A review of solar technologies for buildings

Article · January 2012

DOI: 10.1080/20421338.2013.833378

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RESEARCH PAPERS

African Journal of Science, Technology, Innovation and Development
Vol. 4, No 4, 2012
pp. 11-36

A Review of Solar Technologies for Buildings

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Abstract

Solar energy is receiving attention in applying technologies and energy systems in recent years. Solar technologies for buildings relying on both passive and active systems are developed. Passive solar refers to those that absorb, store and distribute the sun's energy without relying on mechanical devices, while active systems are those where heat is transferred mechanically by the use of a working fluid such as air or a fluid that is typically water, or water based. Some recent innovations in solar technologies for buildings are also presented. It is seen that, today solar architecture is undergoing a true revolution through the integration of renewable technologies into the fabric of buildings. Such systems are designed for heating, ventilation, thermal isolation, shading, electricity generation and lighting of buildings.

Keywords: Solar technologies, Solar heating, Cooling, Passive solar, Active solar.

JEL Classifications: O30; O31; O32; Q55.

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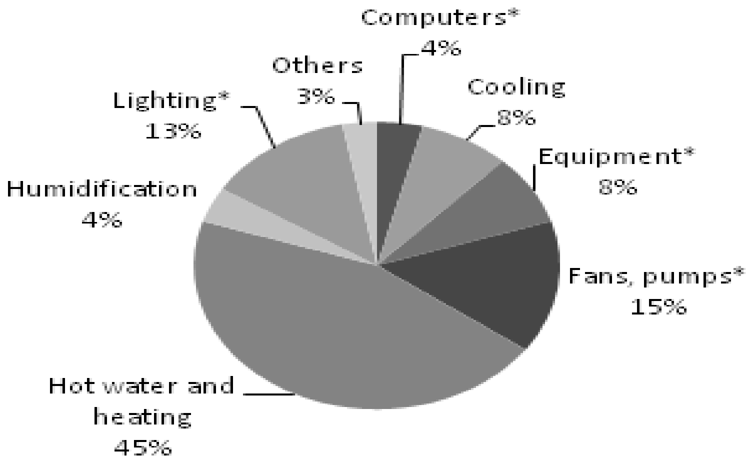
1. Introduction

The recent commitment made by many countries to combat the harmful effects of fossil fuel energy has directed world attention on the implementation of policies geared towards an optimal energy performance and the use of renewable energies. The construction of buildings with sustainable energy systems necessarily plays an important role in such policies. Energy saving is also a high-priority worldwide. For this reason, energy-efficient measures are being increasingly implemented in all sectors (Kapseu *et al.*, 2012).

Buildings are a dominant feature in the modern society. We work, eat, sleep, and enjoy much of our leisure time indoors. Up to 80 % of an individual's life is spent in buildings (Djongyang, 2010). The residential sector accounts today for about 40 % of the final energy consumption (Eicker, 2001; D&R International, 2009; Sadineni *et al.*, 2011). Most of this energy is used in heating, cooling, and in artificial ventilation systems (Schaeffer *et al.*, 2012). The energy used within buildings can be classified under two main categories Kelly (1998): high-grade (e.g. electricity, which can be efficiently converted to work via an electric motor) and low-grade (e.g. heat energy used to maintain conditions suitable for human comfort in buildings). Figure 1 shows the breakdown of energy usage in a typical air-conditioned office building (Kelly, 1998).

Energy use in buildings also accounts for nearly half of the carbon dioxide (CO_2) emissions in the world (BSRIA, 1999). More attention should therefore be paid to the type of energy systems used in buildings, which need to be sustainable and environmentally clean. Solar energy appears to be a good alternative to fossil energy. However, one of the major issues confronting users of solar energy-based systems is the relatively low efficiency of these systems compared to fossil fuel-based systems. Improving the efficiency of such systems has attracted authors for years, including passive, active, and hybrid solar technologies. In recent studies, Eicker and Dalibard (2011) developed a new photovoltaic-thermal system to produce electricity and cooling energy. Some works were also done in vernacular buildings, e.g. Shanthi Priya *et al.* (2012) conducted qualitative and quantitative analysis to investigate the indoor environmental condition of a vernacular residential building in coastal region of Nagapatinam, India. The results of this study showed that the solar passive techniques used in these vernacular residential buildings in coastal region provides comfortable thermal indoor environment irrespective of the outdoor climatic conditions.

Figure 1: The Energy Usage in a Typical Office Building



Many solar technologies have been developed in the past decades. The two main existing solar systems used in buildings are: passive solar systems, which refer to those that absorb, store and distribute the sun's energy without relying on mechanical devices; and active solar systems, where heat is transferred mechanically by the use of a working fluid such as air, or a fluid that is typically water, or water based. In recent technologies such as Building-integrated energy systems, the renewable technologies are integrated into the fabric of buildings. The recent innovations in the field of solar technologies for buildings will be explored below.

2. Solar Design Issues for Buildings

Building design can integrate several solar technologies including passive solar heating, ventilation air heating, solar domestic water heating and shading (Robertson and Athienitis, 2010). This section focuses on some of these technologies.

Advantages of Solar Energy in Building Design

Solar energy can substantially enhance building design. It offers several advantages compared to conventional energy: free after recovering upfront capital costs; payback time can be relatively short; available everywhere and inexhaustible; clean, reducing demand for fossil fuels and hydroelectricity, and their environmental drawbacks; can be building-integrated, which can reduce energy distribution needs.

