Research Status and Development Trend of Solar Heating Technology

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Abstract. As one of the renewable green energy sources, solar energy has great advantages in energy conservation and environmental protection. With the deepening of the research on solar heating technology, more issues have been discussed. This paper summarizes the research status of solar heating technology from two aspects of solar energy heat collection and heating implementation. Firstly, heat collection technology is still the key to solar energy heat utilization, which focuses on the numerical simulation of heat collector and the influence of heat collection structure on heat collection capacity. Secondly, thermodynamic analysis of heat transfer enhancement of ventilation gap and air flow in passive solar heating system is a hot topic; some scholars even put forward new heat transfer theoretical models and improved equations. Whereas in the active solar heating system, due to the imbalance and instability of solar energy, most of the research focuses on the construction of multiple complementary heating system and the corresponding optimal operation mechanism as well as the study of solar energy heat storage materials, devices and their heat storage performance. Thirdly, in view of the actual building environment in rural areas of northern China, it is proposed that using distributed solar energy collection method combined with heat storage technology and using green energy internet to distribute heat energy is the research trend of maximizing the application of solar heating in the region.

1. Introduction
With the development of the world economy and society, the world energy demand will continue to increase. According to BP's world energy statistics yearbook 2018, driven by technological progress and environmental needs, the energy mix is shifting to cleaner and low-carbon. Led by wind and solar energy in particular, renewable energy has developed rapidly around the world. China also surpassed the United States as the world's largest producer of renewable energy in 2017. In the same year, China accounted for 23% of global energy consumption and 33.6% of global energy consumption growth, and the growth of solar energy consumption in renewable energy reached 76% [1]. All kinds of signs show that the world is at the beginning of a new round of energy revolution, and new energy and renewable energy become the direction of energy ecological structure in the future.

At present, there are four basic ways to use solar energy. First, photothermal conversion. Solar radiation energy is collected and changed into heat energy to be used after the interaction with certain
material, such as solar water heater, solar air conditioning, solar oven; Second, solar power generation. Based on the different generation principles it can be classified into solar light-heat-electricity conversion mode and photovoltaic effect to achieve photoelectric conversion; Third, photochemical utilization, such as photochemical conversion mode of directly decomposing water into hydrogen by solar radiation energy; Fourth, photobiosis, the process of converting solar energy into biomass through the photosynthesis of plants, such as fast-growing plants (such as firewood forests), oil crops, and giant algae.

The technical areas covered in this review are providing heating for users through solar thermal conversion. Taking China as an example, at present, the division of heating areas still in use is the boundary of Qinling Mountains-Huaihe River, this "line" determining the north central heating area. However, the rural areas in the north and isolated remote areas are far away from the cities. Due to the difficulties in the coverage of the energy network, centralized heating cannot be realized. In general, decentralized self-heating is adopted as the main method, and heating equipment lacks unified standard, technology is backward. Solar energy can be sourced locally, at no extra cost and without pollution. Therefore, under such circumstances, making full use of renewable energy, especially solar energy, to provide heating energy for such areas has great economic, environmental and social benefits for improving the living environment of farmers, improving the quality of life of farmers and realizing the coordinated development of resources and environment in rural areas. In recent years, along with the domestic and foreign scholars deepening their research on the solar energy heating technology, more and more technical questions are discussed. To realize solar heating, it is essential to solve the two problems of solar energy collection and solar energy heating system application. Therefore, this paper mainly reviews the research status of the solar heating system from two aspects: the input end of the solar heating system, i.e. heat collection technology, and the application end of solar heat energy, i.e. heating realization technology.

2. Research status of solar thermal technology
Solar photothermal technology aims at obtaining thermal energy, and its core component is solar collector. It can be divided into concentrated light type and non-concentrated light type on the basis of whether concentrated light is used or not. Concentrating and concentrating heat is mainly used in solar thermal power generation, solar hydrogen production and other occasions, generally it need to be equipped with tracking device to make the collector face the sun at all times. The non - condensing type is mainly for the purpose of obtaining heat sources below 100°C and does not require a tracking device. The solar energy heat utilization belongs to the non-concentrated light utilization, and the heat collection technology covered in this article mainly involves this kind of solar energy heat collection type.

2.1. Research status of non-concentrated solar thermal technology
Common non - condensing collectors include plate type and vacuum tube type. The flat-plate solar collector is composed of transparent cover plate, heat absorbing plate core, shell, heat preservation material and relevant parts, which has the characteristics of reliable operation, strong bearing capacity and larger heat absorbing area. At present, the research on the performance improvement of the plate solar collector is mainly focusing on the structural design of the collector plate, the study of selective absorption coating, the cover characteristics, and the heat insulation characteristics of the air sandwich and so on.

