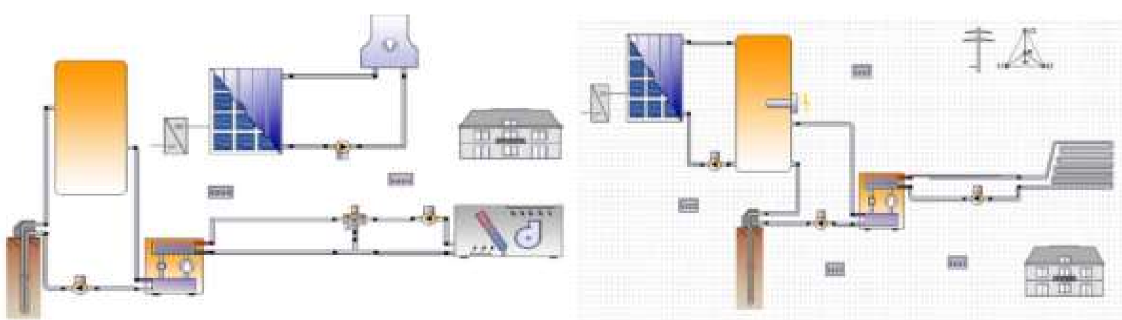


Fig. 4.14 The simulation model was established by Polysun

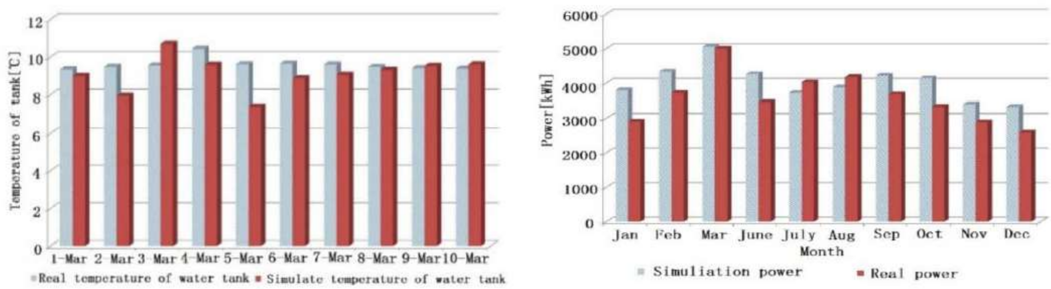


Fig. 4.15.Obtained simulation results

2.2 RETScreen

RETScreen is a software program developed by Natural Resource Canada and available for public use for feasibility analysis of clean energy projects, including energy-efficient technologies and renewable energy systems, such as wind energy, small hydro, photovoltaic, biomass heating, solar air heating, solar water heating, passive solar heating, ground-source heat pump, and combined heat and power projects. The software has been developed in the Microsoft® Excel program. Users can select each technology project according to the purpose of their feasibility study. Each technology project has a standard procedure with the same five-step analysis of the energy model: cost analysis, greenhouse gas (GHG) analysis, financial summary, and sensitivity and risk analyses. Fig. 1 shows the five-step standard project analysis in the RETScreen model flow chart. Each of the five steps in the standard procedure is associated with one or more Excel worksheets.

In the Energy Model worksheet and sub-worksheets, parameters are used to describe the location of the project, the type of systems for the base and proposed cases, the loads such as heating, cooling, and electrical loads, and the renewable energy resources. The annual energy production or savings are calculated in the same sheet. The algorithm associated with each technology is described in the RETScreen textbook and their performance has been validated. In the cost-analysis worksheet, the users input the initial costs, and annual or periodic maintenance costs for the proposed case system. The annual reduction in greenhouse gas emissions is calculated in the GHG-analysis worksheet. In the financial-summary worksheet, the users can specify financial parameters such as inflation rate, discount rate, incentives and so on to calculate various financial indicators of the net present value (NPV), etc. The sensitivity and risk analysis worksheet helps the users to determine the uncertainty in estimates of various key parameters used in the project. To evaluate the performance of the optimal sizing approach using RETScreen, TRNSYS simulation tool has been employed to compare the estimated annual solar fraction.

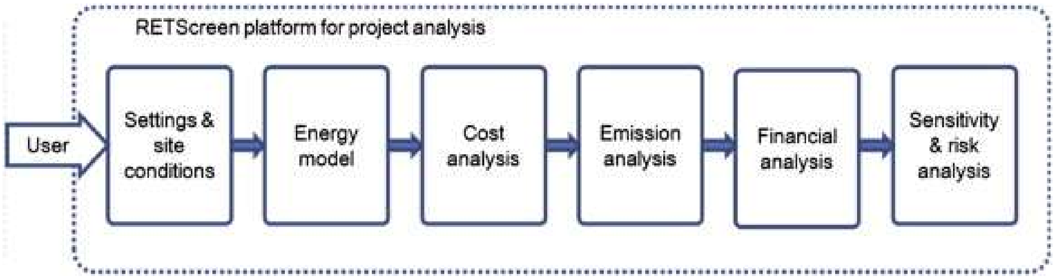


Fig. 4.16.RETScreen software model flow chart: a five-step standard analysis.

