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The Application of Solar Technologies in Building Energy Efficiency - A Review

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ABSTRACT

At present, building energy consumption is growing rapidly in China and it accounts for about 30% of the total energy consumption. Firstly, this paper briefly introduced the characteristics and distribution of solar energy resources in China. Secondly, this paper summarized the three types of solar energy utilization: light-gathering utilization, solar energy photo-thermal utilization and photovoltaic utilization

Keywords: Solar technologies Solar-powered residential buildings Passive SPRBs Active SPRBs BISE design

1. INTRODUCTION

Sustainable development. With speeding urbanization and new rural construction, building area is rising at an annual rate of 2 billion m2 and the total building area has exceeded 40 m2 [32]. Meanwhile, the proportion of building energy consumption in the total energy consumption has risen from 10% in the late 1970s to about 30% in 2010, about a tripling with an annual growth of 5.64% [10,13,21,30. 33]. The situation of energy consumption in 2010 is shown in Fig. 1. In terms of energy demand, supply and consumption, coal plays a dominant part in China, making up 70 percent of its fuel consumption.

In China has exceed the national standard and SO2 concentration in many cities has exceeded national second-class emission standard. In addition, according to the energy reserves and

development intensity calculation, the world fossil energy on average less than one hundred years development time already [7,15,20,27].

Solar energy, as one kind of thermal radiation energy, is also a kind of non-pollution clean energy. For the development and utilization of renewable energy, solar energy has become one of the important research projects for energy saving and environmental protection all over the world.

Nowadays, China appears to be facing the challenges of population expansion and an energy shortage. With rich solar resources in most areas of China, it is an opportunity to develop solar energy and to promote energy saving buildings, which fully reflects the concept of sustainable development and green ecological energy-saving. In the second section, authors have briefly introduced the characteristics and distribution of the solar energy resources in China; meanwhile, the main forms of solar energy utilization are summarized. Next, the utilization of photo-thermal technology in solar-powered residential buildings (SPRBs) is analyzed from the perspective of current technology and economic benefit.

In the fourth section, based on the analysis of active SPRBs and passive SPRBs, the authors have put forward the building integrated solar energy (BISE) design to integrate technology and aesthetics, aiming to realize the harmony between solar technologies and building appearance. This approach alleviates some of the biggest challenges to solar energy adoption and provides a path forward for this technology. [33]

2. THE SITUATION OF SOLAR ENERGY

2.1. The characteristics of solar energy

Solar energy, as the most important basic energy of all sorts of renewable ones, is the most important abundant permanent resources on the earth. Compared with the conventional energy, solar energy has many advantages as following: inexhaustible, clean, safe, reliable and pollution free. And at the same time, there are two main deficiencies in this renewable energy. The first one is dispersion, which is caused by the low solar energy flux density. Near the tropic of cancer, the mean solar energy flux density is 200 W per day, but only half of that in winter and about 1/5 of that in cloudy day.

Another disadvantage of solar energy is discontinuity and instability, and it is caused by the natural conditions, such as day and night, season, geographic latitude and altitude, and it is influenced by the random factors, such as the weather.

According to statistics, the annual total solar energy is 1 1018 kW h, which is equivalent to 13 trillion tons of standard coal. Meanwhile, it is about 1000 times the proven oil reserves, and it is ten thousand times more than total annual energy consumption of the world.

China is located in the northern hemisphere, and spans of north-south and east-west are both more than 5000 km. The unique geographical features bring abundant solar energy resources

for China. Statistics from the long term observation in about 700 meteorological stations in China show that the annual solar radiation amount per square meter all over the country is between 3.3 106 kJ to 8.4 106 kJ, and the mean value is 5.9 106 kJ [17,26,31]. At the same time, the annual total solar energy resource is equivalent to 1.7 trillion tons of standard coal, so there is great potential for solar energy development and utilization in China.

