A Review of Solar Energy and the Built Environment

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Abstract

Solar Energy has been acknowledged as a free and infinite source of energy. In Built Environment (BE), solar energy has been used since pre-historic time. Many improvements and technologies have been developed with respect to their potential. As solar supplies free energy, the issues with regard to their development in the BE will be examined. The solar energy is used in building either in Passive Solar Design (PSD) or Active Solar Design (ASD). Rapid development in BE has caused global warming effect where the heating and cooling of the building contribute to half the total energy consumption of the nation and the construction industry leading to CO_2 emission level at 300 million tonnes. It is found that solar energy produces different energy performances which result from different building technique that affected the environment in various ways. Whether or not the energy performances depend on the materials used, the equipment installed in the building or the energy sources supplied to the building, the improvement and development of solar energy still continues and grows.

Keywords: Solar energy, Active solar design, Passive solar design, CO_2 emission, Global warming

Introduction

Solar energy delivers total solar radiation which is absorbed by the earth and its atmosphere at 3.8×10^{24} J per year. This is more than enough energy to meet global demand, even allowing for the conversion, storage and transmission losses required when putting this resource to human use. It is believed that solar energy has been used in buildings since 2,500 years ago when the heat is used to warm the people through solar collection and storage in thermal properties of the buildings they constructed. Over the last few decades, solar architecture which used this solar energy has started to become popular again because of energy conservation issues and nowadays, considerable progress has been made in promoting the solar renewable energy.

Many people believed that solar energy has contributed and will continue to contribute to the national and global energy utilisation strategies (Ponting, R. L, 1992). Solar energy is used in various parts of industrial and commercial sectors such as agricultural, transportation, communication and others. This paper will focus more on its utility in Built Environment (BE) context.

Why should the application of the solar renewable energy be concerned with BE development? Can't we rely on other energy sources such as natural gas, oil and coal which have been used centuries ago? How are we going to adapt this solar energy in a building design? This paper aims to explore all these issues and raise awareness on the dilemma of the BE development.

Solar Energy

The United Kingdom (UK) has taken several efforts in order to achieve a better and sustainable BE by governments, the scientific communities and environment organisations, such as implementing the new amended energy regulation in Building Regulation Part L (Building, 2001), the government's energy white paper which outlined targets for reducing carbon dioxide (CO_2) emissions from buildings (Building, 2003) and promoting solar non-polluting energy. One reason why solar energy is necessary is its so called 'free energy'. Furthermore, it is the principal source of energy in today's technological world (Porter, G. 1984).

Towards the millennium era, builder specialists have discovered numerous technologies concerning the BE. From the conventional method of construction to the revolution of the concept of sustainability, the development of BE has never stopped. Although development of new urban areas has been on-going, there is now the realisation of the impact buildings have on the environment. This leads to effort to try to minimise detrimental environmental effects and encourage the implementation of the concept of renewable energy and sustainable architecture.

Hence, construction industry and environment can never be considered separately. For example, building structures and fabrics contribute to the degradation of a clean environment from its energy consumption and CO_2 emission (Table 1). Furthermore, energy which is consumed from buildings has a significant impact on the environment by the way the buildings are built, the construction, their orientation and layout by creating shelter by planting design. Currently in the UK the heating of buildings makes up about half the total energy consumption of the nation; meanwhile Britain's construction industry produces 300 million tonnes of CO_2 (Edwards, B. 1999).

Thus, there is a close relationship between the building's performances and energy consumption with several environmental issues such as global warming, the implication of greenhouse gases and carbon intensity of energy supply, CO_2 emissions and depletion of the ozone layer. Therefore the environmental issue that will be addressed in this paper is the CO_2 emission which is a major contributor to green house and global warming effects.

