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Research on PV/T—air source heat pump integrated heating system in severe cold region

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Abstract

Photovoltaic-thermal (PV/T) technique is applied to air source heat pump (ASHP) heating system in severe cold region, which can achieve high efficient heating of ASHP in low-temperature environment and maximize the utilization of renewable energy. The using limitations and common problems of ASHP heating system in severe cold region is studied in this paper. Based on the solar radiation heat transfer mechanism and characteristic of air--heat transfer media, PV/T--ASHP integrated heating system is developed. TRNSYS transient simulation software was used to study the integrated heating system. Through the simulation analysis, the outlet temperature of PV/T collector can reach 76.6℃ and the average COP of ASHP unit reaches 4.1, which improves the heating efficiency of ASHP and provides a new idea for the future heating mode in severe cold region.

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Keywords: PV/T; Air-source heat pump; COP; TRNSYS

1. Introduction

With the outbreak of the global energy crisis and the environmental problem is becoming more and more prominent, people seek for the efficient method of utilizing renewable energy to replace the traditional energy. As a clean and renewable energy, solar energy is the most abundant resources human can make use of. Moreover, there is no transportation problem in development and utilization or negative impact on the ecological environment. Therefore, vigorously promoting the use of solar energy applying in HVAC field is a hot issue in recent years. It is

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also an important measure to reduce building energy consumption, as well as a main tool to solve the energy crisis and environmental problems.

The solar energy resources are very rich in our country. The annual amount of solar radiation in more than 65% of the area is higher than 5016 MJ/m^2, and the annual sunshine duration is greater than 2200h, which makes the development and utilization of solar energy considerable prospect. Over the past ten years, due to the efficiency of photovoltaic cells and solar collector efficiency increased, the PV/T technique develops rapidly, which is used in building and HVAC fields more and more widely. The core of PV/T technique is a photovoltaic-thermal collector, which is combined with photovoltaic cell and solar heat collector by lamination or adhesive technology (Kern 1978). In the absorption process, about 85% of long wave radiation energy of the heat collecting plate converts into heat, and surface temperature of heat plate increases up to 40~60℃. The remaining 15% of the solar radiation energy converts into electrical energy. PV/T technique used in building has the following advantages, such as good thermoelectric effect profit, obvious energy saving effect, long service life and so on. Agrawal studied a photovoltaic-thermal building integrated system, which concluded that the system initial investment compared to the individual collectors and photovoltaic building wall was higher than about 2~7%, but the cost of power generation decreased by 12~25%, the overall system energy efficiency increased 17~20% (Agrawal 2010). The design and application of PV/T technique in building has been more mature. Some countries have carried out the performance parameter test in experimental models of the construction, and gradually applied to the actual construction.

ASHP system is environmental friendly, low energy consumption, in relatively stable performance, huge in energy-saving potential and good in social benefits. All the above advantages promotes its rapid development in China. However, in the application process we found that it affected by conditions of the outdoor environment and climate is relatively large.

When under the low temperature environment in cold region, the heating capacity is relatively low, which cannot fulfil the requirements of building heating in winter. With the outdoor environment temperature decreased, the unit COP decreases gradually and the compressor pressure ratio will increase which leads to an increase in exhaust gas temperature and damage to the compressor in long-term operation, which confines large-scale popularization and application in our country. In order to improve the universality of application and strengthen thermal performance of the thermal system in low temperature environment of ASHP, it is mainly by improving the performance of heating cycle of component, optimizing the control system of thermal cycling system, controlling exhaust temperature of the unit, using the new refrigerant, improving the defrosting technical measures and so on.

On the improvement of air source heat pump heating system in low temperature environment, foreign researchers have done a lot of researches. Nobukatsu put forward a kind of economizer gas injection system with scroll compressor, which heat capacity can be increased by 15% running in low temperature environment (Nobukatsu 1983). Sami transfered traditional refrigerant into non azeotropic refrigerant to improving the thermal performance heat pump system in low temperature environment (Sami 1995). The above measures can improve the thermal performance of ASHP system in low temperature environment. However, there are strictly technical requirements in the optimization design of heat pump units, the system efficiency is still low, and frost technology has not completely been overcome. For the current technical level, it is difficult to widely promote the use of ASHP in cold region. Therefore, a new application mode of ASHP system is put forward in this paper. Based on the traditional ASHP system, photovoltaic-thermal technique is integrated with it, which improves the efficiency of ASHP using in low temperature environment and solves the problems when applying in cold region.