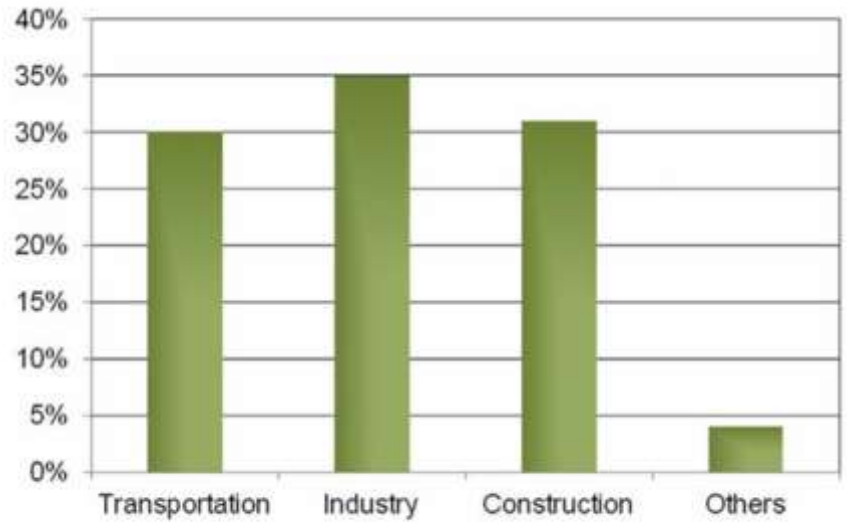

Fig. 1. The present situation of energy consumption in China.

Fig. 2 shows the distribution of solar energy resources in China. The high value center and low value center of solar energy both lie between about 22 and 35 north latitude, and the high value center located on Qinghai–Tibet Plateau. Seen from the locations of annual total solar radiation, the amount in western region is higher than it in eastern region. At the same time, the amount in southern region is basically lower than it in northern region except Tibet and Xinjiang. In addition, we can see from Table 1 the area where the annual total solar radiation per square meter is larger than 5000 MJ and the sunshine hours are larger than 2200 h accounts for more than 2/3 of the national territory area of China. Especially in the northern China and northwest China, the sufficient sunshine provides good conditions for the utilization of solar energy resource. So it will meet the national energy demand if 1% of the annual total solar radiation is converted to available resource in China [33].

2.2. Main forms for solar energy utilization

According to the characteristics of the solar energy, there are four main kinds of solar energy technologies as following: solar energy collection, solar energy conversion, solar energy storage and solar energy transmission. And the combination of the above technologies and other related technologies will realize the utilization of solar energy, such as light-gathering utilization, solar energy photo-thermal utilization, photovoltaic utilization and photochemical utilization.

Light-gathering utilization is the simplest form for solar energy utilization. The solar radiation is converged by concave mirror to provide sufficient power for receiving surface. This technology is the basis of other technologies.