Table 1: The Contribution of Buildings to UK Final Energy Consumption and CO_2 Emissions

Sector	Final energy use		Carbon emissions	
	PJ	% total	MtC	% total
Commercial and public buildings	880	13.1	21.2	15.1
Industrial buildings	282	4.2	5.6	4.0
Total non-domestic buildings	*1162*	*17.4*	*26.8*	*19.0*
Domestic buildings	1960	29.3	39.2	27.8
Total buildings	*3122*	*46.6*	*66.0*	*46.9*
Industrial processes	1231	18.4	27.7	19.7
Transport	2294	34.3	46.0	32.7
Agriculture	49	0.7	1.1	0.8
Total	***6696***	***100.0***	***140.8***	***100.0***

Source: Sorell, S. (2003)

Solar Architecture

Solar architecture can be defined as passive or active solar design. The application of passive and active solar strategies together with the adoption of energy conservation measures and the integration of new materials and technologies can lead to dramatic reductions of 75 - 90% in energy consumption of a building. Brief explanations on passive and active solar design are as discussed below.

- **Passive Solar Design**
  The definition of passive solar design (PSD) is the use of the sun's energy together with the local climate to maintain thermally comfortable conditions in buildings directly (United Nation Centre for Human Settlements, 1990). Moreover, it will use the form and fabric of the building to admit, store and distribute primarily solar energy which will reduce dependence on fossil fuel supplies and enhance the amenity of the building, at no extra construction or maintenance costs (O'Sullivan, P. 1985). Therefore, it is concluded that PSD will rely on the design and architecture of the building to capture and store solar heat which will be distributed around the building by natural thermal conduction, convection and radiation (Flood, M. 1983) without the use of mechanical equipment (Beggs, C., 2002).

- **Active Solar Design**
  Active Solar Design (ASD) is generally very visible with collectors on roofs, pumps, plumbing, control system and storage tanks (United Nation Centre for Human Settlements, *ibid*). It requires an external source of energy to transfer collected solar heat into the building and it consists of solar collectors and solar electric.

  Solar collectors come in a wide variety of shapes and sizes and will deliver heat across a broad temperature range. These collectors include solar pond, flat plate, vacuum tube, compound parabolic or central receiver. In solar electric, the solar heat will convert the light into electricity using semi-conducting photovoltaic cells (solar cells). ASD and some of its solar heat applications is summarised in Table 2 below.

Table 2: Active Solar Design Module

	TYPES	APPLICATION
Solar Collector	Low Temperature Heat (< 90°C) Medium Temperature Heat (90°C – 300°C) High Temperature Heat (300°C)	• Solar space heating • Solar water heating • Medium & high temperature heat for wide range of industrial application
Solar Electric	Thermal – Electric Photo – Electric Building Integrated Photovoltaic	• Remote site system used with batteries and an electronic charger • Grid connected system used in architectural application such as roof top, rain screen cladding, sun shading, curtain walling and roof lights and atria

Source : Flood, M. (1983)

Development of Solar Energy Sources in Built Environment

Solar energy has been used extensively since centuries ago where the Ancient Greeks used their knowledge to build several solar cities such as Olynthus and Priene while the Pueblo Indians of North America built several solar communities in the eleventh and twelfth centuries (Flood, M., *ibid*). However, at that time this development was designed intuitively and without detailed knowledge until awareness of the qualities and benefits of the sun developed.

During late 1940s up to early 1970s, most of the solar buildings were built when energy was cheap but building materials seemed to be expensive so, energy costs were simply taken for granted. As time goes by, people realise that saving energy can mean significant monetary savings as well as a greater level of comfort.

Then, in 1977 UK Government started their R&D and promotion of solar energy. In the early years since then, most of the work was directed towards PSD and continued but work on ASD systems was curtailed (Stainforth, D. et al, 1996).

However, since 1994 the solar programme has encompassed a range of solar technologies which have potential prospects for exploitation in the UK. The new and renewable energies including PSD and Photovoltaic (PV) are reviewed where further research and promotion are now being carried out by various builder specialists. Table 3 below shows the development of solar renewable energy programme funded by the Department of Trade and Industry.

Table 3: DTI New and Renewable Energy Market Programme Funding

	Million of UK £		
Programme Area	1992 – 1993	1993 – 1994	1994 – 1995
Passive Solar	2.09	2.28	1.48
Photovoltaic	0.20	0.10	0.56
Active Solar	0.012	0	0.014

Source : Stainforth, D. *et al* (1996)

Problems of Practising Solar As a Source of Energy in Building

To achieve best result from solar energy, the design and carrying structure might be required to keep the building weather-tight, keep sun from entering the building and allow daylight to enter the building, control glare, help insulate the building, allow the building to be ventilated, get as much sun on the surface of the building as possible and how to get maximum solar sources within obstructed area and disruption from adjacent building (Jones, D. L *et al*, 2000). Therefore, it is essential to predict at the design stage how the building will behave in practice and to ensure that a robust design is produced. Considerable analysis must be undertaken because failure to predict performance will lead to considerable problems and costly mistake can be made (Begg, C., *ibid*).