Characteristics of Building Design Issues

Careful solar designs can (Robertson and Athienitis, 2010):

- Maximize possible solar transmission and absorption in winter to minimize or reduce to zero the heating energy consumption, while preventing overheating.
- Use received solar gains for instantaneous heating load and stores the remainder in embodied thermal mass or specially built storage devices.
- Reduce heat losses using insulation and windows with high solar heat gain factors.
- Employ shading control devices or strategically planted deciduous trees to exclude summer solar gains that create additional cooling load.
- Employ natural ventilation to transfer heat from hot zones to cool zones in winter and for natural cooling in the summer; use ground-source cooling and heating to transfer heat to and from the underground, which is more or less at a constant temperature, and utilize evaporative cooling.
- Integrate building envelope devices such as windows which include photovoltaic panels as shading devices or roofs with photovoltaic shingles; their dual role in producing electricity and excluding thermal gain increase their cost-effectiveness.
- Use solar radiation for day-lighting, which requires effective distribution into rooms or onto work planes, while avoiding glare.
- Integrate passive solar systems with active heating-cooling/air-conditioning systems in both design and operation.

Solar Technology Systems in Buildings

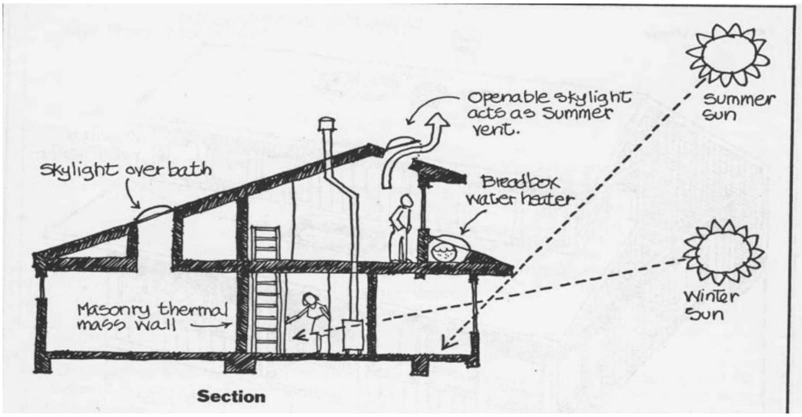
Solar buildings work on three principles: collection, storage and distribution of the sun's energy. These principles are integrated into two main solar systems: passive and active solar systems. They can simultaneously be integrated into building design.

Passive Solar Systems

Passive solar refers to systems that absorb, store and distribute the sun's energy without relying on mechanical devices like pumps and fans, which require additional energy. In other terms, passive solar involves no panels, no batteries, and nothing is fed into the general power grid. Passive systems could be used either for heating or cooling purposes. A passive solar building makes the greatest use possible of solar gains to reduce energy use for heating and, possibly, cooling by using natural energy flows through air and materials-radiation, conduction, absorption and natural convection (Robertson and Athienitis, 2010). It can optimize solar heat gain in direct heat gain systems, in which windows are the collectors and interior materials are the heat storage media. The principle can also be applied to water or air solar heaters that use natural convection to thermosiphon for heat storage without pumps or fans. According to Hibshman (1983), a good passive solar design should be as presented in Figure 2.

- The three most common solar passive systems are Hibshman (1983): direct gain system, which allows sunlight to windows into an occupied space where it is absorbed by the floor and walls.
- Indirect gain system, where a medium of heat storage such as wall, in one part of the building absorbs and stores heat, which is then transferred to the rest of the building by conduction, convection or radiation.
- Isolated gain system, where solar energy is absorbed in a separate area such as greenhouse or solarium, and distributed to the living space by ducts.

Figure 2: Diagram Showing Good Passive Solar Design.



In general, for passive-solar architecture, the most significant design parameters which alter the solar contribution to the total cooling and heating load inside the building are aspect ratio of walls, orientation of the building, window details (size and location) and proper sun shade to control the amount of admission of incident solar radiation (Ralegaonkar and Gupta, 2010). To meet the heating and cooling requirements, the selection of proper building orientation for a particular aspect ratio should be done with the computation of beam radiation falling over exposed wall surface. Small scale modelling technique is one of the easy and best methods of experimentation to analyze the effectiveness of a particular system. For fast and accurate computation simulation, software is the best suitable option to predict and control the indoor environment. Sunlight area is a measure to determine the radiation interception, which regulates temperature inside the buildings. Graphical determination of sunlight area will be helpful for easy visualization and accurate measurement. Windows, which play vital role for solar incursion inside the buildings, should be shaded properly to regulate the sun entry as per seasonal requirements in composite climates. External static sunshades are most efficient among all the types of sunshades as they restrict the sun before it interacts with building components (wall, window). The existing external static sunshades (horizontal, vertical and egg create) satisfy shading needs partially. To check the effectiveness of a particular sunshade shading mask can be plotted. The efficient external static sunshade should be designed as per the location constraint, which will follow sun path at a particular geographic location whose shading characteristics can be controlled as per seasonal requirements.

The key to designing a passive solar building is to best take advantage of the local climate. The key aspects of passive solar design are interlinked and dependent to the following design parameters: location and orientation of a building; fenestration area, orientation and type; thermal massing and envelope characteristics; amount of insulation; shading devices-type, location and area; effective thermal storage insulated from the exterior environment, as well as amount and type; sensible such as concrete in the building envelope with exterior insulation, or latent such as phase-change materials. The major source of heat in a passive solar building is the light energy from the sun, which is converted into heat energy within the building. Apart from warming the inner spaces of the building during the day, this heat can also be stored for use when light is not available, notably at night. Maximizing the amount of light that enters a building in winter is fundamental to its ability to be warm then and reduce reliance on active forms of heating. Conversely, being able to limit the amount of light that enters in the Summer time is vital to preventing overheating at that time of year, thus reducing the need for air conditioning.

Building Orientation

The direction of a building and its major openings face is crucial to its functioning as a collector of light and heat (Kachadorian, 2006). The best way is to orient the house on the east-west axis and concentrate most of the house's glazing on the south wall. This allows the home to receive the most direct sunlight for the longest period of time (Hibshman, 1983; Kachadorian, 2006; Website A). Table 1 show the solar gain received according to the orientation of the building (Kachadorian, 2006).