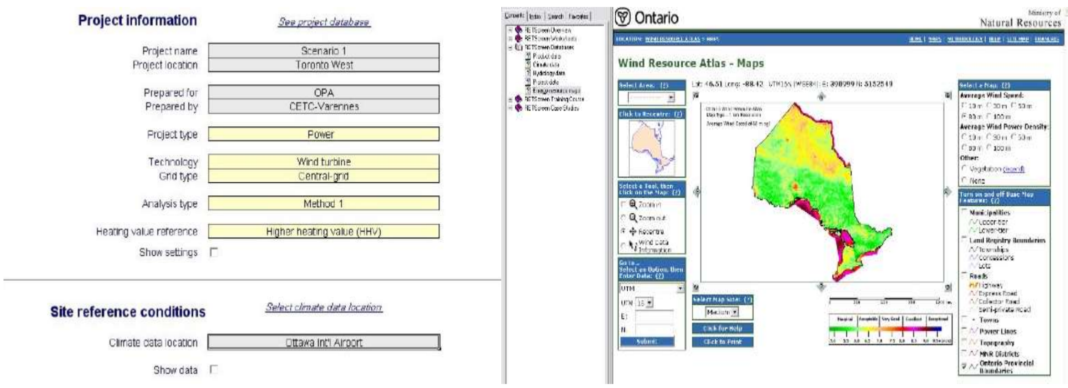


Fig. 4.17.RETScreen design case

3. Computer aided design software for PV architecture

More common PV architecture design auxiliary software includes PVSYST,PV*SOL, PV Designer, Solar Pro, etc.

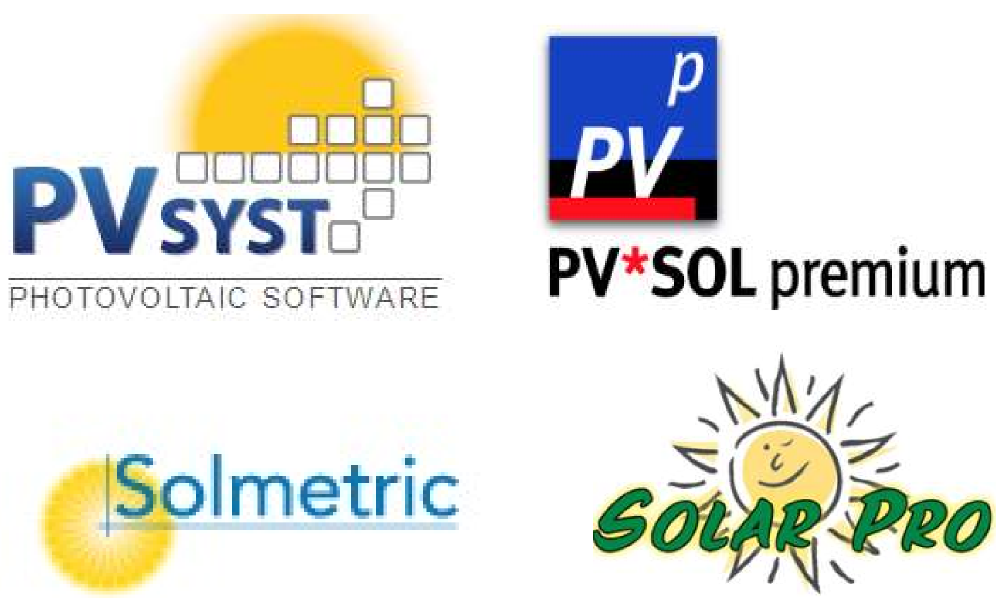


Fig. 4.18.Computer aided design software for PV architecture

3.1 PVSYST

PVSYST is a photovoltaic system design auxiliary software, which is used to guide photovoltaic system design and to simulate the power generation of photovoltaic system.

The main functions are as follows:

1. Set the type of photovoltaic system: grid type, independent type, photovoltaic water pump, etc.

2. Set the configuration parameters of pv modules: fixed mode, pv array inclination Angle, row spacing, azimuth and so on.