2. Methods

Based on the advantages of photovoltaic-thermal technology and the difficulties of ASHP using in low temperature environment in the practical application, a PV/T-ASHP integrated heating system is developed, which can operate safely, stably and efficiently in winter in cold region. Figure 1 shows the schematic diagram of PV/T—ASHP integrated heating system. PV/T air collectors were arrayed on the building envelop composing an integrated PV/T curtain wall. In the PV/T, up and down sides are respectively opened outlets and inlets connected to the ASHP unit with air ducts forming a forced circulation in the system. Air as the medium absorbing the waste heat of PV/T cavity, and the heat pump can utilize this part of heat. By using the PV/T air collector heating the circulated air, it can avoid the deterioration of heat transfer effect and performance drop of unit due to the evaporator frosting when the ASHP operating in low temperature. Besides, there is almost no overheating during the energy transfer process, freezing, boiling, corrosion and leakage problems are not to be considered in the practical application. The maintenance cost of the air collector is lower than the liquid one.

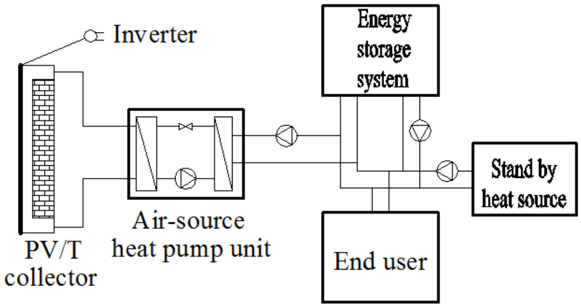

Fig. 1. PV/T—ASHP system schematic diagram.

3. TRNSYS simulation

TRNSYS software, developed by Solar Energy Laboratory of University of Wisconsin-Madison, is a dynamic simulation software. The biggest feature is the modular analysis in the software. It is considered to be one of the most flexible simulation software, we can use the modules easily to build up a variety of complex system. In this study, the PV/T-ASHP integrated heating system was built by the TRNSYS showed in Figure 2, which mainly studies the outlet temperature of the PV/T collector and the COP of the ASHP unit and explores the feasibility of the system using in severe cold region. Using the climate module in TRNSYS to calculate the ambient temperature of the PV/T collector during the heating period from November to March based on the Shenyang typical meteorological data. The PV/T air collector was a 20m×12m large scale apparatus integrated with building envelop. Rated heating power of the ASHP unit was 17.5 kW and the rated air flow of the fan is 5200m^3/h. A 6 m^3 phase change storage water tank was used to store heat water prepared from the ASHP unit, and the outlet temperature of the unit is set to be 55℃. The control scheme of the system was based on the load profile. Simulation time step was set to be 0.25h, tolerance integration and convergence were both 0.001.

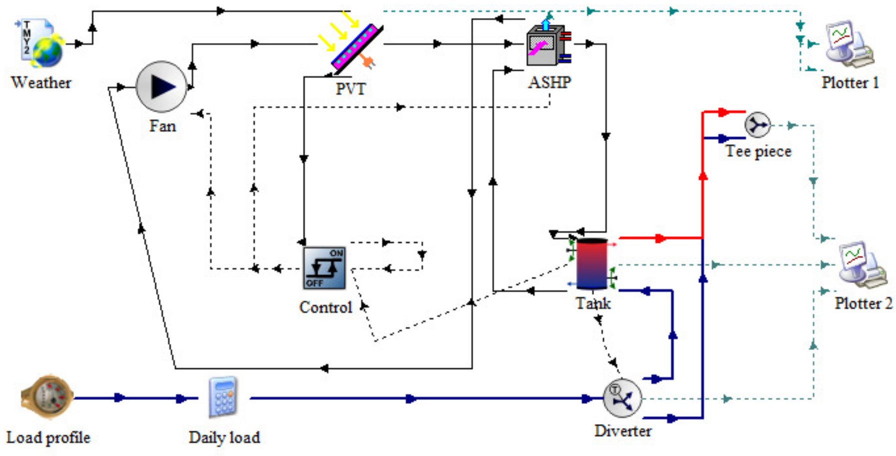

Fig. 2. TRNSYS project of PV/T—ASHP integrated system.

4. Results

As it shown in Figure 3, the outlet temperature of the PV/T collector varied widely ranged from -11.4 to 76.6℃ during the heating period in Shenyang. The operating scheme of the PV/T collector is when the outlet temperature of PV/T collector is 10℃ higher than the bottom temperature of water tank from 8 to 18 in the daytime, the fan then will run, and the ASHP system will produce heat water. Through the picture, we know that during the heating period the outlet temperature of PV/T collector is low when no solar radiation. However, when the PV/T collector was subjecting from solar radiation, the outlet temperature of PV/T collector increases marginally, which can directly supply to the ASHP unit for heating. Meanwhile, some COP data were also obtained from the TRNSYS software showed in Figure 4. The COP of the ASHP unit varied from 3.6 to 4.87, which changes depending on the outlet temperature of PV/T collector accordingly. In most of the time, ASHP unit operates in a relatively high efficiency condition and the average COP can reach 4.1.