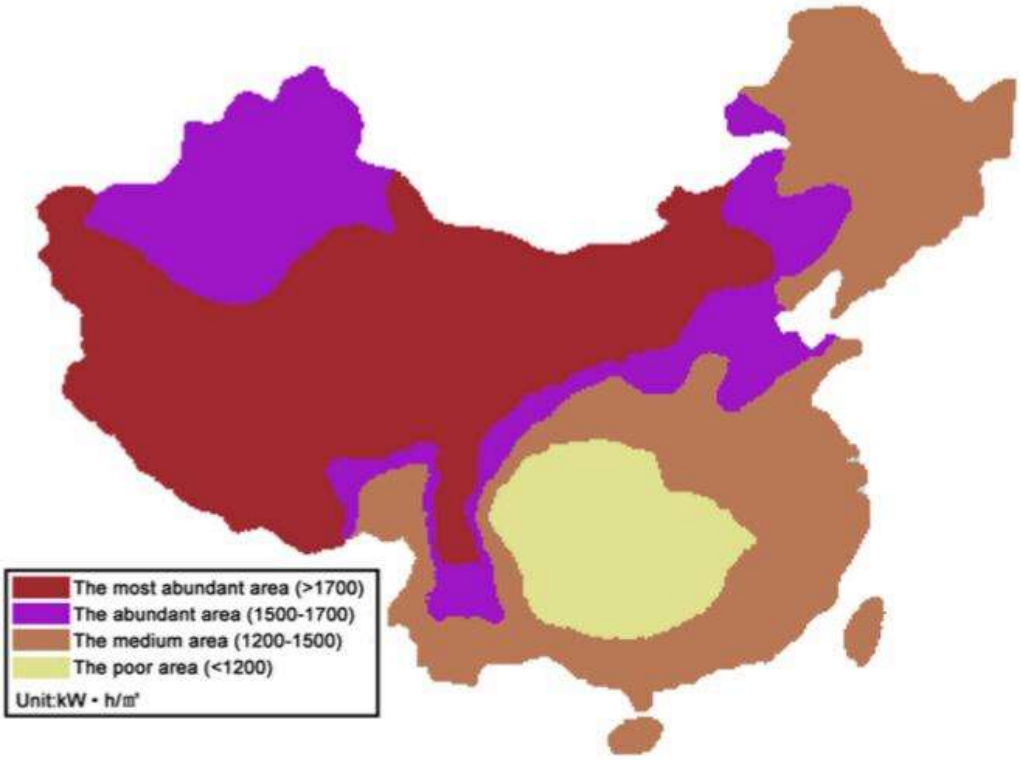

Fig. 2. The distribution of solar energy resources in China.

Table 1
The assessment of solar energy resource in China.

Location class	Annual sunshine hours	Annual total solar radiation (MJ/m^2)	Region (provinces, autonomous regions)	Description
1	3200–3300	6680–8400	Northern Ningxia, Northern Gansu, Southern Xinjiang, Western Qinghai, Western Tibet	This region is the richest in solar resource in China and the annual solar energy is equivalent to 225–285 kg of standard coal.
2	3000–3200	5852–6680	Northern Hebei, Northern Shanxi, Southern Inner Mongolia, Southern Ningxia, Central Gansu, Eastern Qinghai, Southeastern Tibet, Southern Xinjiang	Solar resource is abundant in this region and the annual solar energy is equivalent to 200–225 kg of standard coal.
3	2200–3000	5016–5852	Shandong, Henan, Southeastern Hebei, Southern Shanxi, Northern Xinjiang, Jilin, Liaoning, Yunnan, Northern Shanxi, Southeastern Gansu, Southern Guangdong	The annual solar energy is equivalent to 170–200 kg of standard coal.
4	1400–2000	4180–5016	Hunan, Guangxi, Jiangxi, Zhejiang, Hubei, Northern Fujian, Northern Guangdong, Southern Guangdong, Southern Shanxi, Southern Anhui	The annual solar energy is equivalent to 140–170 kg of standard coal.
5	1000–1400	3344–4180	Most areas in Sichuan, Guizhou	This region is the poorest in solar resource in China and the annual solar energy is equivalent to 115–140 kg of standard coal, but it still has a certain development value

Solar energy photo-thermal utilization is a form that uses heat storage devices to heat thermal storage medium, such as water, gases and walls, then to achieve the purposes of heating water

and indoor heating [29]. This method is a kind of relatively simple, economic, environmental and reliable way to improve the building thermal environment. In addition, photo-thermal technology will not increase the burden of power grid, so it is better than other technologies to solve the problem of energy storage. In solar energy photovoltaic utilization, the received solar radiation is converted to electricity by photovoltaic devices. Stand-alone photovoltaic power system is mainly used in the remote areas and dispersed population areas without power grid, but cost of this system is very high. Gird-connected photovoltaic system has been used in the areas with public supply system, and it has higher efficiency and better environmental performance.

3. SOLAR-POWERED RESIDENTIAL BUILDINGS (SPRBS)

At current, solar energy photo-thermal system is the main form of solar utilization in residential buildings, and it can be divided into direct utilization and indirect utilization. The direct utilization can be subdivided into passive mode and active mode. Compared with active SPRBs, the passive SPRBs are relatively simple. In the process of heat transfer, the passive SPRBs do not need additional systems and devices, and the efficiency of them are relied on the technical operations and design methods of engineers and architects, such as reasonable building layout, indoor space design, exterior form arrangement, building material selection and appropriate building structure [14].