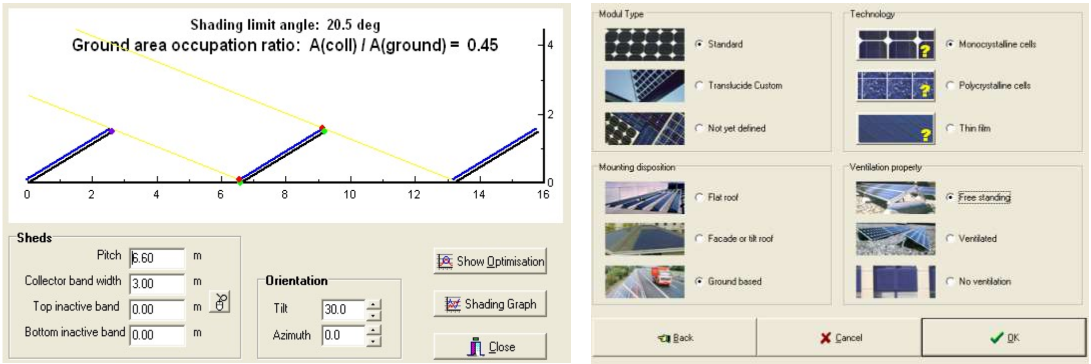
3. The influence of architectural building on shading influence of photovoltaic system, calculation of shading time and shading ratio.

4. Simulate the power generation and system generation efficiency of different types of photovoltaic systems.

5. Study the environmental parameters of photovoltaic system.

Fig. 4.19.The new case tab

In preliminary design stage, PVSYST according to photovoltaic modules available installation area, types of photovoltaic cells, photovoltaic cells, photovoltaic panels transparency ventilation types such as basic data, rough month for photovoltaic system capacity and system cost estimation, according to the result of software simulation optimization is set at the same time, make the system achieve the goal of large capacity and small radiation loss.



	Gl. horiz. kWh/m2.day	Coll. Plane kWh/m2.day	Shed shading kWh/m2.day	System output kWh/day	System output kWh
Jan.	2.42	4.27	4.17	3464	107388
Feb.	3.35	5.01	4.93	4094	114642
Mar.	4.68	6.02	5.93	4920	152507
Apr.	6.00	6.61	6.49	5391	161729
May	6.57	6.48	6.35	5273	163465
June	6.51	6.11	5.98	4963	148891
July	6.05	5.78	5.65	4691	145430
Aug.	5.30	5.46	5.35	4442	137689
Sep.	4.72	5.57	5.47	4540	136190
Oct.	3.67	5.11	5.03	4175	129435
Nov.	2.61	4.33	4.25	3527	105804
Dec.	2.10	3.88	3.77	3127	96930
Year	4.50	5.39	5.28	4384	1600100