Towards a Clean Energy Scenario

Nowadays, fossil fuels represent the most important source of energy all over the world and in BE. Edward, B. *(ibid)* mentioned that these fuels are used first to produce building materials, then in the construction process and subsequently by the building's end-users throughout its 50-60 year life time. Pollutant emissions arise from their combustion accounting for 80 percent of greenhouse gas emission including CO_2 as the major contribution that cause acid rain (Muneer, T. *et al*, 2000) as shown in Table 4 below.

Table 4: Main Greenhouse Gases(Source from CIRIA,1993)

GREENHOUSE GASES	WARMING EFFECT (%)
Carbon dioxide	50
Methane	19
CFC 12	10
Tropospheric Ozone	8
CFC 11	5
Nitrous oxide	4
Water vapour	3
Other CFCs	2

As these gases build up in the atmosphere, more of the sun heat is trapped and warms the lower part of the earth atmosphere. The warmed air radiates the heat back largely in infrared, some will escape and some will return to hit the earth, trapping more heat in what has been termed the greenhouse effect.

According to the Carbon Performance Rating (CPR), suitable carbon emission factors (C) as in Table 5 below show the energy delivered by gas, oil, coal and electricity as among the type of fuel the building uses. This C is related to the extraction, processing and delivery of the fuel to the site.

Table 5: Carbon Dioxide Emission Factor (kgC/kWh)

Natural Gas	0.194
Oil	0.271
Coal0.293	
Grid Supplied Electricity (note 1)	0.422
Grid Displaced Electricity (note2)	0.568
Note 1 : this is the value to use for all electricity consumed in the building	
Note 2 : this is the value to use when crediting any on-site generation system	

Source : Office of the Deputy of Prime Minister (2004)

Since 1827 the issue of global warming has been studied when a French polymath discovered the existence of an atmospheric effect to the temperature of the earth and the analogy of a greenhouse effect. Overall, the moderate scenario brings CO_2 emissions 20% of the way back to 1990 levels by 2010. Therefore, the greenhouse effect, global warming and climate change generated by the human race are beginning to require improvements in building design and construction.

History of Policy Changes

There is an increasing level of legislation and policy addressing building energy impacts on environmental issues. Table 6 below shows some of the important changes towards a clean energy scenario in BE.

The policies and programmes include additional appliance efficiency standards, expansion of technical assistance and technology deployment programmes, an increased number of building codes and efficiency standards for equipments and appliances.

Table 6: Legislation, Energy Awareness and Environmental Issues

Legislation / Statutory	Content
1987 Montreal Protocol	Established an international agreement to phase out the production of various types of CFCs by 1996
1994 Building Regulation for England Wales	More stringent thermal performance and measures for new and refurbished buildings and covering energy efficient heating and lighting control
2001 Kyoto Protocol	First legally binding international agreement in reducing six greenhouse gases
Control of Fuel and Electricity	Specifies a maximum heating level of 19°C in all non-domestic buildings which in some circumstances reduces the comfort of occupants
BS 8207 : Code of Practice for Energy Efficiency in Buildings	Makes recommendation for achieving energy efficient performance in buildings which considers the design and operation of the buildings.
ISO 14001 : Environmental Management Systems	It requires monitoring of any significant environmental impact and a commitment to its reduction.
Building Research Establishment Environmental Assessment Method (BREEAM)	Judging buildings against environmental targets and standards.
Part L of the Building Regulation	Controlling solar overheating and the only important legislation on energy use in new buildings
Renewable Energy	The Europian Union 'Action Plan' to promote renewable sources of energy by the year 2010.