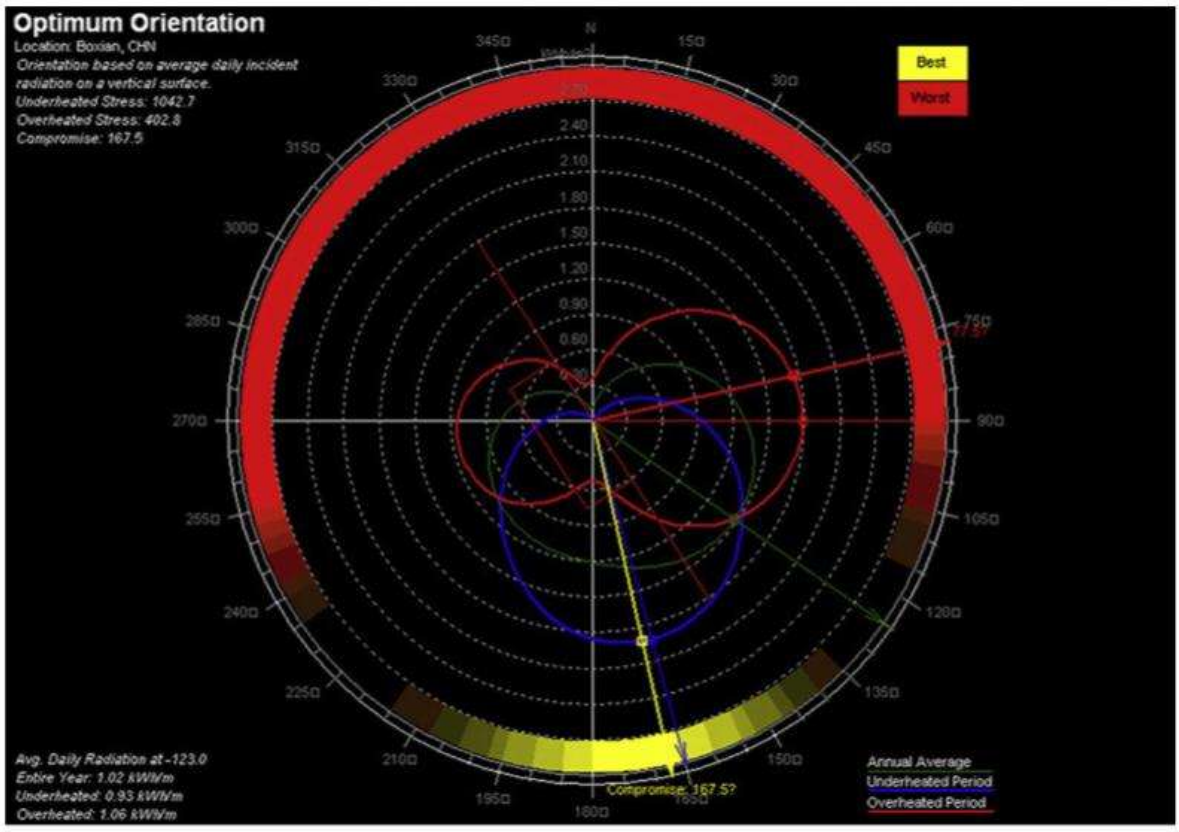

Fig. 3. The optimum orientation of solar buildings.

In active SPRBs , the receive, conversion and transmit of solar energy are relied on solar heating equipment and power systems, such as solar collectors and solar pipelines. At the same time, once encountered bad weather situations, electricity should be provided as auxiliary energy. Compared with passive SPRBs, active SPRBs are relatively complex and high cost [18]. Based on the above reasons, passive solar energy utilization will be the main way of solar energy utilization in residential buildings in a long time following. For the building layout, the best solar orientation can be obtained by ecological ECOTECT Software via loading the local geographic information, as shown in Fig. 3. In general, the heating surface should be within plus or minus 15 of the best orientation to get the most satisfied solar radiation.