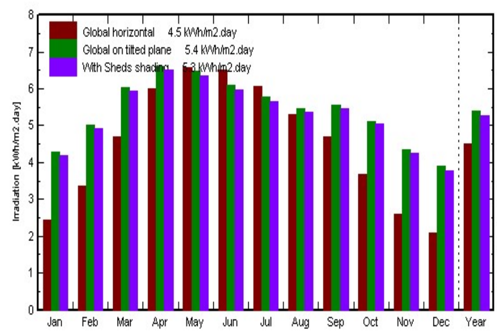


Fig. 4.20.The preliminary design case

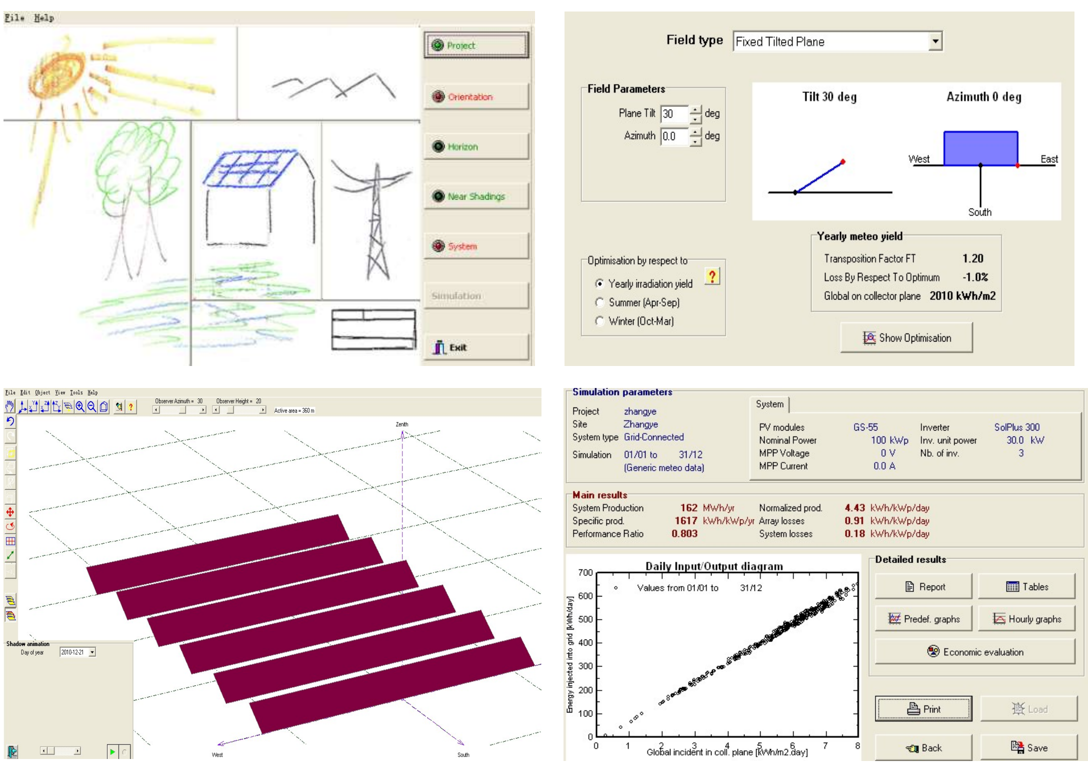


Fig. 4.21.The detailed design case

In the detailed design stage of the project, PVSYST can simulate the photovoltaic system in hours and obtain more accurate and reliable results. At this stage designers need to provide photovoltaic system parameters, including geographical information, project location and spacing of the front of photovoltaic modules, dip, the number of the pv array and the connection way, obstructions around the pv system, pv systems of inverter and controller information, photovoltaic component prices, related accessories, etc. In practice, PVSYST can also based on 3d modeling technology, building or light man array of photovoltaic system around the block, the year's shadow analysis, to determine the optimal installation position of building photovoltaic panels.

3.2 PV * SOL

PV * SOL is dedicated to design and calculation of the PV system software. It also be used to help designers complete photovoltaic building integrated design of the system simulation and analysis, and it guides the designer to obtain the most optimized PV system design.

A real-world representation of the shading from surrounding objects is extremely important for precisely calculating yields. PV*SOL Expert does just that. You can visualize all roof-integrated or mounted systems-even on the ground-with up to 2,000 modules in 3D and calculate shading on the basis of 3D objects.

Fig. 4.22The PV*SOL simulation

The user-friendly 3D menu navigation is divided into the five sections of terrain view, building view, module coverage, module mounting and module configuration. Simply select possible shading objects and position them on the terrain or the building. PV*SOL Expert then calculates how often on average the modules are shadowed by the objects and displays the result in graphical form. The visualization in 3D mode provides with detailed information on shadows cast at various times of the day and year and consequently on likely reductions in yield.

Fig. 4.23 Parameter design

References

[1] http://docplayer.net/33833630-Passive-design-assistant-pda-version-1-0.html

[2] http://www.passiv.de/en/04_phpp/04_phpp.htm

[3] http://www.velasolaris.com/

[4] http://www.pvsyst.com/1

Session V: Case study of solar buildings

This chapter gives a brief introduction to the famous solar buildings in the APEC economy, including Solar Ark in Japan, Chicago Solar Tower in the US, Sun Moon Altar Building in China, National Stadium (Kaohsiung) in Chinese Taipei and Solar Supertrees in Singapore.

1. Solar Ark in Japan

The Solar Ark is an ark-shaped solar photovoltaic power generation facility which offers activities to cultivate a better appreciation of solar power generation, and thereby benefitting both ecology and science. This 315-meter-wide, 37-meter-tall facility is located in Anpachi, Gifu Prefecture, in the geographical center of Japan, and can be seen from the JR Tōkaidō bullet train, which runs past on an adjacent railway. It has over 5000 panels that produce approximately 530,000 kilowatt-hours on an annual basis and a maximum system power of 630 kilowatts.

Stationed at the center of the Solar Ark is the Solar Lab, a museum of solar energy. A hands-on, outdoor light exhibition was planned for opening in 2005. The Solar Ark was an enterprise partner with the 2005 World Exhibition, Aichi Prefecture, Japan. It is one of the largest solar buildings in the world.