Glazing

Glazing should be greatly reduced on the east and west walls and should be virtually eliminated on the north side of the home because most cold winds in winter come from the north and west (Desbarats, 1980; Website A). Table 2 presents coefficient of solar heat gain (ASHRAE Fundamentals, 1997).

Table 1: Solar Gain Received According to the Orientation of the Building

Orientation of building	Solar gain received
True south	100 %
22.5° away from south, either south-south-east or south-south-west	92 %
45° away from south, either south-east or south-west	70 %
67.5° away from south, either east-south-east or west-south-west	36 %

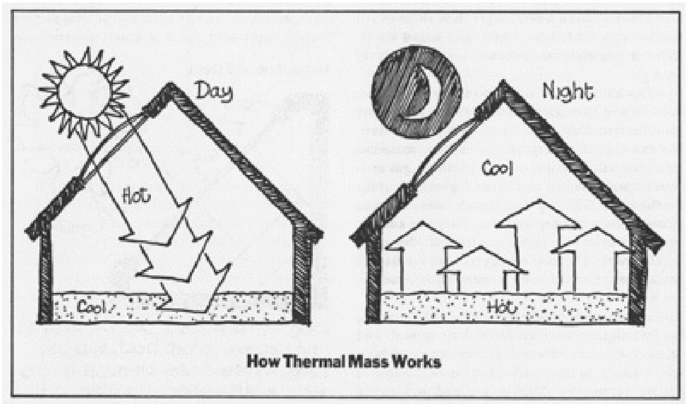
Table 2: Visible Light Transmission - Solar Heat Gain Coefficient (per cent)

Glazing system (6 mm glass)	Clear	Blue-green	Grey	Reflective
Single	89-81	75-62	43-56	20-29
Double	78-70	67-50	40-44	18-21
Double, hard low-e, argon	73-65	62-45	37-39	17-20
Double, soft low-e, argon	70-37	59-29	35-24	16-15
Triple, hard low-e, argon	64-56	55-38	32-36	15-17
Triple, soft low-e, argon	55-31	52-29	30-26	14-13

Thermal Mass

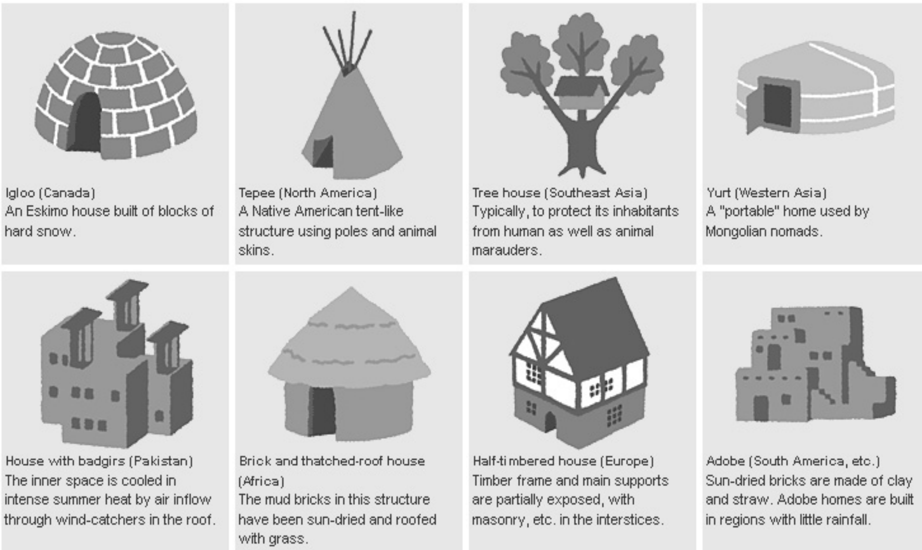
It is important to use building materials that have a large amount of thermal mass. Figure 3 shows how thermal mass works (Hibshman, 1983).

Figure 3: How Thermal Mass Works.



The rudiments of solar passive design were developed and used through the centuries by many civilizations across the globe. Many of these early civilizations built dwellings that were better suited to their climatic surroundings than those built today in most developed and developing countries. Examples of houses built in traditional, indigenous styles are presented in Figure 4 (Website B).

Figure 4: Traditional Home Structures Making the Most of Natural Resources



Passive Solar Heating and Cooling

Heating the building through the use of solar energy involves the absorption and storage of incoming solar radiation, which is then used to meet the heating requirements of the space.

Conversely, passive solar cooling systems function by either shielding buildings from direct heat gain or by transferring excess heat outside. Passive cooling is being employed as a low-energy consuming technique to remove undesirable interior heat from a building in the hot seasons. There are numerous ways to promote this cooling technique.

Active Solar Systems

In active system, heat is transferred mechanically by the use of a working fluid such as air, or a fluid that is typically water, or water based. An active solar system uses mechanical equipment to collect, store and distribute the sun's heat (Robertson and Athienitis, 2010). Active systems consist of solar collectors, a storage medium and a distribution system. Such systems are commonly used for water heating, space conditioning, producing electricity, process heat, and solar mechanical energy. In addition to solar collectors, other renewable energy systems like biomass to support the solar passive features as they allow a greater degree of control over the internal climate and make the whole system more precise.