Source : Austin, B. S et al (1998); Edwards, B. *(ibid)*; Littlefair, P (2002) and Ross, T. (2001)

New Initiatives And Proposed Changes

With the effect of global warming mainly due to the dependence on fossil fuel, the UK government is now accelerating the development of energy from renewable sources where the Department of Energy estimated that by 2025 renewable energy would be providing 20 percent of Britain's energy demand (Edwards, B., *ibid*). Types of renewable energy in UK which are derived from solar can be identified as solar PV, solar hot water and PSD.

In solar PV, the use of electricity generated from it is increasing at 15 percent per year in Europe. Not only in UK, PV has been widely used especially in USA, Japan and Germany. Furthermore, the development of the PV industry will lead to an increasing market for Building Integrated Photovoltaic (BIPV) products and systems. It is believed that BIPV is suited to application in building projects where energy conservation and environmental acceptability are key issues (Rawlings, R. 2000). New initiative in BIPV is expected to grow significantly so that the installed capacity in the UK could be 50 megawatt peak (MWp) by 2005 to 300 MWp by 2010 compared to 2002 market size at only 1.5 MW. Furthermore, as part of the sustainable development movement, many aging concrete buildings will be refurbished in coming years and BIPV has great opportunities to be attached to an existing building to create a ventilated facade.

Meanwhile in PSD, further different strategies may be covered in housing and non-domestic buildings. As for the first time changes in Part L of the Building Regulations included a requirement to limit the 'exposure to solar overheating' (Littlefair, P., *ibid*), there will be great changes in PSD to comply with three specific ways of the requirement; limiting glazing area, limiting solar gain and using more detailed method and sound knowledge of construction.

Research That Has Been Carried Out

Several researches have been carried out in ASD and PSD application either during design stage or as a performance appraisal of several built Solar Buildings. Generally, these researches are funded by government or special agencies especially when the task consists of BIPV as a method of its construction.

Mei, L. *et al* (2003) have conducted thermal modelling of a building with an integrated PV façade. The building structure consists of the PV panel with double glazed window with a 14mm air gap in-between. The model was developed against an experimental data at Mataro Library, Barcelona. One of the methods in this research was a comparison of the energy consumption of the building in terms of heating and cooling loads for the PV facade and a conventional brick structure with glazed window. The result in Figure 1 shows that building with PV does not contribute to larger differences of energy consumption than the conventional building.

However, besides building energy consumption, this research does not include the assessment and impact of PV facades to the environment with respect to CO_2 emission.

Meanwhile, the Passive Solar Programme (PSP), funded by the UK has done research in order to achieve a good solar building performance and monitored over 30 PSD buildings. Dolley, P (1995) mentioned that the research was to determine the energy performance, the costs and amenity of existing and exemplars of domestic and non-domestic solar buildings. Surprisingly, only a few of the buildings had performed as expected by the designers. The various influences which cause the low performance included over-complicated design, the specifying materials did not implement the passive solar strategy, a cost cutting exercise which led to the omission of elements and incorrect usage of the building.

Table 7 : Research on Solar Technologies and Solar Building

PROGRAMME	RESEARCH DONE
Architectural Competition in 1979	• To seek the principles of passive solar design into European building design
3rd Programme in 1986 (ARCHISOAL)	• Introduction of energy conscious building and of energy-efficient building and PSD
PASCOOL Project (1992 – 1995)	• Environmental testing, model development, climate and design guidelines on natural ventilation configuration, thermal mass, solar control devices, thermal comfort and the overall performance of buildings
European Database in Indoor Air Pollution	• Emission data for individual building materials, HVAC components, complete HVAC systems and entire building
COMBINE 1	• Evaluation of resulting levels of indoor air pollution • Provide the interface for six performance evaluation tools covering heating and ventilation, internal space planning, thermal simulation, energy analysis, energy-economic design, geometric modelling and the design of external building elements
INNOBUILD	• Develop and implement energy-efficient building products and technologies to heat, cool and light more efficiently and reduce pollutant emission level
Solar House Intelligent Envelope Components	• The incorporation of photovoltaic cells into conventional facade components
READ Group	• Leading architects agreed to develop Solar City with the principles of sustainable energy and environmental utilisation
APAS-RENA	• Comprised ten projects relating to renewable energies, assessment and evaluation of combined electrical and thermal energy production