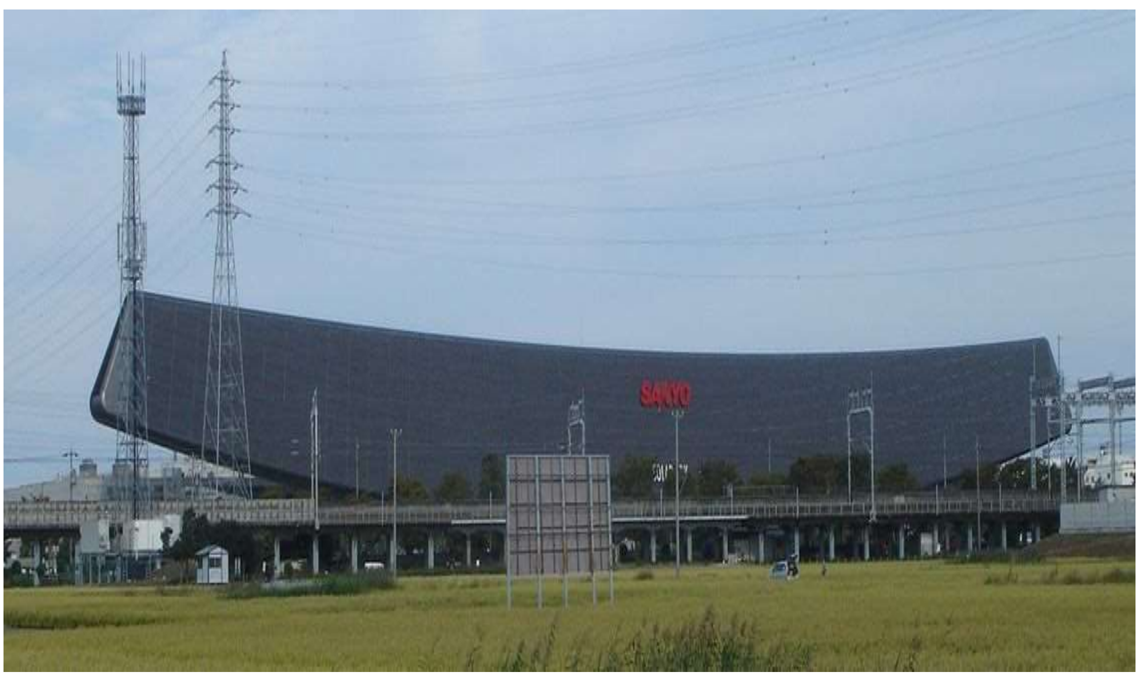


Fig. 5.1. The Solar Ark inside Sanyo Electric Co., Ltd. Gifu Plant

(Source: https://en.wikipedia.org/wiki/Solar_Ark#/media/File:Solar_Ark.jpg)

1.1 History of Solar Ark

The Solar Ark was constructed by Sanyo Electric Co. Its development was accidental among other things. Initially, Sanyo Electric had intended to create the largest photovoltaic system in the world, with a 3.4 megawatt output, to mark the organisation's 50th anniversary. By 1998, designers had already been in discussions about the Solar Ark's appearance. Sanyo had planned on using cutting edge solar technology available to them at the time, using a combination of crystal silicon and thin-film amorphous silicon with 14-15% efficiency. However, during the initial planning, Sanyo had to recall several monocrystalline cells, which were the predecessors of the hybrid technology mentioned before, due to insufficient output.

Sanyo Electric Co. still decided to go ahead with the Solar Ark's construction; however, instead of using the previously planned technology, Sanyo instead, used the recalled monocrystalline cells. Sanyo says "We have done this to show our sincere regret that this problem has occurred and to express our willingness and determination to both remember what happened and how important it is to maintain quality." Construction was completed in December 2001.

Panasonic acquired Sanyo, and as part of its corporate restructuring and re-branding strategy, the red Sanyo logo on the Solar Ark was replaced with a blue Panasonic logo in August 2011.

1.2 Design of Solar Ark

The Solar Ark's design was inspired by the vision of an ark embarking on a journey to the 21st century. This idea led to the Solar Ark's size and overall symbolic shape of being an example of producing clean energy. In total, the construction area for the Solar Ark is 3294.48 m2 reinforced concrete was used for the base of the construction. From one end to the other, the total length of the Solar Ark is 315 metres. The ark is 31.6 metres tall from the centre of the structure. There are 5,046 solar panels in total. Twelve single-crystal silicon solar cell modules per unit were assembled on the ground, and 470 units were lifted up and attached to the main body of the Solar Ark.

The weight of the actual body of the ark (pillars being excluded) is 3,000 metric tonnes and is constructed from structural steel, which is about two times stronger than normal steel and is comparatively thinner than steel. This construction material helps give the impression of the solar ark being suspended in the air. Each column is 2 metres in diameter and 31 meters in length and the Solar Ark is 315 metres long. The entire Solar Ark chassis is supported by four "G-Columns" which are custom built pillars by Kubota and in total, these pillars weigh approximately 5,000 tonnes. These high-quality pillars are homogeneous, the result of the seamless method of construction that utilizes centrifugal force. Due to the Solar Ark's sturdy building materials, the Ark is able to resist winds of up to 34 meters/second and level 7 earthquakes on the Japanese scale[1].

The ark is surrounded by 5-meter high water fountains and two ponds, each having their own cascade. The entrance to the Solar Ark has solar wings which are composed of HIT solar cells that generate electricity on the topside and underside while also functioning as awnings that allow sunlight to filter through. Between the individual solar panels, there are, in total, 75,000 red, green, and blue computer controlled LEDs which are activated at night to produce images and words across the ark.