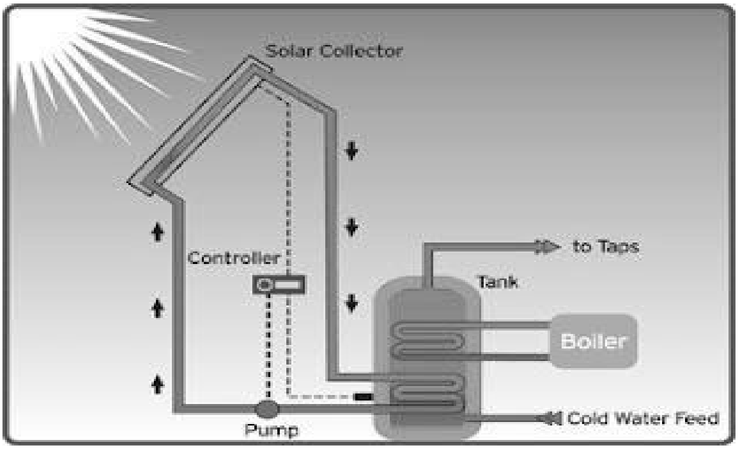
Solar Collectors

The three main types are: flat plate collectors, commonly used for solar water heating systems in home and solar space heating; evacuated-tube collectors which can achieve higher temperatures; and integral collector-storage system also known as ICS or "batch" systems. The growth in the use of solar collectors for covering building loads (domestic hot water preparation and space heating mainly) has shown that these systems are mature and technically reliable. Research and development of solar technologies has led to very efficient solar collectors and systems (D'Antoni and Saro, 2012). The most diffuse solar technologies are flat-plate solar collectors and a wide range of typologies and materials are available on the market. The façades of buildings can be important solar collectors, and, therefore, become multifunctional. In addition, solar collectors can be used to enhance the appearance of the façade when considering their aesthetic compatibility. Currently, installation of collectors on the south tilted roofs, south walls, balconies or awnings of buildings are the feasible approaches for integration of solar collectors into buildings (Wang and Zhai, 2010).

Active Solar Heating and Cooling

Active solar heating main purpose is to use the solar cells to collect and absorb solar radiation. The radiation is converted into heat by solar cells and then transferred to the interior of the building. Flat-plate collectors are typically used for this purpose. Figure 5 shows example of active solar heating system (Website C).

Figure 5: Active Solar Heating.



Active solar heating works in two ways:

- Solar liquid heating where water or antifreeze is warmed through the use of solar cells. Then the liquid is pumped into home and heats it via radiators.
- Solar air heating where solar panels warm the air then that air is pumped into home through a forced air pump.

Conversely, active solar cooling systems transfer a heated liquid from the solar collector to run a generator or a boiler activating the refrigeration loop which cools a storage reservoir from which cool air is drawn into the space.

Solar Electric System

Solar electric systems use photovoltaic cells to absorb solar radiation. These photovoltaic cells are semiconductors. Electrons are loose out when the cells absorb sunlight; this is called photoelectric effect. Then free electrons move to circuit where they form an electrical current. Cells are connected to form panels and each panel creates 10 to 300 watts. Usually a building or home has several panels for its power supply. The panels are fixed in a specific angle, or panels are having tracking device to maximize power for a day. Solar panels can be stand-alone or hooked up to the power grid. There are several solar array systems in the southwest that supply the electric grid.

Hybrid Solar Systems

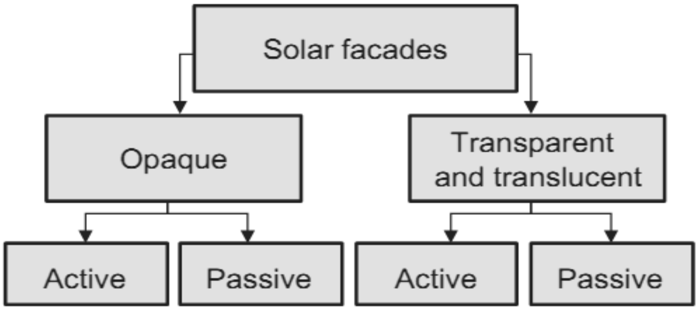
Hybrid powers systems combine two or more energy systems or fuels that, when integrated, overcome limitations of the other, such as photovoltaic panels to supplement grid-supplied or diesel-generated electricity. Hybrid systems are the most common, except for the direct gain system, which is passive. Hybrid renewable energy systems are able to fill a number of roles:

- PV panels with integrated phase change material to maintain low cell temperatures thus improving efficiency while storing enough thermal energy for space or water heating.
- 'Hybrid renewable/energy efficient system' which enhance the effectiveness of the renewable technology being utilised. A renewable technology with a high coefficient of performance (e.g. ground source heat pumps) would produce a synergistic effect when combined with a hybrid PV system.
- Hybrid energy systems can also benefit from being used in conjunction with passive applications. They are useful for applications in environments where daylight is restricted and there is perhaps poor ventilation also.
- Using natural ventilation with natural day-lighting, super-reflective chimneys or 'light pipes' with integral ventilation can be beneficent. Lighting levels can be doubled Hill (2002) and this effect can then be enhanced by coating the pipes with 'dichoric' coatings to absorb increased levels of solar thermal energy to improve performance of the stack effect. The stack effect draws in fresh air without the need for mechanical ventilation equipment.

3. Building-Integrated Energy Systems: Solar Façades Technologies

These are renewable technologies that are integrated into the fabric of buildings, displacing some of the traditional building materials, and drawing energy from its immediate environment (Dwyer, 2003). Building integrated renewable energy sources can either make use of its energy supply directly for electricity generation or heating, or passively in areas such as wind induced ventilation, transparent insulation or natural lighting. Integrating photovoltaic panels into a building façade represents a significant step forward in the application of this relatively new technology. Such a façade serves not only as a renewable source of electricity, but also as a source of heat for building heating and cooling.

Figure 6: Solar Façades Classification

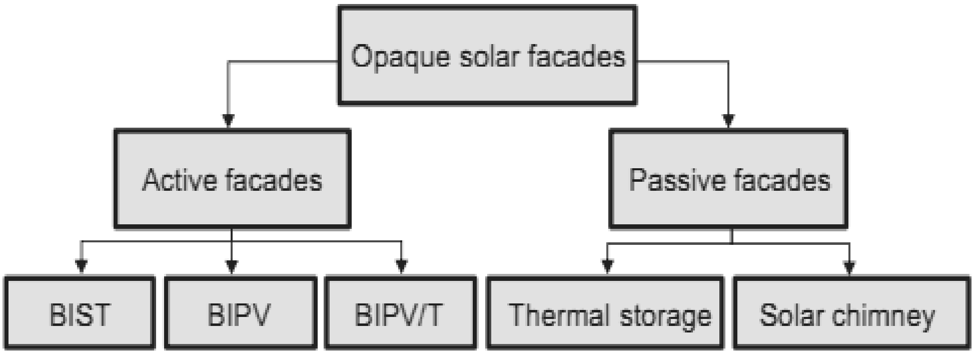


Today solar architecture is undergoing a true revolution because of the development among others, of solar façades designed for heating, ventilation, thermal isolation, shading, electricity generation and lighting of buildings. Figure 6 illustrates their general classification (Quesada *et al.*, 2012).