Alireza et al. [2] studied the flat plate solar collector by installing the distortion belt, spiral spring wire, conical ridge heat transfer device and other heat-strengthening devices, proving that the heat transfer model of a solar collector was convection-mixed and possessed the advantages of free convection and enjoyed higher heat transfer efficiency, whereas heat transfer enhancement using passive way did not have very good effect. El - Sawi et al. [3] made herringbone pattern folding structure in solar collectors by using continuous folding technique. Compared to flat and V groove type, the heat transfer performance of the collector increased by 20%, with hot water outlet
temperature raised 10°C. Huang et al. [4] simulated and analyzed the flow heat transfer characteristics of plate collectors filled with metal foam blocks in the flow passage under forced pulse flow conditions, and studied the influence of pulse frequency, amplitude and porosity of metal foam on the heat transfer performance. Rassamakin et al. [5] conducted an experimental study on the thermal performance of aluminum alloy heat pipes with internal grooves and applied them to flat plate collectors and vacuum tube collectors respectively. Kumar et al. [6] carried out a study on the smouldering collector with corrugated heat absorption plate. Compared with the flat plate collector, corrugated heat absorption plate can improve the heat efficiency of the collector without additional cost. Amer al-damook et al. [7] carried out experimental and theoretical studies on the thermal performance and economic characteristics of permeable solar air collector (UTC) and perforated absorption plate (PAP). UTC can effectively reduce the life cycle cost and provide higher energy saving. To solve the problem of the limited heat utilization and heat collecting area in high-rise buildings, Yang Wansheng et al. [8] proposed a concept of using curtain wall panel as a collector, organically combining aluminum curtain wall panel and solar energy heat collecting elements. Meijie Chen et al. [9] compared and analyzed the solar absorption performance of precious metals NPs (gold, silver, copper, aluminum), and determined the appropriate parameters of effective solar heating by using finite difference time-domain method and finite element method. K Balaji et al. [10] made a transfer enhancers analysis and economic analysis on the application of bar type heat, tube type heat and common tube type heat exchangers used in plate collectors. It was concluded that the maximum fire efficiency of rod type, tube type and ordinary tube type is 11.3%, 10.9% and 8.3%, respectively. Mauricio et al. [11] proposed a thermal simulation strategy for evaluating the performance of flat plate solar collector (FPSC) using integrated phase change materials (PCM). Based on the simplified semi-empirical correlation, the simulation strategy describes the melting process of PCM by using the energy balance of a group of discrete space layers, proving the maximum error between the predicted temperature and the actual temperature of the glass cover, absorption plate, water outlet and PCM is 4.62%. R. w. Moss et al. [12] proposed a submerged plate absorber for vacuum plate solar collector from the perspective of commercial production. Eight absorber plates were produced, including two variants: one for the housing with a metal back tray and the other for the housing with glass on both sides, and the efficiency coefficient of the new collector was estimated to be 3% higher than that of commercial tube sheet designs.

In view of the problem that flat plate collector is easy to corrode and is not anti-freeze, some scholars put forward the heat pipe type plate collector. Azad [13] studied a kind of hot siphon plate collector, who’s intercept efficiency can reach 62%. Although the heat pipe had good thermal conductivity and antifreeze, but there was a high cost and leakage may lead to significantly reduced performance. In order to further reduce the cost and improve the frost resistance and corrosion resistance of the plate collector, Dorfling C et al. [14] proposed to use organic materials to make the heat absorber plate and the fluid pipeline of the collector. These materials will also expanded when water freezes but never break. Although this method had low cost and is easy to process, the material itself had poor thermal conductivity, for example, aging and degeneration would occur if it was exposed to sunlight for a long time. J. Vera-Medina et al. [15] showed a novel freeze protection mechanism in the solar thermal collector by using flexible silicone peroxide tubes inside the absorber of the solar collector. Fan Zhou et al. [16] proposed a flat-plate solar collector system (FPSCs) with antifreeze characteristics which store up a moderate amount of thermal energy during the daytime and release the energy during the night to prevent the FPSCs from freezing damage. A high-precision mathematical model of daytime and nighttime freezing was established for the PCMFPSCs, and the normal operating temperature of the system was calculated to be lower than that of the traditional FPSC system.

The all-glass vacuum tube solar water heater converts the solar energy irradiated to the heat absorber on the outer surface of the inner tube through the outer glass into heat energy, which is transmitted to the inner wall through the outer wall of the inner glass tube, and then heats the internal working fluid. Since the interlayer between the inner and outer glass is vacuumsed, the heat lost to the
environment can be effectively reduced. The heat loss coefficient of all-glass vacuum tube collector is small and water can be directly used as working medium. In recent years, a variety of improved forms of glass vacuum tubes have also appeared in order to solve such problems as non-pressure resistance and easy scaling, such as heat tube vacuum tubes and u-tube vacuum tubes. Liang et al. [17-18] found that the efficiency of the single u-tube vacuum tube was 12% higher than that of the common vacuum tube, and under the same meteorological conditions, the efficiency of the double u-tube vacuum tube was 4% higher than that of the single u-tube vacuum tube. Leong et al. [19] reviewed in detail the application of nanofluids in solar collectors and proposed potential problems. N. Budak et al. [20] demonstrated that adding nanofluids (Al₂O₃, CuO and TiCte nanoparticles of 0.2, 0.4 and 0.8 vol. % were added to distilled water respectively) to a flat-plate solar collector improved the thermal efficiency of the system.

