INTEGRATION OF SOLAR BUILDIGN TECHNOLOGIES IN AN OFFICE BUILDING, CHANGZHOU, CHINA

Wang Yan[1], Zhong Jishou[2], Zhang Lei[2]

[1] **China Architecture Design and Research Group, Beijing (China)**

[2] Special Committee of Solar Buildings, Chinese Renewable Energy Society, Beijing (China)

Abstract

This paper presents a demonstration project concerning the solar building integration design idea for an office building located in south part of China. The project client is a manufacturer of PV products, with relevant system design and installation. Thus, it has strong desire to lay out the PV products via the office building facade. On the other hand, the local climate is humid through the whole year and sweltering in the summer, which prefers passive solar technologies. How to effectively integrate the active and passive solar technologies into the office building is the emphasis of the project design.

Based on the weather characteristics and client requirements, the project develops solar building integration approaches to improve the solar technology diversity, efficiency and to reduce the CO_2 emission for the buildings. The solar energy technologies are integrated and applied includes PV, natural ventilation, atrium lighting, respiration façade and roof planting. The software simulation and on site testing by instrument are adopted and compared to validate the design ideas. The results show that via the application of these technologies, the used approaches and technologies adapt well to the local climate and satisfy the requirements of the enterprise's image as well.

0. Introduction

The project office building of Changzhou Trina Solar Energy Co., Ltd locates in the South of China's Yangtze River, where is hot in summer and cold in winter, the region's climate is characterized by the hot and humid summer season (up to 5 months), the winter is cold, short and perennially wet throughout the year. Therefore the cost for cooling and dehumidification of an office building in this region is very high, and creates a significant financial burden for the building owners.

Tab.1 Brief introduction of the site (China Academy of Building Research, 2003)

Latitude	**32º**
Maximum average Temperature/RH in summer	31.4℃/81% (Jul)
Minimum average Temperature/RH in winter	-3.0℃/73% (Jan)
Average wind Velocity in summer	2.6m/s
Solar Irradiation and Hours	4530MJ/sqm•a, 2049 hr/a

From 2006 to 2010, Chinese government carried out The National "Eleventh Five-Year" S&T Plan, building integrated renewable energy and relevant technologies are included in the main research contents. The initial design for Changzhou Trina Solar Energy Co., Ltd includes abundant use of renewable energy, and in combination with the building construction it focuses on lowering building energy cost principles. The project was completed in 2008, after two years of operation and testing, and in 2010 it was successfully classified as the demonstration project for National Technology Support Program in Building Integrated Renewable Energy Technologies.

1. Solar Building Integration Strategies

In order to achieve the targets of highly solar building integration with low environmental impact, the following three strategies are complied in the project:

1.1 Environmental friendly and ecological sounded

Recent ten years, the environmental protection and ecological development become a main trend. The impact on the ecological environment should be limited from the beginning of building construction till the daily operation, especially for the public building.

1.2 Affordability and accessibility oriented

In order to enlarge the application range of solar building technology, low-cost and easy-handle technologies have to be adopted to reduce energy costs by the utilization of local renewable resources, especially with passive design method.

1.3 Promotion and propaganda approached

The purpose of the demonstration project is not only to reduce the energy cost, but also to encourage more people to participate in the activity of reducing CO_2 emission. Thus, the technologies chosen should become easy-available, easy-handle, dependable, convenient-maintained, and can be promoted in local office building construction.

2. Description of the Demonstration Project

The project is located in Changzhou City, Jiangsu Province, within the light engineering and technology centre in the Changzhou High-tech Development Zone, a public building (Fig. 1). Trina Solar Energy Co., Ltd is a recognized manufacturer of high quality monocrystalline modules and has a long history as a solar PV pioneer since it was founded in 1997 as a system installation company in China.