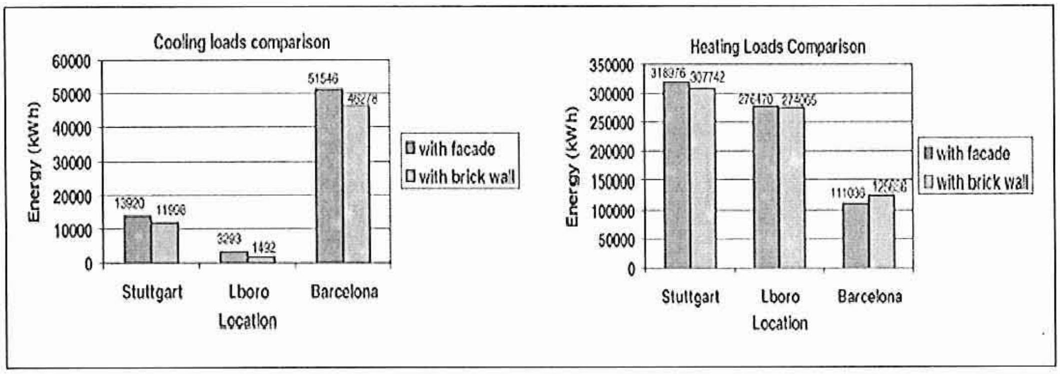
Source : Lewis, J. O *(ibid)*

On the other hand, The European Commission's (EC) energy R&D programmes have completed two decades of Solar Building development progress (Lewis, J. O., 1996). The progress and contribution are as summarised in Table 7 below. All these programmes and research address all of the issues in energy efficiencies and renewable energies and pollutant emission level, and should help the buildings continue and make use of solar technologies and thus contribute to a more efficient use of energy.

The Potentials

ASD and PSD are expected to be extremely developed due to the high level of awareness in low energy building theory. Many believed that by adopting either ASD or PSD their building can save more energy and be environmental friendly.

Figure 1: Cooling and Heating Load Comparison



Source : Mei, L et al *(ibid)*

Passive Solar Design Potentials

PSD is a proven design approach that may achieve great energy efficiencies and cost effectiveness (DTI, 2003) and is expected to continue to evolve and grow as part of the practice of good building design.

A commitment to passive cooling and a low energy strategy has led to numerous amendments to the glazing in an effort to control radiant heat gain (Cadji, M. 2000). Meanwhile Stainforth, D., et al *(ibid)* described these amendments including a number of new glazing materials which range from multi-pane coated glazing through to electrically controlled variable transmission films and evacuated glazing with U-values almost as low as walls. When the glazing is applied, a significant energy impact could be extremely beneficial.

Passive cooling possesses environmental, economic and human comfort benefits (Grace. J, 1999). By proper environmental design, at least 2.35% of the world energy output could be saved and make comfortable conditions even with average peak temperatures as high as 31°C. In terms of being economical, the passive solar building has a design life of 50 years where the structural shell of the building requires only 45% of the initial construction costs. By comparison, the air conditioning plants make up to 20% of the construction cost and will have to be replaced twice during the life of the building and require regular maintenance works.

Furthermore, PSD offers greater thermal stability with respect to human comfort. Radiative cooling from a thermal store is associated with higher level of occupants' satisfaction than air-based comfort cooling systems. On the other hand, PSD does not require significant capital investment where no maintenance, replacement and products test are needed.

Active Solar Design Potentials

In Jones, D. L. *et al (ibid)*, the potential benefits of BIPV include its ability to be integrated into building fabric, supply at the point of use, silent operation, low maintenance and inexhaustible supply of free electricity.

The electricity generated by a PV cladding system can be exported to the grid or used within the building. Using the electricity produced from them has several advantages since it avoids transmission losses and displaces electricity imported from the grid which is at a higher rate (Stainforth, D. *et al*, *ibid*).

In IEA Report (2001), to determine the BIPV potential for selected IEA countries, it can be calculated using a formula comprises of building type, available area per capita given in m², utilisation factor of 0.4 for roofs and 0.15 for facades, population size of people in a country, solar yield, solar irradiation, global conversion efficiency and the production of solar electricity. As a result, figures for the solar electric BIPV potential are tabulated in Tables 8 and 9 below.