In view of the influence of solar radiation, ambient temperature, dust and other environmental factors and operating strategies on the performance of solar thermal collector system, domestic and foreign scholars have also carried out research. Gao et al. [21] studied the influence of heat accumulator and flow rate on the performance of two kinds of solar water heaters under forced circulation, and found the optimal flow rate for solar water heaters to obtain the maximum useful energy under different meteorological conditions (solar radiation, ambient temperature). Xue [22] found in the experimental study on the performance of the solar water heater with phase-change heat storage material in the vacuum tube collector that with the increase of the proportion of heat dissipation in the solar radiation and the increase of the initial water temperature, the system's performance became worse. Li bin [23] et al. studied the heat collection efficiency of heat pipe collector array and found that the heat loss of collector box is the main factor affecting the total heat loss. Dai Weiwei et al. [24] established the mathematical model of heat loss and working medium outlet temperature of pass-through solar vacuum collector tube, analyzed the influence of environmental temperature and wind speed on heat loss and working medium outlet temperature, and found that under good vacuum conditions, they had little influence on outlet temperature and heat collection efficiency. Xu Jiahui et al. [25] established a one-dimensional steady-state heat transfer model for a straight solar collector, analyzed the change rule of heat loss with the temperature difference and wind speed between the inner wall of the metal pipe and the environment, and investigated the influence of solar irradiance and heat conduction oil flow on the heat collection efficiency. Lu Yang et al. [26] experimentally studied the effect of flow rate on the heat collection of flat-plate solar collector, and obtained the efficiency equation of flow rate collector. J. Zhao etc. [27] proved through the experiment that for residential pool heating solar collectors of no glaze, open loop, low pump speed operation system could be used, when the unit mass flow of the collector area reach the optimal parameters, the pump can save 60% energy, thermal coefficient increases 2.5 times, and the thermal performance of the whole system would not be effected. Liu jianbo [28] also studied the effect of dust accumulation on the performance of collector. Wei xinli et al. [29] studied the thermal performance of solar air collector under different air volume through experiment and simulation, and obtained the optimal operating air volume under different working conditions. Aiming at the influence of different control strategies on the thermal performance of the heating system, Federico Bava et al. [30] verified the trnsys-matlab model to evaluate the impact of different measurement methods on the thermal performance of the heating system under different control strategies. The model included the influence of the flow state in the absorber pipeline on the collector efficiency, the flow distribution in the collector field, the heat capacity of the pipeline and the shadows from one row to another. The improvement measures included the change of operating temperature, the accurate input of control strategy, the feedback control of collector field outlet temperature, the control strategy based on weather forecast and the use of different heat exchange liquids. The results showed that the accurate input of the control strategy increases the plant's annual energy output by about 3%. If accurate input was not feasible technically or economically, feedback control of the field outlet temperature appeared to be an effective option.
2.2. Solar photovoltaic integrated utilization technology

The photoelectric efficiency of ordinary photovoltaic cells is between 5% and 20%, and the remaining solar radiant energy is converted into the thermal energy of photovoltaic cells or lost in other forms. After conversion, the thermal energy increases the operating temperature of photovoltaic cells under the combined action of the ambient temperature of photovoltaic cells. Generally speaking, with every 1°C rising in temperature, the output power will decrease 0.3% to 0.6%. Excessive working temperature will also affect the service life of photovoltaic cells.

Photovoltaic/Thermal (PV/T) was first proposed by Kern in 1978, namely, to lay a flow path on the back of Photovoltaic module. The Thermal energy is taken away by fluid and collected to be put in use. This can not only cool the photovoltaic cell, reduce its temperature, improve the photoelectric conversion efficiency, but also realize the solar thermal utilization. Moreover, its environmental benefits are very obvious. The energy recovery period of most PV/T is 1-4 years, and the greenhouse gas recovery period is 0.8-4 years [31]. PV/T system's photoelectric photothermal comprehensive efficiency was much higher than the photoelectric conversion efficiency or photothermal conversion efficiency alone, with the overall efficiency up to 70% or higher. At the same time, it could be coupled to heat pump or absorption refrigeration system, and it had a broad application prospect as a feasible alternative to steam compression system [32]. PV/T can be divided into ordinary PV/T and condensing PV/T according to whether condensing technology is adopted. According to different cooling media, PV/T system can be divided into air cooling type, water/liquid cooling type, refrigeration dosage form and heat pipe type. In general, due to the low thermal conductivity, density and specific heat capacity of the air, the heat transfer ability between the air and the heat sink is poor, and the photothermal efficiency of the air-cooled PV/T system is low. Compared with air cooling system, water/liquid cooling system has stronger heat transfer capacity. However, as water will freeze in winter, it cannot be used in cold and high latitude areas. The problem can be solved by the use of antifreeze and secondary heat transfer with water. In air-cooled and water/liquid-cooled systems, along the direction of fluid flow, fluid temperature will increase continuously, resulting in uneven temperature distribution of the solar panel and decreasing photoelectric efficiency of photovoltaic cells.