The building construction area covers 3880.93 ㎡， consists of 4 floors above ground, a height of 17m, in the form of frame structure, an operation lifetime of 50 years. Building functions mainly includes routine office work, display of main products and business negotiation. Exterior wall has two types, one is made up of 200 mm thickness small aerated concrete blocks, another is a compound one made up of 50mm thickness solid polyurethane layer with bobbles and 120mm thickness bricks with K=0.4W/(㎡℃) (China Academy of Building Research, 2005). Exterior windows are made up of thermal insulating aluminum single layer window plus single frame and 12mm thickness insulating glass with K=2.4W/(㎡℃). Glass curtain wall is made up of aluminum frame and 12mm thickness no-color Low-E insulating glass, radiation rate is lower than 0.15 with K=1.8W/(㎡℃).

Fig. 1 Building Appearance

(photo by Wang Yan, 2009)

3. Technologies Applied and Integrated

The project located in the South of Yangtze River, in the region that is hot in summer and cold in winter, taking into account that cooling load in summer is larger than winter heating load, and high demand for cooling ventilation and dehumidification, in combination with investment limit and advantage of the building owner being photovoltaic cell manufacturer, the research group decided to adopt passive solar energy use as the main integrated solar technology in line with the characteristics of southern climate. Integrated technologies include: PV, natural ventilation, atrium lighting, respiration façade, sun room, heat recovery and green roof.

3.1 PV system

The PV system covers two parts (Fig.2), vertical PV façade and PV rooftop. PV Façade contains TSM DT 180 type PV modules, 78 panels creates a “T” -type distribution that covers 182 m^2. PV rooftop contains TSM DT 60 type PV panels, 160 panels in rectangle distribution with an area of 123 m^2. Four inverters with single capacity in 5kW are adopted.

Fig. 2 PV Façade and Rooftop Installation

(photo by Wang Yan, 2009)

By using RS485 communication cable and A/D data simulator, the analog signals from the PV system is converted into digital signals, at the same time data is uploaded to FTP, so that the query and analysis could be carried out.

3.2 Natural ventilation

The north side of the atrium and the southern entrance to foyer form a natural ventilation path. At the mean time, wind is pulled from east and west chimney to corridor of each floor forming natural ventilation paths (Fig.3).

Fig. 3 Summer Ventilation Diagram

Since the office is a public building, during the day it needs to operate air-conditioning system, natural ventilation will increase energy consumption. Outdoor temperature at night swings 5～7℃ lower than during the day, thus adopting night ventilation measures, i.e. using hot air pressure to achieve ventilation, can reduce the hot air gathered in the room, particularly in upper atrium. Next day the room temperature is lower than usual when operating the air-conditioning system, thus energy efficiency is achieved.

Monitoring using contrast comparison method, under similar weather conditions, monitoring the effects on indoor humidity, carbon dioxide concentration and wind speed, respectively with and without night ventilation, then compared and analyzed with software simulation results.

3.3 Atrium lighting

Atrium uses PV as shading devices (Fig.4), to regulate light level in both summer and winter season, in combination with indoor ventilation, achieving "warm winter and cool summer" indoor climate, in order to meet energy saving requirements.

Fig. 4 Atrium Lighting and Shading

(photo by Wang Yan, 2009)

3.4 Respiration façade

In summer, the ventilation can vent out the indoor hot air along the air flow. During winter, outdoor circulation is closed, only indoor circulation is used so that solar energy can heat up indoor air (Li Yuanzhe, 1993) (Fig.5).