Table 8: Solar Electricity BIPV Potential in UK

	Potential on Roof	Potential on Facades	Potential on Building Envelope	Actual Electricity Consumption	Ratio 'solar electricity production potential electricity consumption'
Solar Electricity BIPV Production Potential	83.235	22.160	105.395	343.58	30.7 %

Source : IEA for Electricity Consumption in 1998 published in IEAReport (2001)

Table 9: BIPV Area Potential for Roofs and Areas in UK

		Residential	Agriculture	Industrial	Commercial	Others	All Buildings
BIPV Area Potential (km^2)	Roof	601.88	71.09	61.61	168.24	11.85	914.67
	Façade	225.70	8.89	23.10	84.12	4.44	343.00

Source : IEA for Electricity Consumption in 1998 published in IEA Report (2001)

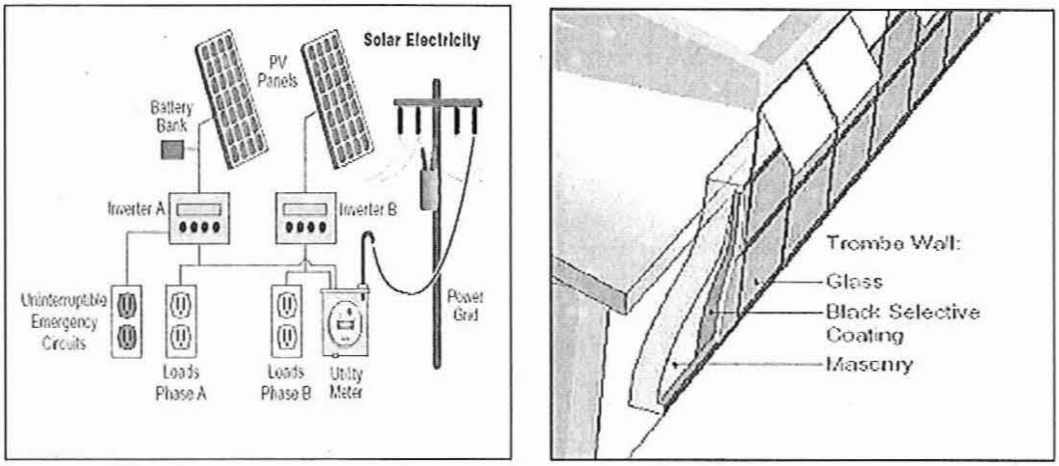
Potential in Combining PSD and ASD Building

Nowadays, there are several buildings which combine the PSD and ASD approaches in their buildings. One significant example is the Solar Office, Doxford International. At first, optimum conditions for PV power generation conflict in many areas with PSD adaptation even though its installation has been determined at the early stages of the design. However, after rigorous testing, it is proved that this combination is capable of being met. Besides, Figure 2 below is another example of buildings which combined the PSD and ASD approach with respect to the installation of PV system and Trombe Wall.

The PV panels installed at the South facade provided the majority of the electricity needed for the building. On the other hand, the Trombe Wall will provide most of the heating for the building. The warm surfaces provide radiant comfort to the visitor.

Another building is the Solar Energy Research Facility which is built at Colorado (Figure 3). The approach is similar as in the above building where the PV systems are installed as well as the Trombe wall.The installation of PV panel is tied directly to

Figure 2: Installation of PV and Application of TW at Zion National Park Visitor Centre



Source : US Department of Energy (2000)

the building's electrical supply and integrated with the building design. Moreover, the Trombe wall helps to heat part of the building along the South-face of the wall.

