#573: Numerical study on hybrid heating technologies for a greenhouse

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Abstract: In this paper, we used TRNSYS software to firstly investigate the economics and environmental friendliness of three heating systems, namely, electric boiler (EB) heating system, solar assisted electric boiler (SAEB) heating system and solar assisted air source heat pump (SAASHP) heating system, in greenhouses, and the results showed that the SAASHP system has the lowest operating costs and a payback period of 8.7 years. Subsequently, the greenhouse with SAASHP heating system and built-in film was simulated using ANSYS Fluent software. The purpose of the film is to reduce the heating space and energy consumption, and the changes in the energy consumption of the system and greenhouse heating before and after the film was placed were compared using TRNSYS software, and the velocity field and temperature field before and after the film was placed were simulated and compared with the film using ANSYS Fluent software. Temperature field before and after film placement were simulated and compared using ANSYS Fluent software.The simulation results show that after the film is used in the SAASHP system, the greenhouse heating heat load is reduced by 42.8%, the heating operation energy consumption is reduced by 19.9%, the greenhouse temperature distribution is more uniform, and the film return on investment cycle is 1 year, so it has a higher value of use. The above results show that greenhouse built-in films are beneficial for greenhouse heating in cold regions. This study provides new ideas for clean and efficient greenhouse heating in cold regions and provides data support for related research.

Keywords: Glass Greenhouse; Numerical Simulation; Heating System

1. INTRODUCTION

The global energy and food crises, exacerbated by factors like COVID-19 and extreme weather, have driven a surge in greenhouse agriculture (Nguyen et al., 2021). As a result, greenhouses are booming all over the world. In China, the area of new greenhouses, particularly glass greenhouses, has expanded significantly (Guo et al., 2024). However, heating in these greenhouses during cold winter periods presents challenges related to insulation and energy consumption.

The use of plastic film as a greenhouse covering material has developed rapidly since the 1950s and is still growing (Parlato et al., 2020). Mulching has played an important role in Chinese agriculture because of its warming and moisturising effect on the soil (Liu et al., 2014). Cui (Cui et al., 2012) studied ethylene vinyl alcohol (PVA), polyethylene (PE), and ethylene vinyl acetate copolymer (EVA) blown into films, and investigated the optical properties, infrared transmittance, and their effects on the warming and heat preservation capacity of agricultural greenhouses of the three types of films, respectively. It was found that PVA film covering greenhouses could significantly improve the greenhouse thermal insulation capacity.

Controlling indoor air temperature for optimal plant growth consumes substantial energy, making greenhouse operations energy-intensive. In many countries the energy consumption for indoor air control accounts for up to 50% of the total cost of greenhouse gas production (Banakar et al., 2021), Making the greenhouse sector one of the most energy-intensive agricultural sectors, with significant economic and environmental impacts (Mazzeo et al., 2021). These problems can be mitigated by the use of renewable energy sources, such as solar energy (Raptis et al., 2017).

Solar energy is a good renewable energy source, and the energy generated by solar energy can provide part of the heating demand for greenhouses (Devabhaktuni et al., 2013). Air source heat pump (ASHP) is an energy efficient and environmentally friendly device that has been widely used for building heating (Zhang et al., 2017). Solar-assisted air-source heat pump (SAASHP) systems have gained attention due to their energy efficiency and environmental benefits. Several studies have explored the integration of solar collectors (SCs) with Air source heat pumps (ASHPs) to optimize heating performance (Fraga et al., 2015).

In this paper, we aim to compare the economic and environmental performance of three different heating systems, namely, electric boiler (EB) heating system, solar-assisted electric boiler (SAEB) heating system and solar-assisted air-source heat pump (SAASHP) heating system, for greenhouses. Subsequently, the impact of using a film cover on the greenhouse's energy consumption and temperature distribution will be investigated using TRNSYS and Fluent software.

2. PHYSICAL MODELLING AND METHOD

2.1. Greenhouse heating model

The present study was carried out on a glasshouse located in Tai'an City, which is a Venlo-type glasshouse with a width of 6 m, a length of 60 m, an area of 360 m^2, an eave height of 3.5 m, and a ridge height of 4 m. The top of the greenhouse was made of 5 mm toughened glass; and the sides of the greenhouse were made of 5 mm + 6 mm (air)+ 5 mm insulating double glazing. The thermophysical properties of the materials used are shown in Table 1.

Table 1: Thermophysical properties of materials

Materials	Density (kg/m^3)	Specific Heat (J/kg·K)	Thermal Conductivity (W/m·K)
Glass	2220	830	1.15
Soil	1800	840	2.00

The city of Tai'an (36°11′35.1″N, 117°7′44.3″E) is located in Shandong Province in the northern region of China, and Tai'an belongs to the warm-temperate semi-humid monsoon climate zone. Figure 1 shows the hour-by-hour outdoor dry bulb temperature map of Tai'an City, with 1295 h of temperature less than 0 °C and 304 h of temperature less than -5 °C throughout the year, and cold winters (Sterling et al., 2012). The required growing temperature for planting cash crops such as tomato and cucumber is about 15 °C, with a minimum of not less than 13 °C. The plant selected for this study wastomato, and the greenhouse heating temperature was set at 13 °C.