Opaque Active and Passive Solar Façades

The opaque solar façades can absorb and reflect the incident solar radiation but cannot transfer directly solar heat gain into the building (Quesada *et al.*, 2012). When such opaque solar façades transform the incident sunlight into electricity for immediate use or for transmitting the thermal energy into the building by the use of electrical or mechanical equipment (pumps, fans, valves, control equipments), then they are called opaque and active solar façades (Figure 7).

Figure 7: Opaque Solar Façades



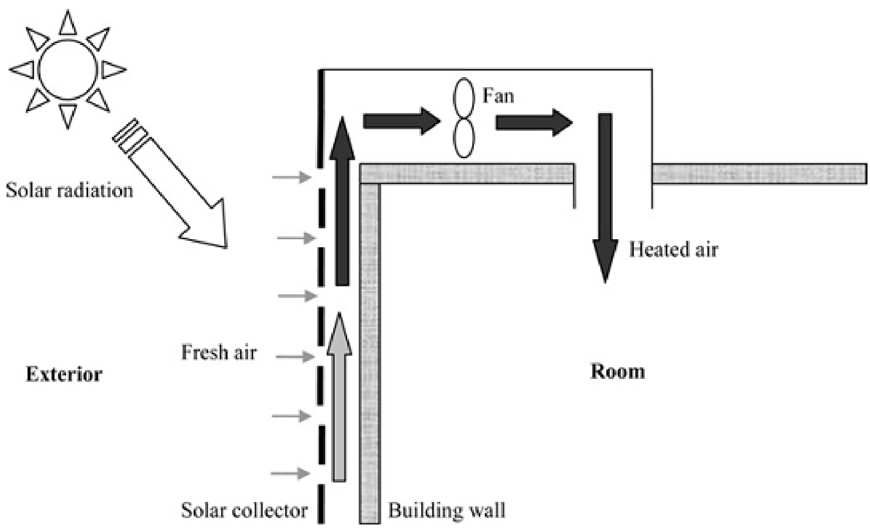
Active Solar Façades

Active and opaque solar façades include Building-integrated solar thermal (BIST) system, Building integrated photovoltaic (BIPV) system, and Building-integrated photovoltaic thermal (BIPV/T) system.

Building-Integrated Solar Thermal System

A building-integrated solar thermal system for façades can be conceived as the application of solar collection equipment to the façade of a building so that the equipment performs the function of an envelope while it simultaneously collects solar energy for heating purposes (Figure 8) (Quesada *et al.*, 2012).

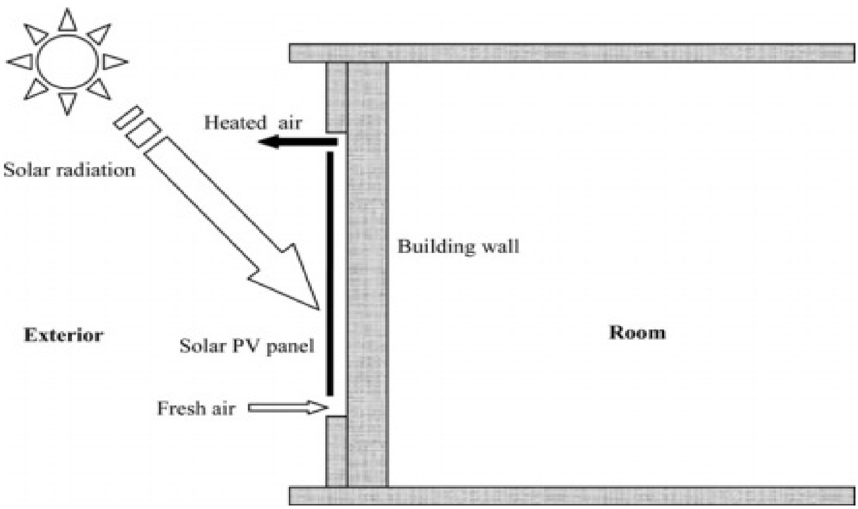
Figure 8: Schematic Diagram of Building-Integrated Solar Thermal System



Building Integrated Photovoltaic (BIPV) System

Henemann (2008) describes a building integrated photovoltaic (BIPV) system as photovoltaic cells which can be integrated into the building envelope as part of the building structure, and therefore can replace conventional building materials, rather than being installed afterwards. BIPV (Figure 9) use photovoltaic surfaces that can be integrated with standard roofing, glazing or cladding products.

Figure 9: Schematic Diagram of Building Integrated Photovoltaic System.



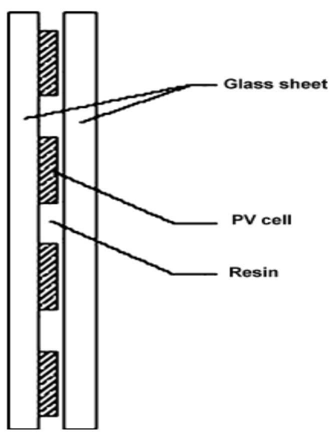
BIPV can be used in any external building surface. Rather than sticking out like a sore thumb, BIPV modules can be naturally blended into the design of the building, creating a harmonious architecture. Also, as an added benefit, air flow behind the solar cell reduces their temperature which improves their efficiency and longevity (Quesada *et al.*, 2012).