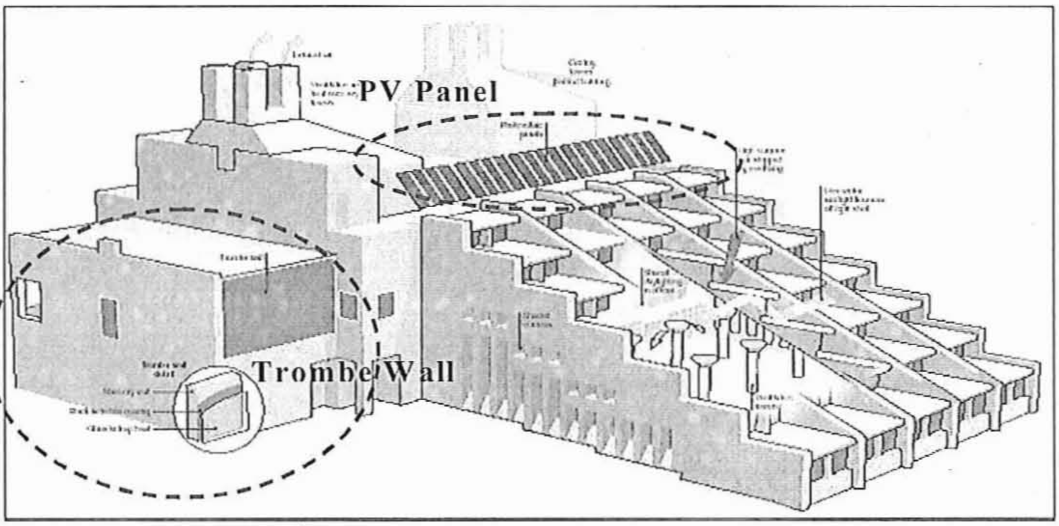
The Difficulties

Difficulties in adopting these theories may influence the development of a good Solar Building Design. However, whether it is identified as a weakness of the design or as threats of the development, the PSD and ASD difficulties still need to be known.

Passive Solar Design Difficulties

Beggs. C, *(ibid)* mentioned that to create a good passive building the designer must have a comprehensive knowledge and understanding of heat transfer and fluid mechanics. This is due to the rigorous

Figure 3 : Location of Trombe Wall and PV Panel at The Solar Energy Research Facility, Colorado



Source : US Department of Energy (2001)

analysis that has to be taken at the design stage where a considerable problem may arise and costly mistakes can be made. The major problem is how to predict the behaviour of the buildings in practice.

It is suggested that to assist in the design of passive buildings, designers have to use complex and powerful tools such as 'computational fluid dynamics' to predict accurately but the costs involved are high and in need of expertise.

Generally a PSD Building is found to be unsuitable for larger complex building types as they can place severe constraints on the overall building. If the building envelope is poorly design, over-heating problems may occur during the summer months.

Therefore, the building still needs a supplementary mechanical plant to maintain a comfortable environment.

Active Solar Design Difficulties

The installations of PV systems have several difficulties as in PSD building. The efficiencies may decrease when they reach their lifetime warranty as well as when the temperature rises due to the lacking of ventilation provision. Therefore, the PV cells need to be replaced and required regular maintenance.

On the other hand, it is difficult to provide the building with adequate sizing of PV array with respect to the required load of the building. Budget and available area of façade or roof may differ.

Nowadays, BIPV systems are still expensive although costs have been going down. However, rapid development in PV technologies is likely to bring down the costs further. Table 10 indicates the comparison of conventional approach against the PV installation in a building.

Table 10 : Approximate Breakdown of Costs for BIPV Systems and Comparison With Conventional Building Elements

System / Element	Installed cost (£/m²)
PV curtain walling, glass/glass crystalline modules	780
PV curtain walling, glass/glass thin film amorphous modules	250
Conventional wall system- double glazing	*350*
- cavity wall (brick/block)	*50-60*
- stone cladding	*300*
- granite faced pre-cast concrete	*640*
- polished stone	*850 – 1 500*
PV rainscreen cladding	600
Steel rainscreen over cladding	*190*
PV roofing tiles (housing estate)	500
Roofing tiles (clay/concrete)	*32*
PV modules on a pitched roof (large office)	650
Aluminium pitched roof	*44*

Source : Rawling, R. *(ibid)*

Conclusion

Following from the above discussion, it is clear that the problems which need to be solved nowadays are reducing the pollutant level especially CO_2 from the building materials, components and systems through an energy-efficient building. As there is significant development in renewable energy and sustainable materials, solar architecture and solar energy hopefully can achieve the aim of energy efficiencies and carbon saving. Several researches on Solar Technologies and Solar Building optimistically will create a new dimension of a clean BE scenario. Furthermore, the potentials of solar energy which can be used in a building either passively or actively need to be explored whilst the difficulties may not hinder the development of this energy.