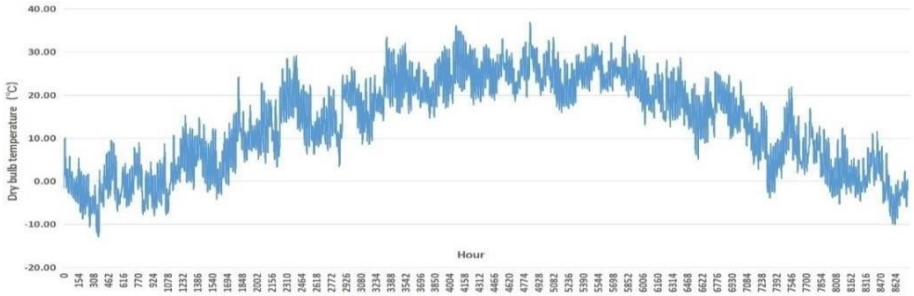


Figure 1: Hourly dry-bulb temperature for Tai'an, from the Typical meteorological year data

Taking 7 January in Tai'an City as an example, the outdoor hour-by-hour temperature and indoor hour-by-hour temperature

are shown in Figure 2. With the change of the outdoor temperature, when the greenhouse is not heated, the temperature inside the greenhouse only reaches 13 °C from about 12 o'clock to about 18 o'clock, and the temperature meets the demand of tomato growth for 6 hours in a day, and the temperature of the rest of the time cannot satisfy the normal growthof the plants; When the greenhouse is heated, the greenhouse does not need to be heated from 11 o'clock to 20 o'clock and needs to be heated for the rest of the day, depending on the initial indoor temperature, the outdoor temperature and the sun's light. Heating the greenhouse is necessary in order for tomatoes to grow properly in the winter and increase income. According to the temperature in the greenhouse and the growth cycle of winter tomatoes, we set the heating period from 1 December to 31 March of the following year, a total of 121 days.

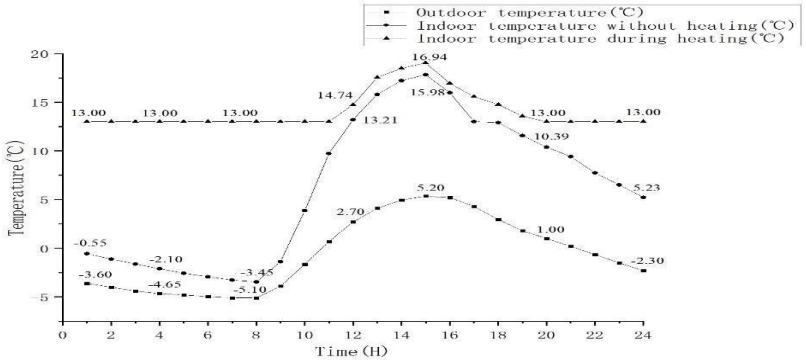


Figure 2: The ANSYS simulated greenhouse indoor air temperature profiles under given ambient air temperature profile predicted from the Typical meteorological year data in Tai'an

2.2. System design

The payback cycle calculation determines the feasibility of using the equipment and optimises the system results to be more in line with the actual needs of the project. Return on investment calculation should not only consider the impact of investment costs, but also need to consider the impact of inflation, tax factors, compound interest effect. The payback cycle calculation in the text only considers the impact of investment costs, and the construction of heating equipment is only used for winter greenhouse growing tomatoes, so this calculation is only for winter growing tomatoes, for the summer andautumn seasons of tomato income is not taken into account, the specific calculation formula is as follows:

Equation 1: Return Cycle Calculation Formula.

$$Y = \frac{N}{X - C}$$

Where:

- Y = the payback period (Year)
- N = the total amount of investment in heating equipment, i.e. solar collectors, hot water storage tanks, water pumps, electric boilers, air source heat pumps (Yuan)
- C = the annual cost of electricity for heating (Yuan)
- X = the annual income from growing tomatoes during the heating season (Yuan)

The solar collector is the most important part of the heating system. Its area directly affects the amount of solar radiation absorbed by the system and the initial investment of the heating system, which is a key factor in determining the energy saving and cost of the system. According to GB 50495-2019 (China Academy of Building Research, 2019), the collector area can be calculated as follows:

Equation 100: Solar collector area calculation formula.

$$A_c = \frac{86.4 Q_{\mathrm{H}}}{J_T \eta_{cd} (1 - \eta_L)}$$

Equation 101: Design heat load of the heating system.