![Figure 1. A plate-tube PV/T structure and temperature profile](image)

The integrated system with the building is the main application occasion of PV/T system. PV/T collector can be installed in the structure frame of the building as part of the maintenance structure, or combined with the building ventilation system, which can significantly reduce the building energy consumption. Ji et al. [33] simulated the PV wall structure in two forms of ventilation and unventilation based on typical annual climate data in Hong Kong, and the annual electrothermal performance of PV wall in various orientations. The simulation results showed that the power output
was significantly improved when ventilated, and the heat gain of the building could be reduced, and the load of the air conditioning system could be reduced. Meanwhile, it was found that the west PV wall could obtain the most solar energy in a year. By changing the direction of the air flow, PV wall could also provide the heating energy for the buildings. Yi Hua et al. [34] built a one-dimensional model of PV endothermic wall and compare the indoor temperature of two houses, one with a heat absorption wall installed, and the other without endothermic wall. After three days, the maximum temperature difference of the two room’s room added up to 12.3°C, and then 13.4°C after seven days. Fu huide [35] studied the influence of heat pipe spacing on the photovoltaic and photothermal performance in the heat pipe PV/T system, indicating that reducing the heat pipe spacing and increasing the contact area between the heat pipe and the photovoltaic module was conducive to the heat transfer from the photovoltaic unit to the photothermal unit, reducing the battery temperature and collecting more heat at the same time. Brideau et al. [36] found that in an air-cooled PV/T system, high thermal conductivity could be obtained by using the impingement jet between air and the heat sink. Bakar et al. [37] proposed a PV/T collector that uses both air and water as working medium, which could not only produce hot air and hot water at the same time, but also improve the utilization efficiency of solar energy per unit area.

In PV/T, the photothermal unit absorbs heat from the photovoltaic unit. The temperature of the photothermal unit is lower than that of the photovoltaic unit. To ensure the solar cell works at a lower temperature to output more electric energy, the photothermal unit can only provide low-temperature heat. Conversely, to obtain high temperature heat, photovoltaic efficiency must be sacrificed. If there is a glass cover plate, the electrical power and electrical efficiency of the system will decrease, but because of the reduction of heat loss, the system heat collection and heat collection efficiency will increase, and for the natural circulation hot water system, the increase of water quantity in the water tank will increase the electrical power, heat collection and energy utilization efficiency of the system, but will reduce the heat temperature. Therefore, under certain input conditions, electrical and thermal performance parameters will show a reciprocal relationship with their own structure and operation mode.

3. Application of solar heating research status

In terms of the application of solar energy heating technology, there are mainly passive solar room application and active solar heating system application.

3.1. Passive solar housing applications

Passive solar house is the earliest application of solar heating system, a way to reduce the energy consumption of building by reducing the energy consumption of mechanical system. Through the reasonable arrangement of building orientation and surrounding environment, the ingenious treatment of internal space and external form, as well as the appropriate selection of building materials and structural structure, not only the greenhouse gas emission is greatly reduced, but also the efficiency of residential space heating and cooling is improved [38]. However, shortcomings exist such as it is easy to be affected by seasons and climate and hard to control the temperature, mono-functioning and so on. Figure 2 is a schematic diagram of the passive solar heating system.
Figure 2. Passive solar heating system