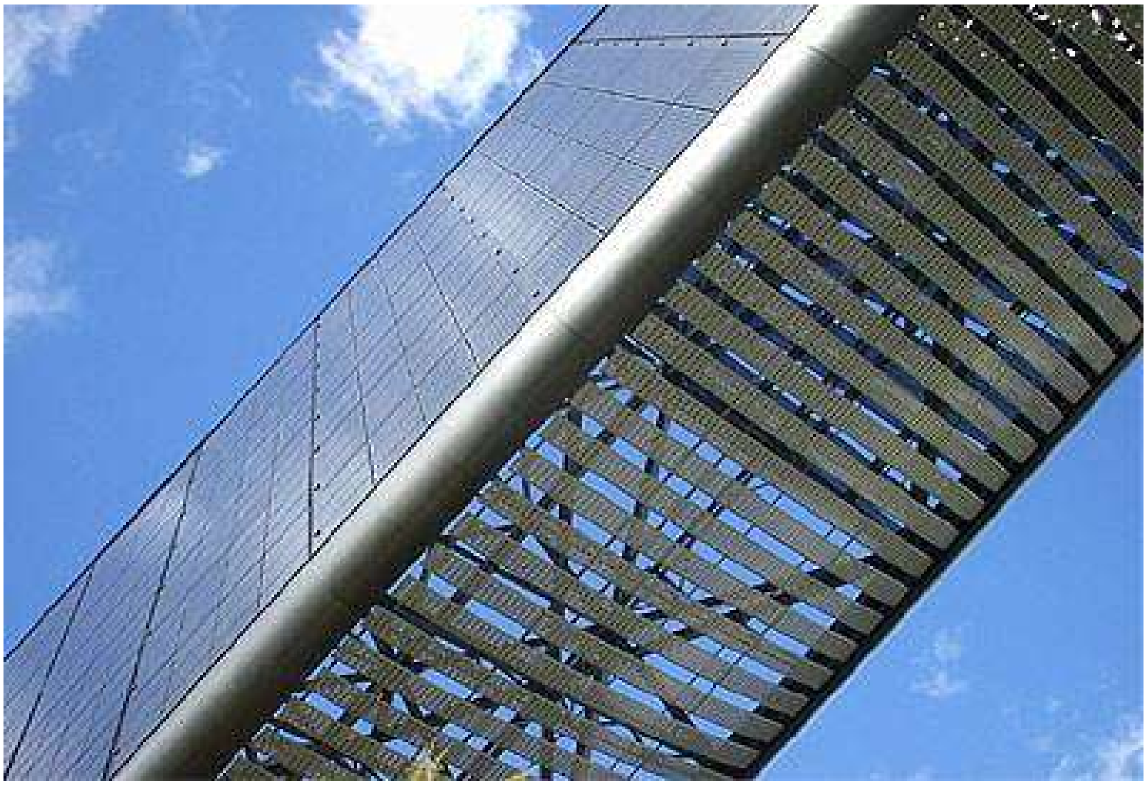


Fig. 5.2. The Solar Ark inside Sanyo Electric Co., Ltd. Gifu Plant

(Source: https://en.wikipedia.org/wiki/Solar_Ark#/media/File:Solar_Ark.jpg)

2. Chicago Solar Tower in the US

The proposed Solar Tower for Chicago by Zoka Zola Architects features an active solar array mounted to the facade which maximizes solar gain throughout the day. The spherically based design takes advantage of the large surface of a building by mounting the panels on the vertical plane. By incorporating tracking arms that the solar units mount to, summer electrical production can be improved by as much as 40% compared to a static mounted solar array, and even more compared to traditional vertically mounted solar facades. The array's full potential is then realized, creating the greatest kWhrs production per square foot of any design. Wind pressure exerted on the solar panel holding mechanisms can be converted into energy.

Fig. 5.3. The Solar Tower for Chicago by Zoka Zola Architects

(Source: http://www.evolo.us/architecture/chicago-solar-tower-zoka-zola-architecture/)

The spherical panels are mounted in such a way as to maintain views for the interior but to reduce heat gain. This results in a minimized dependency on a cooling plant. The panels are evident from the interiors of the tower to emulate the technology. The siting of the tower will have a dramatic effect on its power production-being isolated or adjacent to a southerly body of water or park is preferable. The entire building will have a kinetic profile raising onlooker's awareness of renewable onsite energy production and sustainable urban design.