Building-Integrated Photovoltaic (BIPV) has been developed rapidly in the past decade. A number of BIPV projects are found worldwide. Currently there is much development in PV roofing, PV shading elements and PV cladding or semi-transparent curtain wall components. With PV cladding it is best to have a vented cavity behind the panels so as to operate at lower temperatures. By following such a construction approach one may also develop an effective rainscreen system which hinders rain penetration. PV roofing is installed much the same way as conventional roofing and is available in shingles; tiles and metal standing-seam roofing. PV shading can be effective as a window shading element, entrance canopy or walkway shading. PV panels can be opaque, used where no light transmission is needed, or semi-transparent for areas where light is wanted, such as atriums or skylights, but some shading is needed to reduce cooling loads.

Sunshade PV claddings are typical applications of the BIPV systems to achieve an aesthetically pleasing outlook and energy efficiency in buildings (Fung and Yang, 2008). In addition to sunshade PV claddings, architects and building engineer s have tended to use semi-transparent BIPV modules to replace the traditional glazing in recent years for energy efficiency and aesthetic consideration. This kind of PV modules is usually composed of two layers of highly transparent glass sheets, and a serious of opaque solar cells that are encapsulated in between the two glass sheets (Figure 10).

By comparison with centralised PV plants, BIPV systems offer the "double dividend" of reduced economic costs and improved environmental performance. This double dividend is increased if the economic and energy costs of avoided cladding materials are taken into account (Oliver and Jackson, 2001).

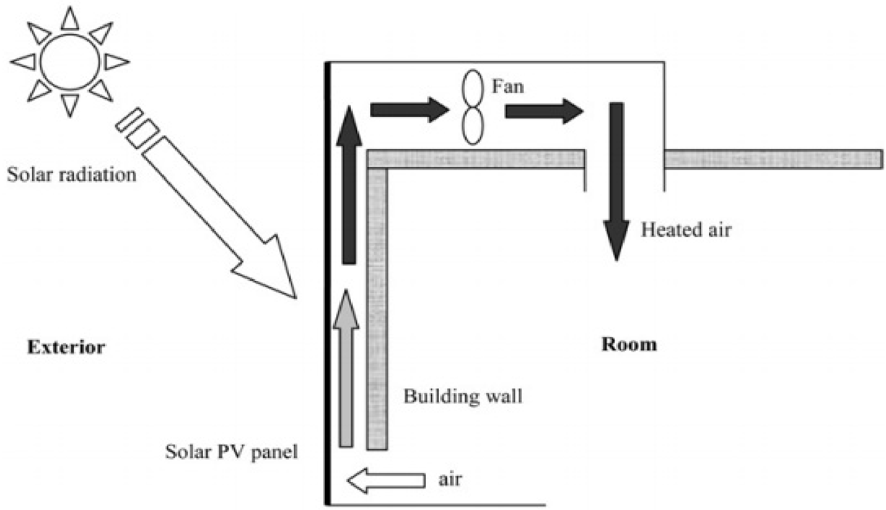
Figure 10: A Typical Structure of a Semi-Transparent PV



Building-integrated Photovoltaic Thermal (BIPV/T) System

A building integrated photovoltaic thermal (BIPV/T) system combines the functions of a building integrated photovoltaic system with those of a building-integrated solar thermal system. This combination seeks to achieve a most efficient use of a solar energy-collecting surface in terms of both an optimal electrical conversion and air/water heating (Figure 11) (Quesada *et al.*, 2012). Building integrated photovoltaic thermal (BIPVT) systems have been growing under rapid development over past decades and several buildings with BIPVT systems exist across the world.

Figure 11: Schematic Diagram of Building-Integrated Photovoltaic Thermal System (BIPV/T).



Building Integrated Concentrating Photovoltaics

For building integration, Concentrating Photovoltaic (CPV) systems can offer a host of advantages over conventional flat panel devices, the most notable being Chemisana (2011): a higher electrical conversion efficiency in the PV cells, better use of space, ease of re cycling of constituent materials, and reduced use of toxic products involved in the PV cells' production process. However, the viability of Building-Integrated Concentrating PV (BICPV) systems is dependent on their ability to offer a comparative economic advantage over flat panel photovoltaic technologies whose market prices are decreasing from day to day and which offer other advantage s such as ease of replacement of structural elements.

However, buildings Integrated Concentrating Photovoltaics (BICPV) need to be designed in such a way which minimizes costs allowing them to compete with standard flat panel technology, the manufacturing costs of which are falling continually. In addition to being technically and structurally sound, solar concentrators apt for architectural integration must fulfil the following requirements, these being a generalization of the criterion formulated by the IEA PVPS Task 7 workgroup for evaluation of the aesthetic quality of buildings integrated photovoltaics Chemisana (2011): Natural integration; Architecturally pleasing design; Good composition of colours and materials; Dimensions that fit the gridula, harmony and composition; Conformity to the context of the building; Well-engineered and innovative design.

BICPV systems may be installed either on the building façade or on the roof (which may be flat or sloped) producing in each case a different visual impact. Depending on the type of device, the system may be integrated in such a way that it is unseen, plays some role in the architectural aesthetic or that it constitutes in itself an architectural concept (Swanson, 2000).