The experimental research on the passive solar house has been carried out in foreign countries for a long time. China's solar building started relatively late. The first passive solar house was built in MinQin county, Gansu province in 1977 by Gansu Natural Energy Research Institute. Through the investigation to the cold areas of rural residence, Jin Hong etc. [39], based on the characteristics of climate, the local residential status quo and the farmers' living habits, put forward a form of passive solar house for cold areas environment - "directly benefit type + additional sunshine shed type". Through analysis and comparison, the energy-saving rate of this mixed structure is over 70%, of promotional value. Olenets et al. [40] pointed out the obvious defects of the traditional Rambo wall, which could not control the heat entering the room and had a negative impact on the indoor climate in summer. The Rambo wall with soft shutter was more conducive to the heat entering the room than the traditional Rambo wall. Rempel et al. [41] used EneryPlus building model to study the energy transfer mechanism of four additional sun shed houses in Oregon, the United States, and verified the model with test data. The results showed that more than half of the solar energy entering the additional sunlight was scattering radiation, and 60-70% of which was from the glass on the inclined roof. Matthias Winkler et al. [42] compared the calculation results of passive solar house shadow calculation with the results of existing static calculation methods in the way of dynamic simulation, and found that there were sometimes large errors in the static calculation methods. They hoped to propose a possibility to combine the two methods. Jiayin Zhu et al. [43] Zhu jiaying et al. proposed a simple mathematical model of passive solar house, which combines the house with the color-changing solar wall. Steady state heat transfer equations were set up to determine the temperatures of surfaces and air by using a thermal resistance network. By solving MATLAB, the simulation data and experimental data have a good correlation. Haider Albayyaa et al. [44] analyzed two types of four-bedroom two-floor detached houses in Sydney by using a building energy simulation program. By using passive solar energy and energy-saving designed strategy to build standard fibro and brick masonry veneer houses, the total energy consumption of heating in winter was reduced by 37% and 36% respectively. On the other hand, by increasing the thermal mass (building materials with higher R values) through utilizing different walls and flooring system, replacing fibro house with brick veneer house and applying the PSEEDS, the total energy requirement could be reduced by up to 58%. Liu Yanfeng etc. [45] measured the thermal property of the traditional Tibetan dwellings with direct gain passive windows in the Lhasa area, it was concluded that the renovation of the passive solar house would not produce significant effect on indoor lowest temperature, under the typical meteorological condition, the indoor average temperature and maximum temperature increased by about 7°C and 3°C respectively, but the improvement of the level of building thermal insulation and heat storage performance were needed to improve the problem of room temperature fluctuations. Wang tingting et al. [46] replace the ordinary roof with thermal heat storage roof, setting up physical and mathematical model of the thermal heat storage roof, after optimization analysis it was concluded that the best heating capacity could be obtained when the roof Angle is 45 °, and it was advised the best circulation
air volume 0.086 ~ 0.115 m³/s. Wang Dengjia et al. [47] put forward the structural design of intermittent heating floor and the selection principle of operating parameters matching the heat load of passive solar house. Chen Mingdong et al. [48] reconstructed the solar house with additional sunlight in goucha village, Qingdao, studied the change of indoor temperature with outdoor meteorological conditions in cold season, and proved the feasibility and economy of the transformation of passive solar house in this area.

The promotion of passive solar houses has been slow in the past decade due to the fact that it is difficult to fully meet farmers’ demand for winter heating solely by relying on passive strategies and the lack of efficient cooperation between the solar energy industry and the construction industry. But in the research field, heat storage materials, especially phase-change heat storage materials, have attracted more and more attention. Because of the discontinuity of solar energy, passive solar heating cannot work stably and continuously. Therefore, Safari et al. [49] used phase-change materials to absorb solar energy during the day and release it at night, and studied the influence of phase-change materials on room temperature and air velocity with CFD method. Soares et al. [50] expatiated on the role of phase-change heat storage materials in buildings through a large number of literature investigations. Phase-change heat storage could significantly reduce the energy consumption of heating and cooling in buildings and reduce indoor temperature fluctuations. Zhou et al. [51] pointed out that long-term stability and other aspects such as safety, reliability and practicality of phase-change heat storage materials should be further studied after they were combined with existing buildings. Uros Strith et al. [52] used TRNSYS to carry out numerical simulation on the hot air solar collector for heating latent heat storage (LHTES) developed by Brno University of technology. Compared with district heating, the annual cost savings of the low-energy system was 91%. However, the return on investment in the system evaluation without LHTES was 1 year, while the return on investment in the system evaluation with LHTES was 2 years.