3.1. Passive SPRBs

According to the techniques to receive solar energy, the passive SPRBs can be divided into two forms: direct-gain passive SPRBs and thermal heat storage wall passive SPRBs. In the former type, the amount of solar absorption is mainly depended on the residential building layouts and south windows, which are influenced by natural and human factors. In this system, the inner room is a complex of solar heat storage and distribution, so window is a key element in the process of solar utilization. For example, to reduce the heat loss caused by the window, double-layer Low-E (Low emissivity) glasses are always adopted in severe cold areas.

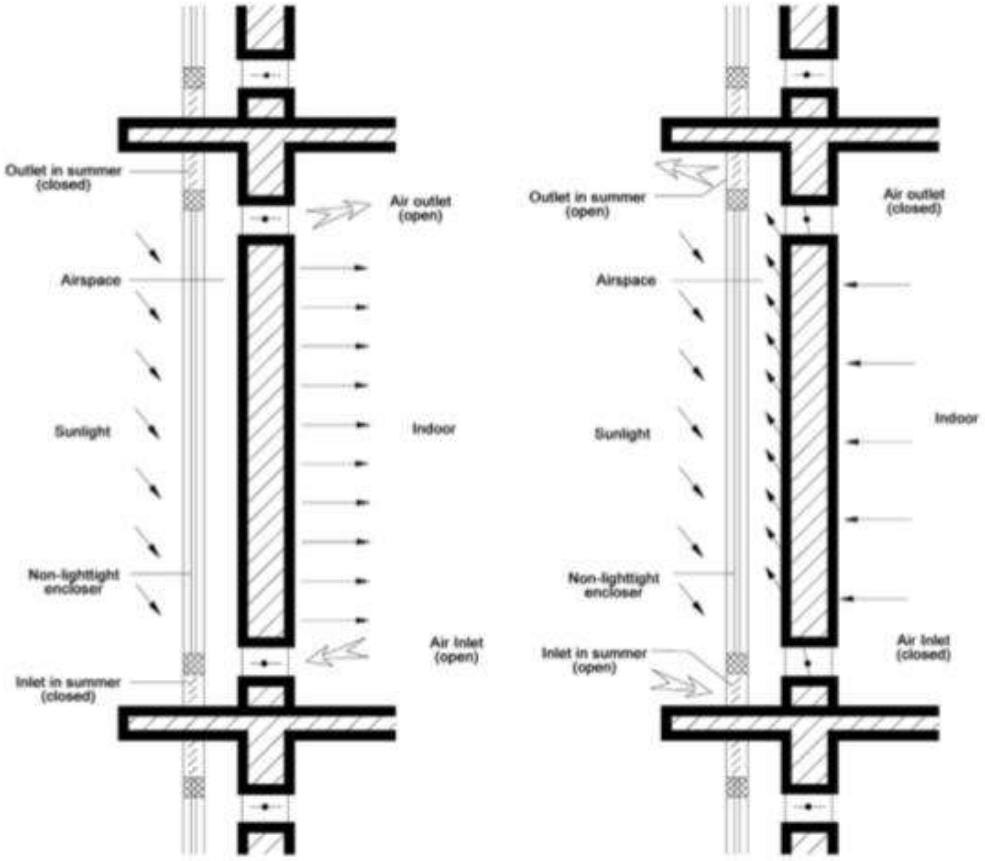

Fig. 4. Operating principle of solar collecting wall.

In terms of window dimensions, it is conducive to day lighting when window is larger, but correspondingly the heat loss in nigh will increase, therefore it is necessary to take some heat preservation measures. In summer, shading measures should be taken into account to prevent much solar radiation getting into interior, such as setting sun shading board.

Thermal heat storage wall is a typical method of passive SPRBs, which takes full advantages of the characteristics of south solar radiation. As shown in Fig. 4, the south wall is covered by a layer of glass cover, so an air layer forms between this glass cover and the wall, namely a simple model of thermal heat storage wall. Once the heat wall captures solar energy, they will be transferred onto interior surface of the room [23]. To get the maximum solar heat, a general practice is to coat the inner surface of glass cover with heatabsorbing materials . For work principle, the air in air layer and the adjacent wall will play a role of indoor temperature regulator at different times if they are heated. In the daytime, airs with heat in the glass cover flows into room by the way of air convection via the outlet that connects the inner space and airspace, as shown in Fig. 4.