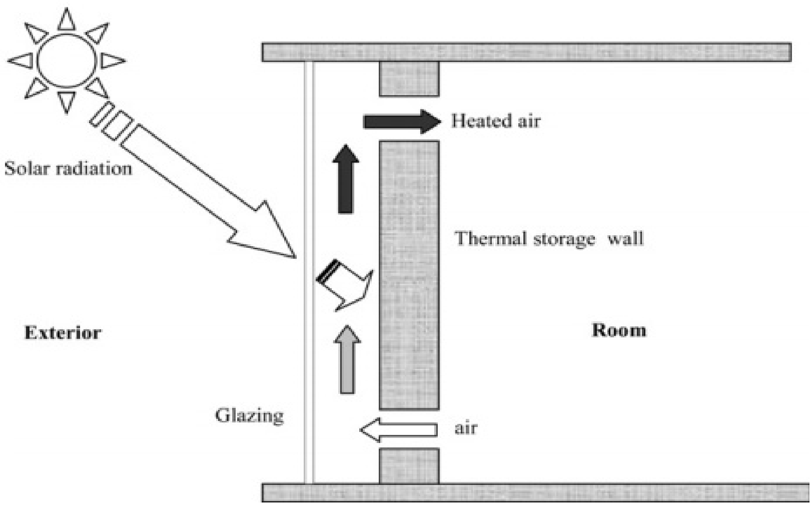
Passive Solar Façades

Passive Solar Façades Include Thermal Storage Wall and Solar Chimney.

Thermal Storage Wall

Thermal storage wall combines the functions of solar collector and storage into a single unit. Heat is transferred from the wall to the room air and to the air between glazing and wall, by radiation and natural convection. Reducing indoor air temperature swings is one of its principal functions (Figure 12) (Quesada *et al.*, 2012).

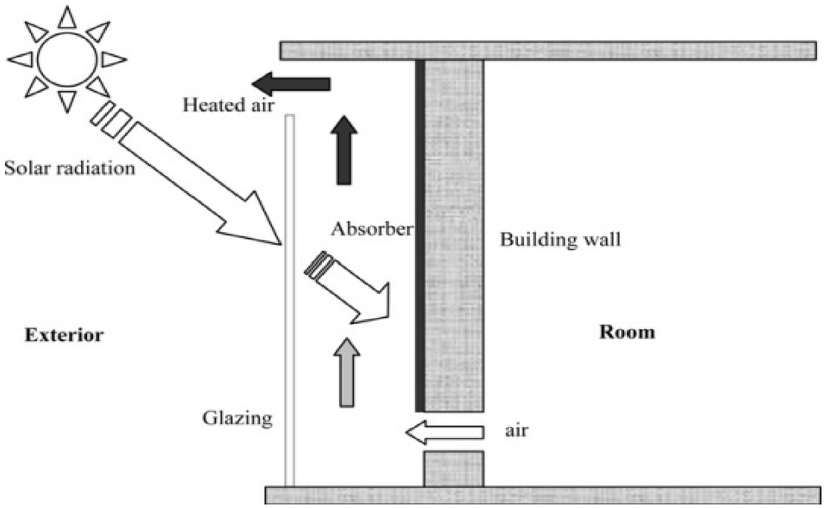
Figure 12: Schematic Diagram of Thermal Storage Wall



Solar Chimney

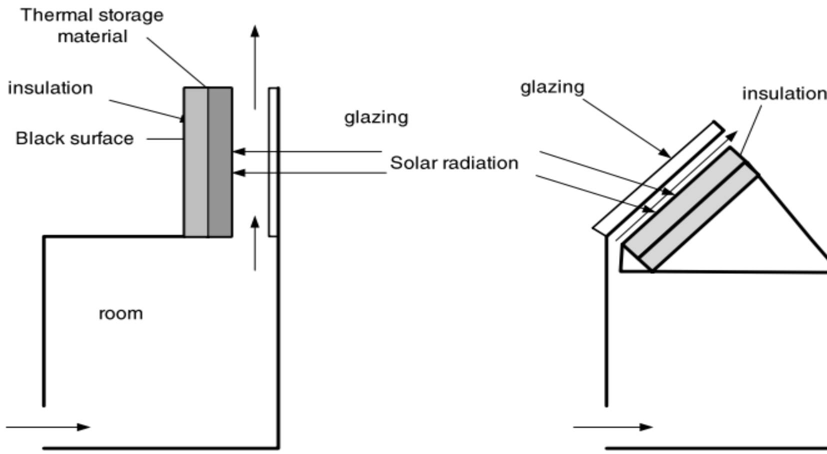
A solar chimney is a structure that consists mainly of one heat-absorbing glazed surface and it is constructed on the wall facing the direction of the sun. When solar energy heats the chimney and the air within it, it produces an updraft of air in the chimney. The natural aspiration created at the chimney's base can be used to ventilate the building (Figure 13) (Quesada *et al.*, 2012).

Figure 13: Schematic Diagram of Solar Chimney



As a simple and practical bioclimatic design methodology, solar chimneys are receiving considerable attention for reducing heat gain and inducing natural cooling or heating in both commercial and residential buildings because of their potential benefits in terms of operational cost, energy requirement and carbon dioxide emission. In practical civil buildings, solar chimneys can be installed on the walls and roofs. For the purpose of improving natural ventilation performance and achieving better indoor thermal comfort, solar chimneys are always applied in the form of integrated configurations. Solar chimneys can also be used to combine with natural cooling systems so as to enhance the cooling effect inside buildings. Besides, active solar systems may be utilized to enhance the ventilation performance of solar chimneys (Zhai *et al.*, 2011). Figure 14 shows solar chimney configurations (Harris and Helwig, 2007).

Figure 14: **Solar Chimney Configurations**



4. Example of Low Energy Building: Solar XXI Building

Solar XXI building is a low energy office building with 1500 m^2 of gross floor area located in Lisbon, Portugal (38° 46′ N, 9° 11′ W) (Marta *et al.*, 2011). It is a low energy office building where passive and active solar strategies have been applied to reduce the use of energy for heating, cooling and lighting, combining also an extensive photovoltaic façade for electricity production. Solar XXI opened in 2006, is considered as a high efficient building, close to a net zero energy building (NZEB), where the difference between the energy consumed and that produced is 1/10th of the energy consumed by a Portuguese standard new office building. Its design includes many energy efficiency concepts, such as a high insulated envelope, south sun exposure, windows external shading, photovoltaic panels heat recovery, ground-cooling system, daylighting, stack effect and cross ventilation.