3.2. Active solar heating
Active solar heating systems capture, store, and convert solar energy to generate heat to achieve the desired room temperature of a building. The common active solar heating system can be divided into air type and hot water type according to the type of heat medium. According to the utilization mode of solar energy, it can be divided into direct type or indirect type. According to the heat storage capacity, it can be divided into short-term heat storage system and long-term heat storage systems. In order to make full use of solar energy and solve the problem of solar intermittence, many scholars combine active and passive technologies, solar energy and other energy sources for research. Li An-gui etc. [53] took Taoli village as an example to analyze the rural residential construction of three forms of solar energy utilization, solar hot water system, solar heating and hot water all year joint system and energy saving building solar energy heating and hot water system, making a comparative analysis on the economical efficiency cost of three kinds of technology using the method of dynamic calculation. It was concluded that system thermal performance and the economic effect was more significant when using combined solar houses. Jiang Qingyang et al. [54] studied the heat storage characteristics of solar Kang, a kind of heating bed in Northeast China. Cui Yuqing etc. [55] proposed a new solar heating system, combining the Trombe wall (solar heat absorption wall) and solar kang and compared its thermal performance with that of solar power heating system and Trombe wall heating system alone, the results showed that without auxiliary heat source, the solar energy heating can keep the surface temperature of kang in a maximum 28 to 30°C during the day, barely meeting the heat demand, but kang surface temperature dropped to only 12 to 28°C, and the indoor temperature 7 to 13°C at night, the heating requirements could not be met, therefore 750 w auxiliary heat source is needed; with Trombe wall and solar kang coupling operation, the surface temperature of solar kang could be maintained, at the same time, the room temperature is higher than that of single solar kang systems by 4-5°C. Based on the simplified concept of energy balance, Omer K et al. [56] improved the thermal performance of the Trombe wall with porous media and proposed a mathematical method for predicting the performance of pv /TW systems in light of the influence of porous media, dc fans and
glass masks on PV/TW performance. The results showed that the system had good performance when
the porous medium was combined with the DC fan, while the glass cover had a conflict effect.
Rekstad et al. [57] made a comparison test on the solar energy consumption of two passive solar
houses with identical structure, but using different heat source for a year in 2013; one of them using
the active solar energy heating system, the other with an air-water source heat pump heating. The
results showed that the energy consumption of the buildings using heat pump for heating was higher
15-20% than that of active solar energy heating system. Bendong Yu et al. [58] proposed a new solar
gradient-utilization photocatalytic-Trombe wall system, which could realize the dual functions of
space heating and indoor formaldehyde removal. Taking Hefei city of China as an example, the
accuracy of the model was confirmed to be within 8%. In the technology field of multi-energy
complementary heating combined with solar thermal utilization, Esen et al. [59] made an experimental
research on the performance of utilizing methane, solar energy and ground source heat pump for
greenhouses heating in a city in Turkey; the size of the greenhouses was 6 m×4m×2.1m, and the
research lasting from November 2009 to March 2010, the biogas system providing 2231.83 L methane.
Ground source heat pump and complementary biogas system could be used as a separate heating
system, solar energy could sed as another heating system; the required temperature of 23°C had been
met for a variety of plant growth. Hansani et al. [60] proposed a hybrid integer linear programming
method to minimize the operating cost of solar-assisted ground source heat pump system by
considering the use of electricity price (peak, o_peak). The results showed that the integrated heat
storage system improved the peak regulation effect, reduced the grid's demand for expensive peak
power generation, and reduced the operation cost by 7.8% with the lowest optimization cost. Liu
Yanfeng et al. [61] established a three-dimensional unsteady heat transfer model for the domestic
underground biogas digester, and combined it with the surrounding environmental parameters to
calculate the dynamic heat loss of the biogas digester with no parameters as boundary conditions. M.
Zhao et al.[62] proposed a solar phase change thermal storage (SPCTS) heating system using a
radiant-capillary-terminal (RCT) to effectively match the low temperature hot water, a phase change
thermal storage (PCTS) to store and continuously utilize the solar energy, and an air source heat pump
(ASHP) as an alternate energy. Through a series of experiments, the relationship between solar
radiation utilization rate and heating temperature was obtained, and the performance of RCT module
and indoor thermal environment of the system were evaluated. Seyed Houman Razavi et al. [63] used
TRNSYS to simulate five different combinations of SAGSHP for a house in Zahedan, Iran. COP,
GSHP power consumption, soil temperature and building and domestic hot water temperature were
obtained and compared. Weibo Yang et al. [64] conducted an experimental study on the thermal
performance of SGSHPS under different double-heat source coupling modes. COP, solar collector
efficiency and inlet and outlet temperature of heat pump in different modes were tested experimentally,
and TRNSYS dynamic simulation model of SGSHPS was established to discuss the influence of key
parameters on system performance. Guodong Qiu et al. [65] proposed a new type of heating system
combined solar energy and air source heat pump, and made a comparative analysis between the system
and the other two traditional systems through simulation, and proposed an i-t diagram to quantitatively
divide the optimal operating range of the three systems, which could effectively guide the selection of
the optimal system under different operating conditions. Zhao qintong [66] experimentally studied the
heating performance of a solar energy -- biomass energy -- air thermal energy -- electric energy
complementary heating system, and verified the feasibility of applying the multi-energy
complementary heat pump heating system in cold regions. Ze-long wang etc. [67] put forward a kind
of biomass energy- solar complementary heating system, and took an office building in Beijing
covering an area of 200m2 area as an example, from the perspective of economy, optimized the
system's main parameters through linear programming. The results showed that when the biomass
particles burner in biomass energy - solar complementary heating system was 20 kW of power, solar
collector area of 15m2, heat storage water tank volume of 430 l, the system could achieve the most
economical interest. Sun Weita [68] et al. designed a solar-heat pump joint heating system of active
heat storage- release. In the daytime the active heat storage system operated, received the solar radiant
energy and stored them in the tank; the heat pump units timely open, according to the reservoir temperature and weather conditions. This model reduced water temperature of the active circulating heat storage system, thus improves the heat collection efficiency. Hong-ting ma [69] made a comparative experiment on a new type of solar energy-water source heat pump complementary floor radiant heating system with the traditional urban heating system under same environmental conditions, and the results showed that the new type of heating system energy saves 30.55% than traditional central heating system, floor radiant heating saves 18.96% energy than the radiator heating energy, and solar assurance rate could reach more than 24%. Liu jian et al. [70] took a 90 m2 demonstration house in Shanghai as the object, and proposed a solar-assisted CO2 heat pump heating system to provide residential heating and domestic hot water. Han Zongwei et al. [71] introduced the compound system of solar energy and low-temperature air source heat pump that uses underground pool for seasonal heat storage, and established a mathematical model for the design of system optimization according to the climate and building load characteristics in cold regions. Giovanni Ciampi et al. [72] made dynamic simulation of a solar central heating system consisted of a solar collector arrays, short-term thermal energy storage (STT), long borehole thermal energy storage (bt), a secondary natural gas boiler and heat distribution network, analyzed the single-family homes under 6 kinds of typical climatic conditions during the five years, emphasized that energy and environmental benefits were mainly affected by the size of solar collector, and the economic parameters greatly depended on the volume of a thermal energy storage.