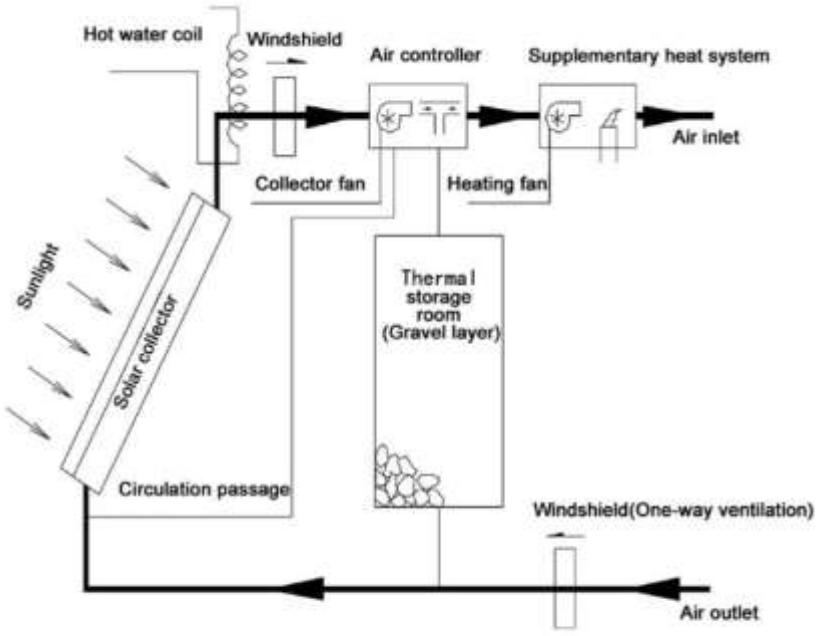

Fig. 5. The solar air heating system (air supply by collector).

For translucent materials, light transmittance of previous glass is about 65%–80%, but now the transmittance of lighting board is above on 90%. For heat storage materials, two methods could increase the storage capacity, the first one is to increase the thickness of the wall and the second is to use better regenerator medium.

Due to simple structure, low investment, high applicability features of passive SPRBs, they are widely used in residential buildings, even in some high-rise public buildings. In these buildings,

the double deck glass curtain wall can be considered as a thermal heat storage wall, which not only uses solar energy, but also beautify the building façade. Looking at current situation in China, the passive SPRBs can be promoted on a large scale. On the one hand, energy saving should be taken into consideration in a new residential building construction on the basis of costeffective and energy-efficient. On the other hand, the retrofitting of old buildings which currently are almost high energy consumption buildings in China should reduce the residential heating energy consumption, especially in north China with cold weather and abundant solar energy resources [3,16, 33].

3.2. Active SPRBs

Active SPRBs is a type of building that transport received heat into house with the help of mechanical equipment. Compared with passive SPRBs, the application of active SPRBs is no longer confined to the wall, but extends to theroof and the slope where can accept solar radiation [4]. For solar energy heating system, the heating media (HTM) temperature should be as low as possible, so the radiant floor heating is the most suitable for solar heating system. Air and water are two types of HTM, but each of them has advantages and disadvantages. Hot air collector is cheaper and less heat transfer, but heat transfer power is larger, air duct and heat storage devices occupy a larger space; Solar hot water collector is complex and expensive, but the price reduces in recent years with the development of vacuum tube collector technology. Therefore, given the situation, the development direction of solar heating system is given priority to with solar hot water system [11,28].