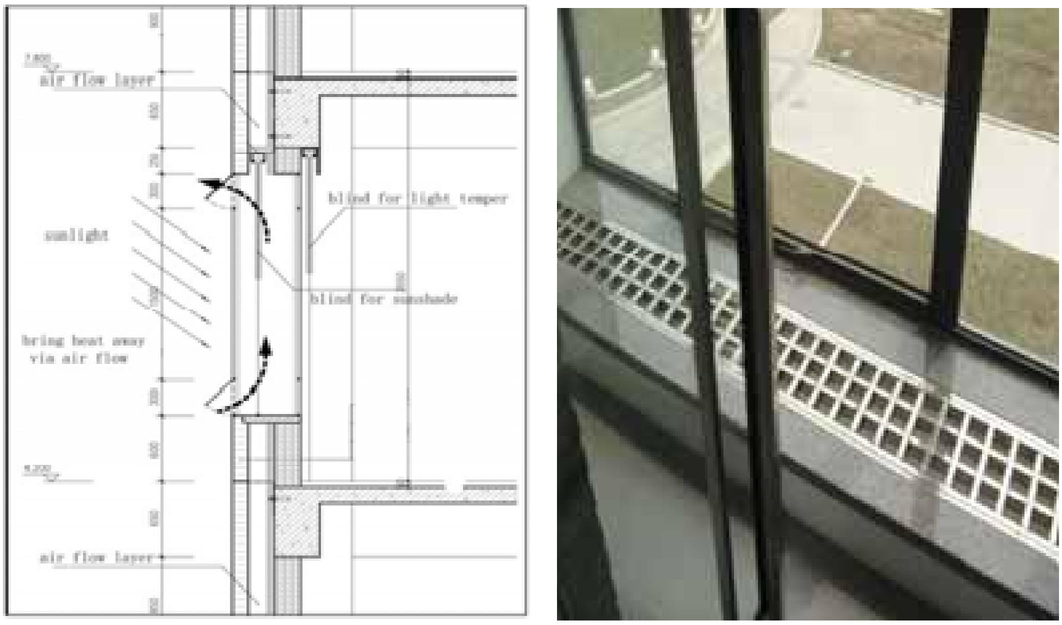


Fig. 5 Schematic Diagram of Summer Conditions

(photo by Zhang Peng, 2009)

3.5 Planting roof

The roof is covered by a area of 600 ㎡ of vegetation, which not only reduces roof temperature also provides leisure space (Fig.6).

Fig. 6 Planting Roof

(photo by Zhang Guangyu, 2010)

4. Evaluation

In order to evaluate the technologies used in the project a durative monitoring and a valuation of the performance of the building have been in process by environment simulation software. Key indicators for evaluation including electricity generation, indoor thermal environment changes, energy consumption for cooling and CO_2 emission are monitored and evaluated.

4.1 PV system

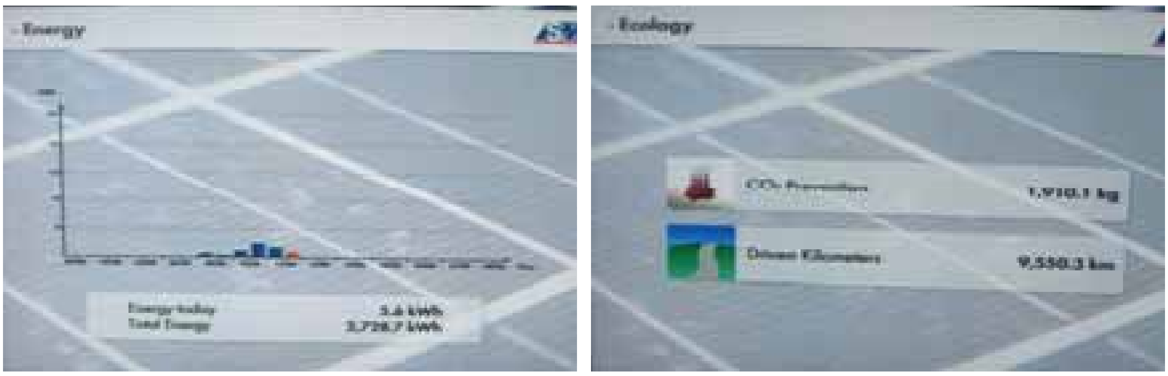


Fig. 7 Electricity generation screen

(photo by Wang Yan, 2009)