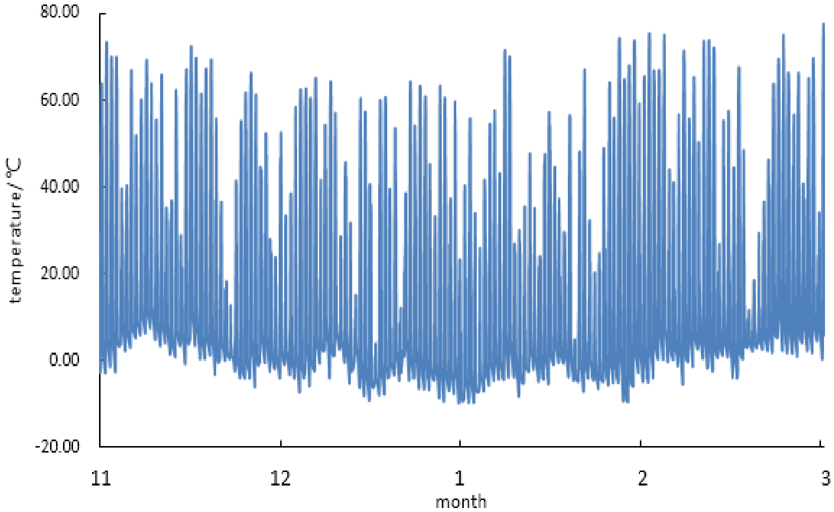

Fig. 3. Outlet temperature of the PV/T collector.

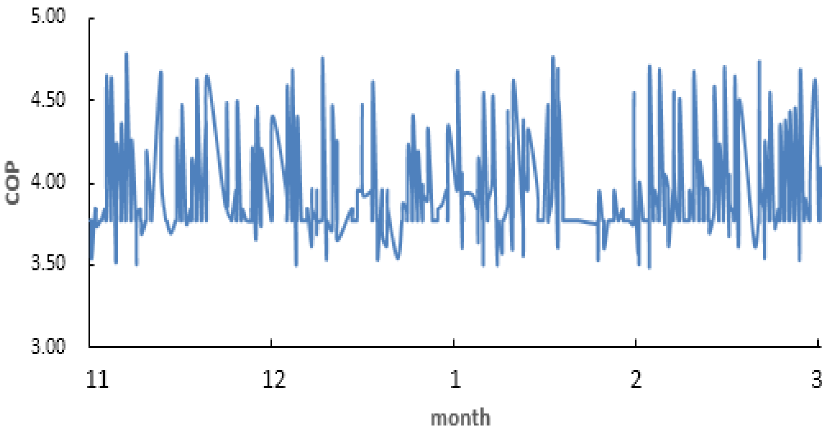

Fig. 4. COP of the ASHP unit.

5. Discussion

Through the simulation, it concludes that the PV/T--ASHP integrated heating system can effectively increase the COP of the ASHP unit when the outdoor temperature is low. Theoretically, it can supply part of energy to a building with the solar energy, a sort of non-continuous energy source. However, there still some researches need to be taken. Due to the PV/T collector is affected by random factors such as weather, the fluctuation of heat is huge. Without auxiliary heat source, the integrated system cannot achieve heating stably and continuously. The outlet temperature of phase change water tank is not studied in this research. Besides, only on type PV/T collector was used in the study, there should be several kind of collectors compared to find out the most suitable one.

6. Conclusions

In the context of energy-saving and emission reduction, vigorously promoting the use of renewable energy replacing traditional fossil fuels has become one of the main measure to deal with the energy crisis and environment problem. There are a lots of advantages of PV/T and ASHP technology, they should be popularized in the engineering. However, due to the existing technical level, the use of large-scale PV/T collector has a series of problems, such as higher initial investment, longer recovery cycle, low system efficiency, easily suffering from the outdoor environment, which restricts the development in our country. In this paper, according to the operation condition of ASHP system in severe cold area and the application characteristics of PV/T technique, a PV/T-ASHP integrated heating system is developed. TRNSYS transient simulation software was used to study the outlet temperature of PV/T collector and the COP of ASHP unit during a heating period in Shenyang. Through the simulation analysis, the outlet temperature of PV/T collector can reach 76.6℃ and the average COP of ASHP unit reaches 4.1. Through this integrated system, we hope to provide some new ideas for popularizing the use of ASHP and PV/T technology in severe cold region.

Acknowledgements

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