In order to improve the stability and economy of renewable energy supply, wind-solar complementary power generation system has also attracted people's attention. Juan et al. [73] introduced a mathematical model to realize the electrification of remote rural areas by using distributed energy. The main goal of the model was to solve the multi-objective decision problem as best as possible according to the local environment and requirements. Borhanazad et al. [74] pointed out that in Malaysia, 3.8% of the population lived below the poverty line, and the power shortage aggravated the poverty in rural areas. Abundant renewable energy in rural areas was an effective option to reduce rural energy shortages. They analyzed the potential of using solar, wind and small hydro power in rural areas, especially in poor areas. By comparing the social and economic benefits of these three ways, the study found that solar energy had the greatest potential to realize rural electricity supply. Liu Yanfeng et al. [75] put forward a dc drive air conditioning system based on solar photovoltaic power generation, which could maintain indoor temperature in 28°C when outdoor temperature 35°C, better keep the demand of the indoor thermal environment, meet the demand of air conditioning and at the same time, excess electricity was stored in the battery. Gupta et al. [76] optimized the parameters of the capacity of solar photovoltaic array, the capacity of battery and the thickness of insulation layer of the refrigerator, which was used to store vaccines in areas without electricity, and the photovoltaic system was used to provide electricity. Compared with the overseas researches which focused on the optimization of the distributed power supply system based on renewable energy in terms of resource distribution, energy demand and economy, the domestic research was still in the stage of component and design of optimized system. Taking Qinhuangdao region as the research object, Yang zhao [77] constructed a household independent photovoltaic power generation system according to the electricity demand of a family, and studied the optimal configuration scheme of the system. Hong-bin Wu et al. [78] set up the capacity optimization model of the battery - super capacitor hybrid energy storage system on the basis of steady state simulation of wind power, photovoltaic power generation, storage battery and super capacitor, proposed the multi-objective optimization function of hybrid storage unit, and probed into various constraint conditions, solved the objective function using genetic algorithm. Considering the diversity of user demand, many studies have focused on power system which can meet user needs of the multi-level energy, as described previously, Lanzhou University of Technology research and development of solar powered thermostatic biogas digester system is a typical use of solar energy and biomass energy to provide living hot water and cooking gas micro distributed energy supply system. Dagdougui et al. [79] integrated flat-plate solar collectors, biomass energy utilization devices, wind turbines and
photovoltaic modules to provide thermal energy and power demand for a green building. Gaul et al. [80] compared and studied the technical reliability and economic feasibility of using jatropha oil, biogas and other small-scale rural energy service methods to realize the energy demand of lighting, cooking and mechanical energy, based on the whole life cycle analysis framework. Gonzalez et al. [81] introduced a plan to use biogas and solar pv in the pig slaughterhouse to solve their own energy and environmental problems. The results showed that the optimal choice was to establish an anaerobic fermentation biogas tank with 79 KW power generation capacity and a 225KW photovoltaic power generation system, with the overall investment payback period of 9 years. Hosseinalizadeh [82] took solar radiation and the average wind speed data of four typical areas in Iran as the foundation, by comparing the technology economics of the different integration of wind power, photovoltaic, fuel cell and battery energy storage system, found that the combination of wind power, photovoltaic and battery system cost minimum; fuel cell was not suitable for integrated system due to its high cost and short life. HOMER software was used to analyze and compare the technology economy of integrating micro-hydropower, biogas, biomass, solar energy, wind energy, battery and other renewable energy utilization technologies in different ways to meet the local electricity and cooking energy demand in remote rural areas of Jemali county, Uttarakhand state, India. Hai-tao gao [83] built a set of energy supply system integrated by solar low-temperature heating technology, biomass anaerobic fermentation technology and wind power technology, which could provide users with life gas, hot water and electricity power system, and carried on an experimental study on its performance. Research showed that the new integrated system can meet the single-family farmers demand for living hot water, gas and electricity, and the energy conservation and emissions reduction benefit is remarkable.