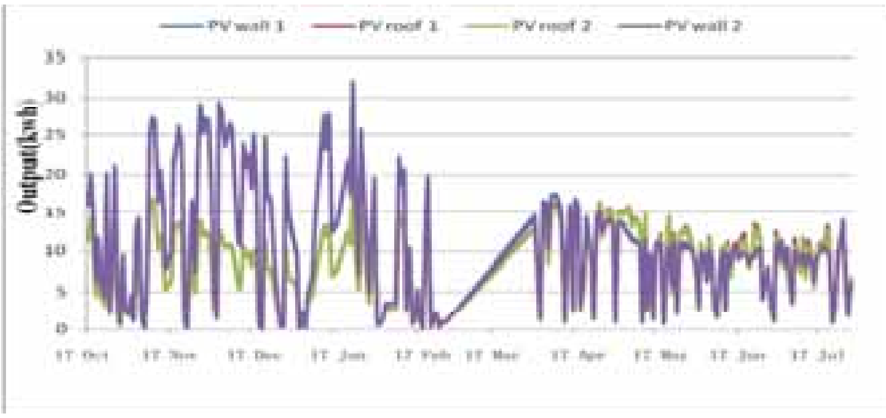


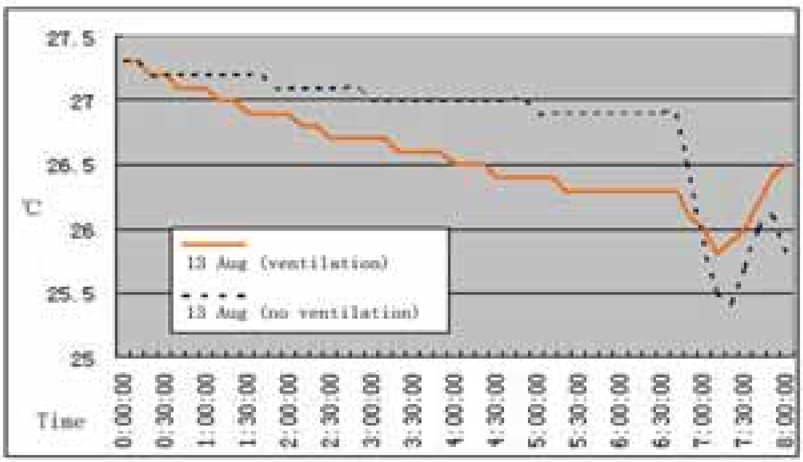
Fig. 8 Annual Statistics of Electricity Generation in Comparison with PV Façade and PV Roof

Fig. 8 shows that during the monitoring period, PV façade system (PV wall 1and PV wall 2) generates more power than PV roof (PV roof 1and PV roof 2). In winter, PV façade system generates a much larger amount of electricity than PV roof, whereas the difference between the two is relatively small during spring and summer. From Fig. 8 it is known that PV systems generates more electricity in winter and less in summer, this is caused by the impact of rising temperature on the PV systems. However the drop in power generation in February, in reference to weather records, is caused by the large number of cloudy days and severe fog.

Statistics show that office PV systems generates a total of 14003 kWh electricity a year, renewable energy replacement rate is 3%, annual saving of tons of equivalent coal is 5.6 tons, equivalent to annual saving of 9.8 tons of CO_2 emission.

4.2 Passive solar building technology

Using natural ventilation measures means opening the windows on the south-facing PV facades, the northern windows on top of the lobby, the doors and windows in the ventilated smoking (chimney) area at the East and West corridor ends, and the main door joining the office. Passive solar building technologies including natural ventilation, atrium lighting, respiration façade and sun room, after monitoring and adopting natural ventilation, are found to significantly lower the indoor temperature after operating air-conditioning system at 8:00 am, as shown in Fig. 9. After working hours the indoor CO_2 concentration is also at a relatively low level (Fig. 10).