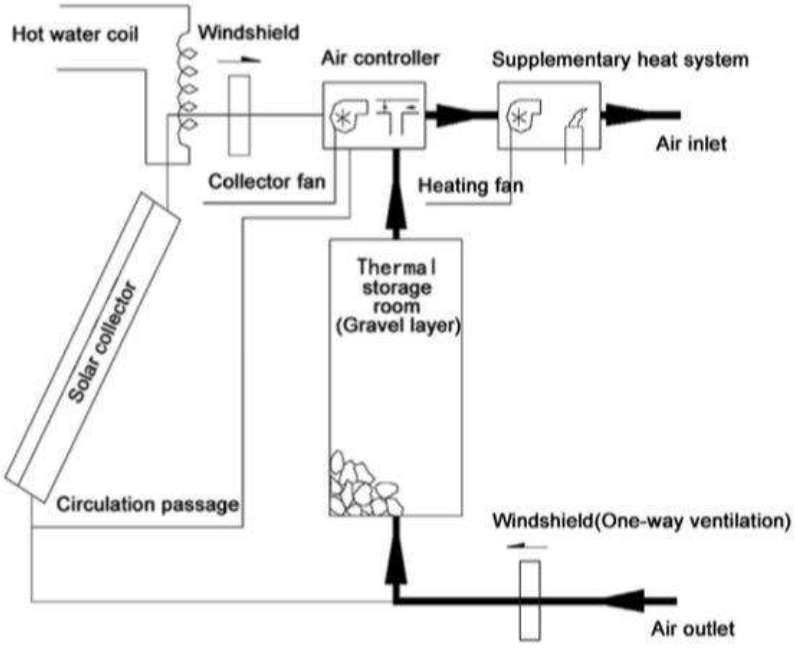

Fig. 6. The solar air heating system (air supply from heat storage room).

Figs. 5–8 show the work principle of active SPRBs. There are two fans in this system, the first one is collector fan, and another is heating fan. When this system depends on solar radiation, as shown in Fig. 5, two fans are running to ensure the air flows through solar collector, and then flow back to the room.

Two electric fans in air controller are all turned to the direction of room when direct heating. At the same time, solar water system can be set at the outlet of solar collector to provide room hot water. As shown in Fig. 6, collector fan starts and heating fan stops, at the same time, the electric fans access to the room are also turned off.

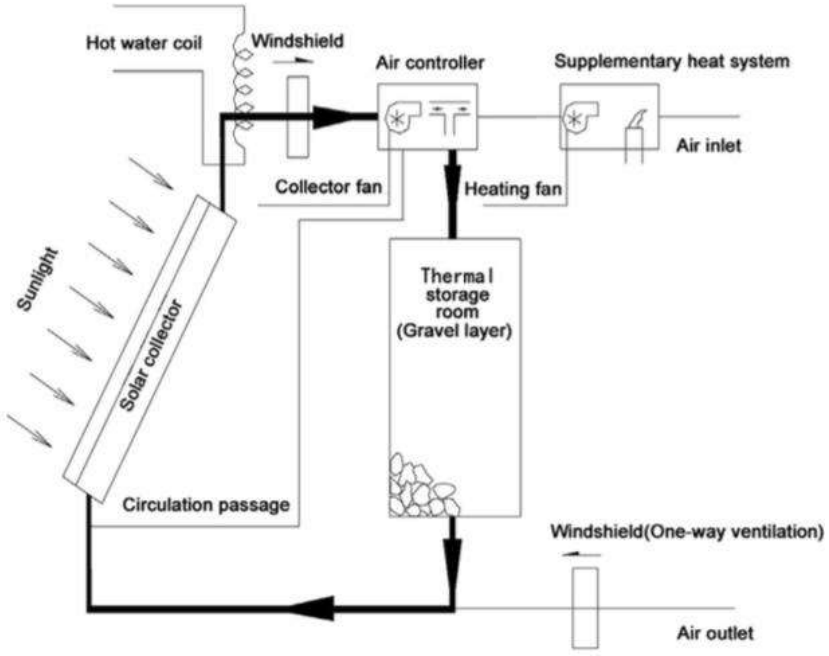

Fig. 7. The solar air heating system (heat storage for running).

As shown in Fig. 7, the first electric fan in air controller is turned off, the second one is turned on, and the heating fan is started. The cold air in the room flows into gravel layer, and back to heating control system to provide indoor space heat. When the heat in thermal room is used up, auxiliary heating system can be started. When heating is not required in summer or the thermalstorage room is saturated, solar collector can be used to provide hot water, work principle is shown in Fig. 8. Although work principals in all SPRBs are same, the HTM are different, some use water as HTM, and some use air.