4. Solar heating research trend under the energy Internet

Through the analysis of the research status of solar heating technology, more and more technical problems have been overcome, and at the same time, the technical application fields and methods involved are more and more extensive. But at present, most of the research objects focus on the centralized solar heating model or the single-user solar heating model in a single independent area. As for the actual construction situation in northwest rural areas, Liu Yanfeng et al.[84] chose Xi’an, Lanzhou, Urumqi etc. as survey sites, under good heat preservation condition, the northwest rural heating load was significantly lower than the traditional rural residence, satisfied the requirement of solar heating applications, but in Xi’an, Lanzhou region more than 80% of the villages did not provide enough concentrated heating area, in Xining and Golmud, villages meeting the standard of residential building volume rate were less than 30%. Therefore, in the rural areas of northwest China, there was no objective condition to adopt the centralized solar heating system, but the single user solar heating system could not realize the maximum utilization of solar thermal energy. According to the characteristics of rural residential structure, mostly of top or flat-roofed, the method of distributed solar heating could be adopted for numbers of users in a particular area, under the premise of meeting their basic heat need, effective complementary linkage mechanism could be formed with the surrounding residents, so as to achieve the maximum application of solar energy as well as meet the different requirements of users. In addition, when calculating the performance of solar thermal utilization system and equipment, the investment cost is generally calculated under the current cost accounting mechanism. The initial cost is relatively high, but it cannot be ignored that when renewable energy is used as the energy cost, the unit marginal cost is almost zero. Thus, similar to communications today, renewable energy production is almost free of charge when fixed costs such as research and development and operations are reinvested. On the other hand, with the breakthrough of each new technology and the large-scale production of a new product, the cost change of this kind of product will be brought along. When the cost of solar heat collection and heating system is low enough, the revolution of solar heat utilization and heating technology will be ushered in.

With the introduction of the concept of Energy Internet, many scholars have devoted themselves to the research work of energy Internet. Zhou kaile et al. [85] proposed a systematic research model of energy Internet from the perspective of management, proposed four stages of energy system evolution,
and proposed to analyze the business value of energy Internet system from the perspective of energy big data.

A martin-garin et al. [86] proposed a low-cost system for monitoring the building environment developed based on the open source Internet platform. The system used sensors to collect information and store it on memory cards, which was sent to the cloud in the form of a spreadsheet and allows real-time access. Christian DeFeo et al. [87] conducted an introductory discussion of two key emerging research topics. The first was processing techniques such as "energy harvesting" or "energy harvesting", which aimed to harness various sources of environmental power. The second was the concept of the "Internet of things" (iot). The energy used Internet monitoring system based on user energy demand application was formed. But the researches on energy Internet at home and abroad are mainly from the perspective of the energy producers or energy Internet builders, mostly concentrated on smart grid, whose main focus is the optimization of power supply and demand in large range, which is based on the large power grid, with complex system and allocating difficulties, thus can not be directly applied to small energy system. The renewable energy Internet of things (iot) system in a specific area based on the utilization of solar energy for heating is rarely involved in theory and practice.

Therefore, building renewable energy heating system based on the utilization of solar energy, setting up distributed solar cell in each separate heating users, distributing heat energy through green energy Internet will allow the all users in an certain area share the solar heat on the solar energy heating system Internet which is close to zero marginal cost, as well as completely change the way of energy production and energy distribution of solar energy heat utilization.

5. Conclusion and prospect

(1) The study of solar energy heat utilization still focus on the heating technology, including the researches to improve heating capability through the numerical simulation of collector and the improvement of collector structure, and the influence of solar radiation, ambient temperature, dust and other environmental factors and operation strategy on the performance of the collector.

(2) In the passive solar heating system, the researches focus on the thermodynamic calculation and analysis of the heat transfer enhancement in the air gap and the air flow state and on this basis, the proposal of new theoretical model and improved equation. At the same time, directing at the structure and type of different passive solar house, the heating capacity and the impact on the thermal environment of the room can be analyzed. Some researches also involve the indoor end heating matching with the passive solar heating mode.

(3) In order to make up the discontinuity of single solar heating, scholars put their research focuses on the collaborative optimization operation of electricity needed by the renewable energy such as solar energy and conventional energy sources in heating system, at the same time, in-depth researches were conducted to study the reliability, high efficiency and stability of the multi-energy complementary heating system, in order to make it combine with construction application, give full play to the economic efficiency of solar energy and reduce building energy consumption. In addition, in order to realize the stable operation of the system, it also involves the research of solar thermal storage materials, devices and thermal storage performance.

(4) With the concept of Energy Internet proposed, the application of multi-energy complementarity research has gradually become a hot spot. However, at present, domestic and foreign researches on energy Internet are mainly based on the energy producers or energy Internet builders; most of them focus on smart power grid, which has a huge and complex system, difficult to deploy and cannot be directly applied to small energy systems. So directing at heating system of renewable energy sources such as solar energy, building the distributed solar cells for separate heating users within the region, combined with store thermal energy storage technology, distributing heat energy on green energy Internet would allow the all users in an certain area share the solar heat on the solar energy heating system Internet which is close to zero marginal cost, which is research trend of solar heating in the future.
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