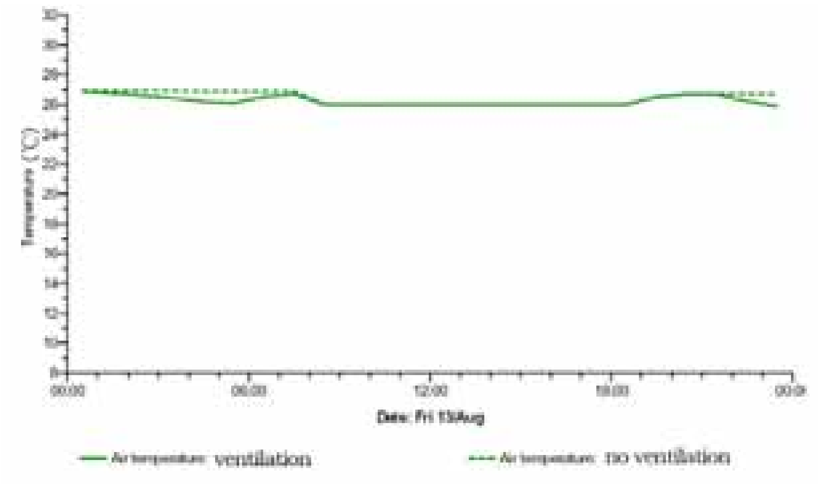


Fig. 9 Temperature Measured of First Floor Atrium Compared with Simulation

Fig. 9 shows that due to air sinks and accumulates during the day, temperature changes only slightly, only after temperature difference reaches 0.5℃ at around 6:30, temperature of first floor atrium rapidly reduces, when switching on air-conditioning system there is basically no difference. Diagram to the left shows, after the comparison and analysis of software simulation, that two curves have similar patterns before switching on the air-conditioning system at 8:00 am, therefore measured results are consistent with simulation.

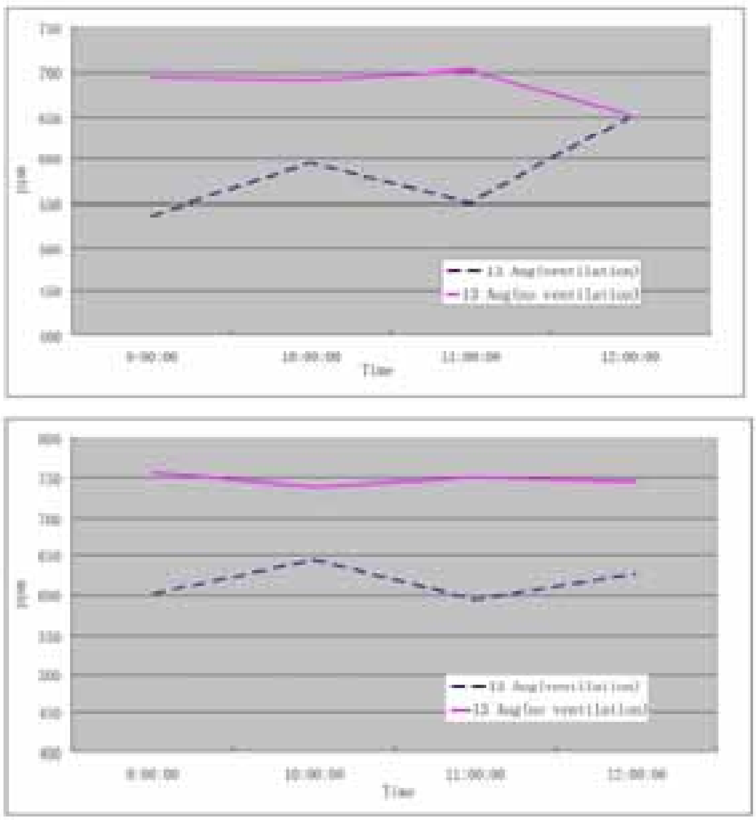


Fig 10 CO_2 Concentration Comparison of First and Fourth Floor Atrium

On the other hand, shading effect of PV and glass façade is analyzed through infrared thermal imaging instrument as shown in Fig 11.