5. Conclusion

Some solar technologies for buildings are presented: passive solar systems which refer to those that absorb, store and distribute the sun's energy without relying on mechanical devices, and active systems where heat is transferred mechanically by the use of a working fluid such as air or a fluid that is typically water, or water based. Building-integrated energy systems are also presented. Here, renewable technologies are integrated into the fabric of buildings. Today solar architecture is undergoing a true revolution through the integration of renewable technologies into the fabric of buildings. Such systems are designed for heating, ventilation, thermal isolation, shading, electricity generation and lighting of buildings.

References

ASHRAE Fundamentals, (1997), Available at: http://www.filestube.com/ec305724730bb5c903e9,g/ash-rae-handbooks-1997-2000-p.html.

BSRIA (1999), 'Environmental Code of Practice for Buildings and Their Services', Available at: http://www.bsria.co.uk (Accessed: 07 August 2012).

Chemisana, D. (2011), 'Building Integrated Concentrating Photovoltaics: A review', in *Renewable and Sustainable Energy Reviews*, 15: 603-611.

Desbarats, G. (1980), 'Low energy Building Design Awards and Competition', *Minister*, Canada.

Djongyang, N. (2010), 'Contribution to the study of thermal comfort and coupled heat and mass transfer through building components in the Sub-Saharan Africa region', *PhD Thesis*, University of Yaounde I, Cameroon, 245 pages.

Dwyer, S.M. (2003), 'An Investigation of the Barriers that Exist for Building Integrated Renewables and their Implication for Sustainable Development', *Master Thesis*, University of Strathclyde, U.K.

D'Antoni, M. and Saro, O. (2012), 'Massive Solar-Thermal Collectors: A critical literature review', in *Renewable and Sustainable Energy Reviews*, 16: 3666-3679.

D&R International (2009), 'Buildings energy data book, buildings technologies program, energy efficiency and renewable energy', Report prepared for the U.S. Department of Energy, Silver Spring, Maryland.

Eicker, U. (2001), 'Solare Technologien für Gebäude', *B.G.Teubner*, Stuttgart/ Leipzig/ Wiesbaden.

Eicker, U. and Dalibard, A. (2011), 'Photovoltaic–thermal collectors for night radiative cooling of buildings', in *Solar Energy* 85: 1322-1335.

Fung, T.Y.Y. and Yang, H. (2008), 'Study on thermal performance of semi-transparent building-integrated photovoltaic glazings', in *Energy and Buildings,* 40: 341-350.

Harris, D.J. and Helwig, N. (2007), 'Solar Chimney and building ventilations', in *Applied Energy,* 84: 135-146.

Henemann, A. (2008), 'BIPV: built-in solar energy', in *Renewable Energy Focus*, 9(14): 16-9.

Hibshman, D. (1983), *Your Affordable Solar Home*, Sierra Club Books.

Hill, M. (2002), 'Friend of the Earth', in *Design Advice*, Issue 2.

Kachadorian, J. (2006), 'The Passive Solar House', *Chelsea Green Publishing Company*, White River Junction, Vermont, second edition.

Kapseu, C., Djongyang, N., Nkeng, G.E., Petsoko, M. and Ayuk Mbi Egbe, D. (2012), *Energies renouvelables en Afrique subsaharienne*, Harmattan, Cameroun.

Kelly, N.J. (1998), 'Towards a design environment for building-integrated energy systems: the integration of electrical power flow modelling with building simulation', *PhD Thesis*, University of Strathclyde.

Marta, J.N., Panao, O., Helder. and Gonçalves, J.P. (2011), 'Solar XXI building: Proof of concept or a concept to be proved?' in *Renewable Energy*, 36: 2703-2710.

Oliver, M. and Jackson, T. (2001), 'Energy and economic evaluation of building-integrated photovoltaics', in *Energy,* 26: 431-439.

Quesada, G., Rousse, D., Dutil, Y., Messaoud, B. and Hallé, S. (2012), 'A comprehensive review of solar façades: Opaque solar façades', in *Renewable and Sustainable Energy Reviews,* 16: 2820-2832.

Ralegaonkar, R.V. and Gupta, R. (2010), 'Review of intelligent building construction: A passive solar architecture approach', in *Renewable and Sustainable Energy Reviews*, 14: 2238-2242.

Robertson, K. and Athienitis, A. (2010), 'Solar Energy for Buildings', in *Canada Mortgage and Housing Corporation*.

Sadineni, S.B., Madala, S. and Boehm R.F. (2011), 'Passive building energy savings: A review of building envelope components', in *Renewable and Sustainable Energy Reviews*, 15: 3617-3631.

Schaeffer, R., Salem S.A., Frossard Pereira de Lucena, A., Soares M.C.B, Pinheiro P.N.L., Pereira F.F., Troccoli, A., Harrison, M. and Sadeck B.M. (2012), 'Energy sector vulnerability to climate change: A review', in *Energy*, 38: 1-12.

Shanthi, P.R., Sundarraja, M.C., Radhakrishnan, S. and Vijayalakshmi, L. (2012), 'Solar passive techniques in the vernacular buildings of coastal regions in Nagapattinam, Tamil Nadu-India: A qualitative and quantitative analysis', in *Energy and Buildings*, 49: 50-61.

Swanson, RM. (2000), 'The promise of concentrators', in *Progress in Photovoltaics Research and Applications*, 8: 93-111.

Wang, R.Z. and Zhai, X.Q. (2010), 'Development of solar thermal technologies in China', in *Energy*, 35: 4407-4416.

Website A: http://www.lightningcanyon.com/pages/passive-solar (Accessed: 10 August 2012).

Website B: http://www.omsolar.net/en/index.html (Accessed: 10 August 2012).

Website C: http://2.blogspot.com/Active+Solar+Heating (Accessed: 10 February 2012).

Zhai, X.Q., Song, Z.P. and Wang, R.Z. (2011), 'A review for the applications of solar chimneys in buildings', in *Renewable and Sustainable Energy Reviews*, 15: 3757-3767.