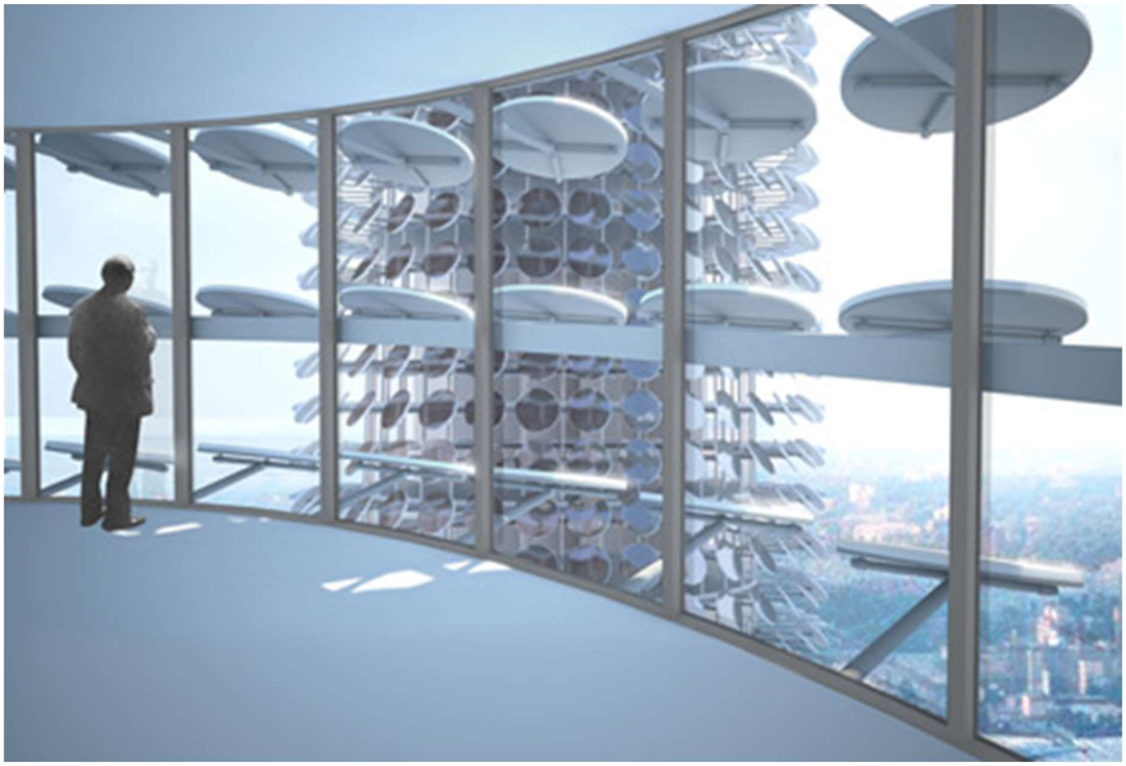


Fig. 5.4. Solar Tower seen from a second solar tower

(Source: http://www.zokazola.com/solar_tower.html)

Fig. 5.5. The Solar Tower for Chicago by Zoka Zola Architects

(Source: http://www.evolo.us/architecture/chicago-solar-tower-zoka-zola-architecture/)

3. Sun Moon Altar Building in China

The “Sun Moon Altar - Micro-arrangement Building” under the night sky and micro-arrangement building set showcases, scientific research, office work, conferences, training, hotels, entertainment and other functions. The world’s first-ever realization of solar hot water supply and heating , cooling, photovoltaic grid-connected power generation and other technologies and constructions are the perfect combination of building energy-saving 70%, plus 60% heating, cooling, energy-saving efficiency of 88%, fully in line with energy-saving environmental protection, humanization, ecology and other future fashion perspective of the "green The five-star "building standard" is a model project that combines the comprehensive utilization of solar energy with building energy-saving technologies.

Fig. 5.6. The Sun Moon Altar Building in China (Source: http://www.himin.com/)

3.1 Design concept

Sun Moon Altar House not only ingenuity of design ingenuity, but also incorporates advanced green design concepts in architectural design. It is understood that in the construction of the “ bird nest ”, experts believe that “The Bird’s Nest uses up to 110,000 tons of steel, which is expensive and bulky, and runs counter to the idea of a modern large-scale sports building that tends to be lightweight.”

In addition to the selection of materials, the Sun and Moon Towers used only 1% of the Bird's Nest (110,000 tons) of steel as the outer steel structure to build a heat collector; the entire building penetrated the concept of energy saving and environmental protection, and integrated the green design concept into the construction. The roofing and exterior walls adopt polyphenylene insulation boards that are much higher than the current national standard thickness, and the overall heat transfer coefficient is greatly reduced, which is about 30% lower than the energy conservation standard. Especially for doors, windows, skylights and curtain walls, the use of warm-screen energy-saving glass With BIPV thermal photovoltaic modules, the heat transfer coefficient is reduced to half of the national energy saving standard, and the heat insulation, sound insulation, and anti-frost exposure make people feel as if they were in the " Apollo Temple" in the 21st century and experience the energy life in the future. The wonderful "refining" (greenhouse gas) of renewable energy.

Fig. 5.7. The Sun Moon Altar Building in China (Source: http://www.himin.com/)

3.2 Technical breakthrough

As the main venue for the 4th World Solar City Conference in 2010, the "Sun Moon Alcove Micro-arrangement Building" combines solar energy comprehensive utilization technology with building energy-saving technologies. It not only perfected the solar energy application technology standard system, but also developed a batch of autonomous intellectual property of solar energy products, also provides for the promotion and application of large-scale solar valuable technical support, breaking the overall general construction of conventional energy consumption of a huge bottleneck, a number of solar integrated application of new technologies, such as ceiling radiant heating and cooling, photovoltaic power generation , photovoltaic shade, swimming pool water, rainwater collection, water treatment systems, stagnant water layer trans-seasonal energy storage technologies, the application of a number of energy-saving technology to play to the limit.