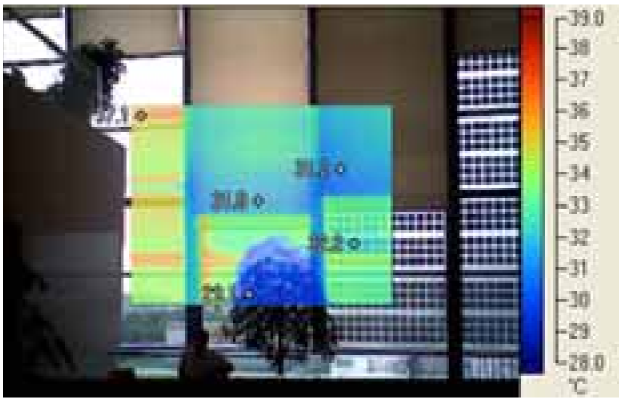


Fig. 11 Atrium Shading Effect

Fig. 11 shows picture of the shading effect of the glass façade in atrium. It is clear that the part of glass façade not shaded by PV panels can reach up to 37.1℃, whereas part not covered by PV but with indoor shading device reaches to 31.8℃, and part only shaded by PV panels reaches to a temperature of 32.2℃. This means that using indoor shading device gives a better shading effect than using PV panels alone. The best shading effect can reach the lowest temperature of 31.2℃, this is achieved by using both PV and indoor shading device.

By using British building energy analysis software IES-VE (Virtual Environment), the Trina office building energy consumption is modeled and analyzed:

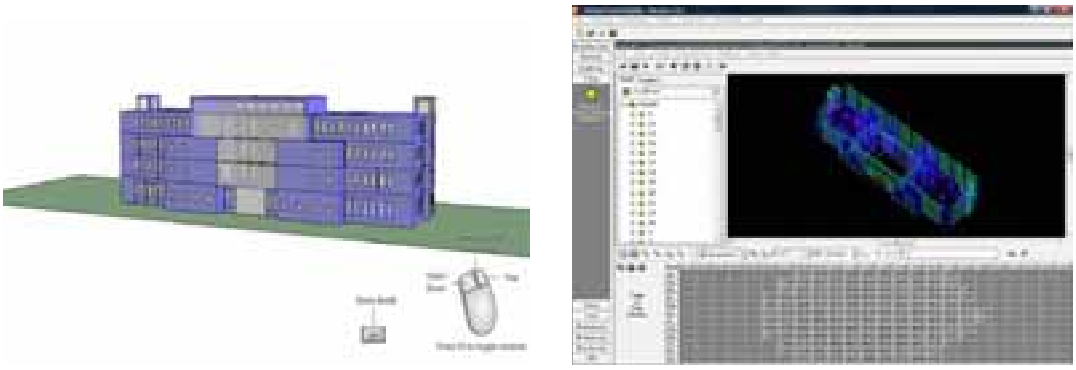


Fig. 12 Office Building Model

Month	Heating (boilers etc.)	Cooling (chillers etc.)	Fans, pumps and controls	Lights	Equip.
Jan	4.805	0.000	0.875	7.290	8.302
Feb	2.905	0.000	0.577	6.730	7.691
Mar	0.570	0.000	0.099	7.571	8.652
Apr	0.000	0.000	0.000	7.290	8.302
May	0.000	4.515	3.419	7.290	8.302
Jun	0.000	9.665	5.892	7.290	8.302
Jul	0.000	14.528	7.777	7.571	8.652
Aug	0.000	13.546	7.344	7.290	8.302
Sep	0.000	8.412	5.409	7.290	8.302
Oct	0.000	1.777	1.491	7.290	8.302
Nov	0.149	0.000	0.016	7.290	8.302
Dec	2.076	0.000	0.366	7.571	8.652
Total	**10.505**	**52.441**	**33.266**	**87.765**	**100.302**

Total energy consumption = 284.279 MWh

Month	Heating (boilers etc.)	Cooling (chillers etc.)	Fans, pumps and controls	Lights	Equip.
Jan	2.916	0.000	0.505	7.290	8.302
Feb	1.653	0.000	0.285	6.730	7.691
Mar	0.207	0.000	0.022	7.571	8.652
Apr	0.000	0.000	0.000	7.290	8.302
May	0.000	8.533	5.503	7.290	8.302
Jun	0.000	11.634	6.664	7.290	8.302
Jul	0.000	15.211	8.025	7.571	8.652
Aug	0.000	14.506	7.881	7.290	8.302
Sep	0.000	10.597	6.285	7.290	8.302
Oct	0.000	3.492	2.449	7.290	8.302
Nov	0.073	0.000	0.004	7.290	8.302
Dec	1.001	0.000	0.143	7.571	8.652
Total	**5.849**	**63.872**	**37.566**	**87.765**	**100.302**