-Building integrated solar energy (BISE)-

The BISE is a method that integrates solar technologies or devices into residential buildings on the basis of keeping original cultural features and unique appearance of buildings. From the aspects of technologies and aesthetics, BISE not only achieves the full integration of buildings

and solar systems, but also realizes the harmony and unity of the overall appearance. As residential component elements, each component in solar system is reasonable arranged and they are organically integrated with roof, wall, etc. It is well known that BIPV (Building Integrated Photovoltaic) is a kind of new concept in solar power, which has been the early form of BISE. In BIPV, the system provides electricity by solar photovoltaic panels laid on the external surface of residential building envelope enclosures. BIPV has many advantages, such as saving the power grid investment, reducing the transmission losses and relieving the demand for electricity. According to the construction technology, BIPV can be divided into two categories: building integrated photovoltaic materials and building combined photovoltaic materials. In the first form, the solar battery is pre-installed on the surface of building envelope enclosures in manufacturing plant, and then it is installed on buildings with ordinary building materials on site. In the latter form, the solar battery components composed of toughened glasses and aluminum alloy framework have the functions of building materials, especially the good waterproof, so it could be directly used to replace building materials. Building Integrated Photo-thermal (BIPT) is another part of BISE. Solar thermal energy could provide hot water, improve indoor air quality and air comfort, and generate power. Solar ventilation is a kind of natural ventilation measures by means of hot pressing. In this system, the air temperature difference between inlet and outlet will provide buoyancy for air flow to increase indoor ventilation volume, and then the room temperature will decrease correspondingly.

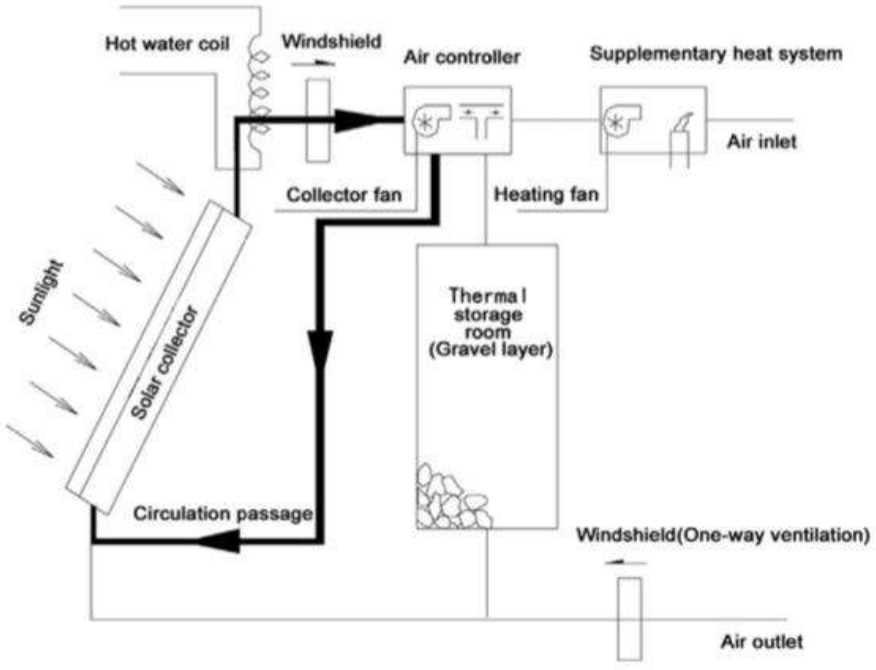

Fig. 8. The solar air heating system (supplying hot water in summer).

4. CONCLUSIONS

The BISE design is a method that integrates solar technologies or devices into residential buildings, which not only achieves the full integration of buildings and solar systems, but also realizes the harmony and unity of the overall appearance. China is a large country and regional resources differ from each other, so it is necessary to develop local technology to realize the wide use of BISE design in residential buildings. For China to become a sustainable society in terms of energy use, the application of solar technologies is a critical element of a long-term plan to promote the development of building energy efficiency.

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