4. National Stadium (Kaohsiung) in Chinese Taipei

The National Stadium (official name) , formerly known as the World Games Stadium, is a multi-purpose stadium in Zuoying District, Kaohsiung, Chinese Taipei. It is currently the largest stadium in Chinese Taipei in terms of capacity. Completed in 2009, it is used mostly for football matches and it hosted the main events for the 2009 World Games. The stadium has a capacity of 55,000 people. Since the conclusion of the games, the stadium has been used for some football team matches.

The stadium, designed by Japanese architect Toyo Ito, makes use of solar energy to provide its power needs. The stadium's semi spiral-shaped, like a dragon, is the first stadium in the world to provide power using solar power technology. The solar panels covering the vast external face of the stadium are able to generate most of the power required for its own operation, as well as additional power that can be saved.

Fig. 5.8. The Solar Tower for Chicago by Zoka Zola Architects

(Source: https://en.wikipedia.org/wiki/National_Stadium_(Kaohsiung)#/media/File:WorkdGame2009_Stadium_completed.jpg)

5. Solar Supertrees in Singapore

An imposing canopy of artificial trees up to 50 meters is high towering over a vast urban oasis.

The colossal solar-powered supertrees are found in the Bay South garden: it is part of a 250-acre landscaping project -- Gardens by the Bay -- that is an initiative from Singapore's National Parks Board that sees the cultivation of flora and fauna from foreign lands.

The man-made mechanical forest consists of 18 supertrees that act as vertical gardens, generating solar power, acting as air venting ducts for nearby conservatories, and collecting rainwater. To generate electricity, 11 of the supertrees are fitted with solar photovoltaic systems that convert sunlight into energy, which provides lighting and aids water technology within the conservatories below.

Varying in height between 25 and 50 meters, each supertree features tropical flowers and various ferns climbing across its steel framework. The large canopies also operate as temperature moderators, absorbing and dispersing heat, as well as providing shelter from the hot temperatures of Singapore's climate to visitors walking beneath.

The project is part of a redevelopment scheme to create a new downtown district in the Marina Bay area, on Singapore's south side. Project organizers hope Gardens by the Bay will become an eco-tourist destination showcasing sustainable practices and plants from across the globe.

Lee Kuan Yew, the first prime minister of the Republic of Singapore, said the project would "showcase what we can do to bring the world of plants to all Singaporeans," adding that the gardens would become "the pride of Singapore."

Fig. 5.9. Solar Supertrees in Singapore

(Source: https://edition.cnn.com/2012/06/08/world/asia/singapore-supertrees-gardens-bay/)

Bridges dubbed "skywalks" have been erected connecting several of the higher 50-meter supertrees (the same height as the Arc de Triomphe in Paris), letting visitors stroll between them and view the gardens from dizzying heights.

The horticultural heaven also boasts two green conservatories in close proximity -- the Cloud Forest and Flower Dome -- climate-controlled biomes inspired by the shape of an orchid flower, which project organizers hope will become the park's main attractions. The biomes are the equivalent size of four football fields and will become the new home for 220,000 plants from almost every continent.

These are some of the only areas where an admission fee is charged -- approximately US$22 (S$28) for holiday-makers or US$16 (S$20) for Singapore residents.

Fig. 5.10. Solar Supertrees in Singapore

(Source: https://edition.cnn.com/2012/06/08/world/asia/singapore-supertrees-gardens-bay/)

Fig. 5.11. Solar Supertrees in Singapore(Source: https://edition.cnn.com/2012/06/08/world/asia/singapore-supertrees-gardens-bay/)

One of the sustainable features of the Flower Dome is that horticultural waste feeds a massive steam turbine and generates the electricity on-site to help maintain the cool temperatures of the biome.

However, the supertrees and biomes only make up 5% of the multimillion-dollar landscaping development won after an international design competition by UK landscape architects Grant Associates. The remainder of the Bay South garden will pay homage to the ethnic makeup of the country. In the Heritage Gardens, visitors can explore the Chinese, Malay, Indian and Colonial-themed areas and learn about the links between plants and Singapore's history. Surrounding these cultural green spaces in the rest of the 103-acre Bay South park are sprawling areas complete with lakes and bridges.

The horticultural oasis stands in contrast to the country's extremely dense urban environment, forming part of the government's overall strategy to transform Singapore into a "city in a garden."

References

[1] "Large-Scale Solar Power Generation Facility “Solar Ark” Panasonic Corporation of North America. Retrieved January 11, 2013.3

[2] https://en.wikipedia.org/wiki/Solar_Ark#/media/File:Solar_Ark.jpg

[3] http://www.evolo.us/architecture/chicago-solar-tower-zoka-zola-architecture/

[4] http://www.zokazola.com/solar_tower.html

[5] http://www.evolo.us/architecture/chicago-solar-tower-zoka-zola-architecture/

[6] http://www.himin.com/

[7] https://en.wikipedia.org/wiki/National_Stadium_(Kaohsiung)#/media/File:WorkdGame2009_Stadium_completed.jpg

[8] https://edition.cnn.com/2012/06/08/world/asia/singapore-supertrees-gardens-bay/