Total energy consumption = 295.455 MWh

Fig. 13 Calculation Results Comparison between Two Situations

(With Natural Ventilation and without Natural Ventilation)

After using natural ventilation during summer and transition seasons, the second situation consumes 11176kWh more energy than first situation, accounts for 11% of cooling energy consumption, building annual energy saving is 3.8% of the total energy consumption, plus atrium lighting can contribute 1.8% of energy saving, total energy saving rate is 5.6%, which summarizes that the renewable energy replacement rate of passive solar technologies, for the Changzhou climate region where the project is taken place, is 5.6%, saving about 10.5 tons of standard coal a year, equivalent to saving 18.6 tons of CO_2 emissions a year.

5. Conclusion and discussion

5.1 Total energy saving

The PV system accounts for 3% renewable energy replacement rate, together with the 5.6% from passive solar technologies, the total renewable energy replacement rate is 8.6%.

5.2 Project investment estimation

An example of incremental cost estimation, the cost of PV system increases: 1.2 million RMB (1 Euro approx. equal to 10 RMB), heat recovery and air exchanger cost increases: 0.16 million RMB, so total project investment increase: 311.8 RMB/㎡.

Besides, the natural ventilation, atrium lighting and respiration façade are accounted within the building construction cost, it is relatively small compared with conventional building, therefore can be neglected.

5.3 Impact of PV Module surface temperature on power generation efficiency

From October to January, the power generation efficiency of PV system is higher, however from March to July the efficiency is very low, therefore it can be concluded: the surface temperature of PV directly affects the power generation efficiency. Lower PV surface temperature, the efficiency of the system is then higher; higher surface temperature, then lower efficiency. Furthermore, the amount of solar radiation, solar incident angle, corresponding reflectance and temperature have a greater impact on generation efficiency compared to PV surface temperature, however there is a large amount of solar radiation available during spring and summer, but the PV efficiency still reaches the lowest and supports the conclusion, this is more obvious in the façade PV system.

5.4 Organization and management experience

During design, clients often make a variety of requirements, design process is easy, equipments can be bought, but operation and management are difficult. The design of renewable energy technologies largely depends on management and operation, for example, cleaning of PV panels, operating ventilation, the use and maintenance of roller blinds, operating heat recovery system and maintenance of the roof plants etc. Providing staffs with management training is a must, only when staffs know how to operate the technologies can they be working effectively, otherwise they fail to deliver and it would be a waste of investment.

5.5 Variety of technologies should not be adopted blindly

China is still in the primary stage of socialism, different variety of technologies should not be used blindly for the sake of image, low-cost solar energy technologies are the most suitable for China today.

5.6 Feed-in tariff should be increased

Compared with developed European countries, China’s feed-in tariff is still relatively low, feed-in tariff system has not fully matured, this reduces the positive impact on the development of enterprises.

5.7 Passive technologies testing

Research found that the effects of passive solar technologies such as natural ventilation are difficult to determine using measurement data, in comparison with active solar technologies such as PV, solar thermal etc. Software simulation parameters cannot reflect the true situations in which people use the building, therefore the simulation results show a relatively large difference from building’s actual energy consumption. How to effectively quantify the effect of passive solar technologies will be the direction of further research.

Acknowledgement

The research in this paper is funded by China National "Eleventh Five-Year" S&T plan with project number of 2008BAJ08B020, named as “Integration and Demonstration of Energy Efficiency Technology Standard Mode Research in Village and Small Town”.

References:

[1] China Academy of Building Research, 2003. Code for design of heating ventilation and air conditioning GB 50019-2003[S], China Architecture & Building Press, Beijing.

[2] China Academy of Building Research, 2005. Design standard for energy efficiency of public buildings, GB 50189-2005[S], China Architecture & Building Press, Beijing.

[3] Li Yuanzhe, 1993. Passive solar house design and construction, [M] Tsinghua University Press, Beijing.