References

Austin, B.S. *et al* (1998), *CIBSE Guide F – Energy Efficiencies in Building*, CIBSE, London

Beggs, C. (2002), *Energy – Management, Supply and Conservation*, Butterworth Heinemann, Oxford

Building (2003), *So Much Energy, So Little Time*, 4/03, available from http://www.bsjonline.co.uk

Building (2001), *No More Hot Air*, 3/01, available from http://www.bsjonline.co.uk

Cadji, M. (2000), *Here Comes the Sun*, RIBA Journal, 7/00, available from http:www.bsjonline.co.uk

CIRIA (1993), *Environmental Issues in Construction*, (Vol. 2), Technical Review, pg 25

Dolley, P. (1995), *Good Intentions: Are They Enough to Achieve Good Solar Building Performances*, Renewable Energy, Volume 6, No.3, pg 353 - 358

DTI (2003), *Passive Solar Design*, available at http://www.dti.gov.uk/index.html

Edward, B. (1999), *Sustainable Architecture 2nd Edition*, Architectural Press, Oxford

Flood, M. (1983), *Solar Prospect: The Potential for Renewable Energy*, Wildwood House, London

Grace, J. (1999), *Design Issues for Thermal Stores*, Building Services Journal, 7/99, available at http:www.bsjonline.co.uk

IEA Report (2001), Potential for Building Integrated Photovoltaic, IEA International Agency Agency, Report IEA – PVPS t7 – 4: 2001 (Summary)

Jones D.L *et al* (2000) *BIPV Projects (Photovoltaic in Buildings)*, DTI New and Renewable Energy Programme, Norwich; Page Bros

Lewis, J. O. (1996), *Solar Building – European Union Research And Development Programmes*, Solar Energy (Vol. 58), pg 127 - 135

Littlefair, P (2002), *Controlling Solar Overheating*, Building Services Journal 11/02, available at http://www.bsjonline.co.uk

Mei, L. *et al* (2003), *Thermal Modelling of a Building With an Integrated Ventilated PV Façade*, Energy and Building (Vol 35), pg 605 – 617

Muneer, T. *et al* (2000), *Windows in Buildings – Thermal, Acoustic, Visual and Solar Performances*, Architectural Press, Oxford

Office of the Deputy Prime Minister (2004), *Proposal for Amending Part L of the Building Regulation and Implementing the Energy Performances of Building Directive*, A Consultation Document, Section 4/pg 9

O'Sullivan, P. (1985), *Passive Solar Technology and Their Application in Existing and New Technology*, Passive Solar Energy in Building, Elsevier Applied Science Publisher, London

Ponting, R. L (1992), *Exploring the Limits of Solar Power: Defining the Boundaries and Pushing the Envelope*, Solar Energy Technology – 1992, presented at the Winter Annual Meeting of The American Society of Mechanical Engineers Anaheim, California, November 8 – 13, 1992, The American Society of Mechanical Engineers

Porter, G. (1984), *Criteria for Solar Energy Conversion*, Light Chemical Change and Life: A Source Book in Photochemistry (2nd Edition), Walton Hall, Milton Keynes

Rawling, R. (2000), *CIBSE TM 25: 2000 – Understanding Building Integrated Photovoltaic*, DETR (London)

Ross, T. (2001), *No More Hot Air*, Building 03/01, available at http://www.bsjonline.co.uk,

Sorell, S. (2003), *Making the Link; Climate Policy and the Reform of the UK Construction Industry*, Energy Policy 31, pg 865 – 878

Stainforth, D. *et al* (1996), *An Overview of the UK Department of Trade and Industry Programme in Solar Energy*, Solar Energy (Vol. 58), pg 111 – 119

United Nation Centre for Human Settlement (1990), *National Design Handbook Prototype on Passive Solar Heating and National Cooling of Building*

US Department of Energy (2000), Zion National Park Visitor Centre (A Sustainable Building for the Future), DOE National Laboratory

US Department of Energy (2001), *The Solar Energy Research Facility (Highlighting High Performance)*, DOE National Laboratory