$$Q_{\mathrm{H}} = Q_{\mathrm{r,max}}$$

Where:

- A_c = the solar collector area (m^2)
- Q_{H} = is the design heat load of the heating system (W) determined from the maximum heating heat load for the year $Q_{\mathrm{r.max}}$
- J_T = the local solar irradiation ($kJ/m^2 \cdot d$)
- η_{cd}= the average collector efficiency based on the total collector area (%)
- η_L = the heat loss rate of the piping and storage device (%), the empirical range of values for the range of 10% ~ 20%, here it takes a value of 15%

The volume of the heat storage tank is calculated as (Sun et al., 2015):

Equation 102: Volume of heat storage tank.

$$V = \frac{3.6K_1K_2Q_H\tau_w}{c \cdot \rho \cdot (t_h - t_l)}$$

Where:

- V = the volume of heat storage tank (m^3)
- K_1 = the safety coefficient of heat loss in the conveying process, the recommended value is 1.05~1.10, 1.05 used
- K_2 = the safety coefficient of heat loss in the heat storage tank, the recommended value is 1.05~1.10, 1.05 used
- r_w = the time of heating in the heat storage tank (h)
- c = the specific heat capacity of water (kJ/kg·K)
- ρ = the density of water (kg/m^3)
- t_h = the average maximum temperature in the tank after heat storage (°C)
- t_l = the average minimum temperature in the tank before heat storage (°C)

2.3. TRNSYS Modelling

At present, the greenhouse can use more types of heating equipment. More commonly used is the boiler heating, burning coal boilers is more polluting to the environment, and the need to add fuel artificially, is now less used, the use of more is the electric boiler heating system. In this paper, the heating system is simulated based on TRNSYS software, TRNSYS is a transient system simulation program, which is widely used in the dynamic simulation of building energy consumption and the optimisation simulation of system control strategies (Wu et al., 2023).

In this paper, we first established the electric boiler (EB) heating mode, solar-assisted electric boiler (SAEB) heating mode and solar-assisted air-source heat pump (SAASHP) heating mode respectively, to study their operating costs and select the best heating method for greenhouse heating. After design and calculation, the equipment selection is as follows:

(1) Solar collector system: the main equipment of the solar collector system includes solar collectors, as shown in Figure 3 Vacuum tube collector is selected, with a single tube length of 1800 mm, outside diameter of 58 mm and inside diameter of 30 mm, a silicone connection between the collector tubes, an installation tilt angle of 40°, and a collector tube spacing of 30 mm, and a total area of 120 m^2.

(2) Air source heat pump: water-water air source heat pump with a heating capacity of 75.3 kW is used.

(3) Heating equipment: Six fan coils (rated input power of 133 W, rated air volume of 1360 m^3/h) are selected, and the fan coil air supply outlet is installed on the north wall at a height of 2 metre from the ground; a return air outlet is placed on the north wall at a distance of 0.1 m from the ground. The heat storage tank is a cylindrical tank with an effective volume of 10 m^3.

(4) Electric boiler: the heating power is 67.1 kW.

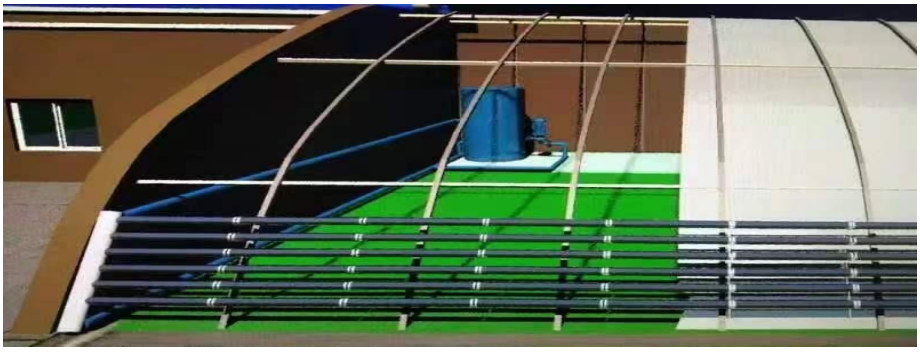


Figure 3: Solar collector systems

As shown in Figure 4, the greenhouse heating model mainly consists of a glass greenhouse, a hot water production system (EB system or SAEB system or SAASHP system) and a fan coil. The following heating control strategy is considered: when the temperature T_0 in the greenhouse is less than 13 °C, the fan coil system turns on. If the temperature of the hot water storage tank T_1 is greater than 45 °C, the fan coiler uses the hot water in the hot water storage tank to heat the greenhouse; when the temperature of the hot water storage tank T_1 is less than 45 °C, the hot water production system will first provide heat for the hot water storage tank, and when T_1 is greater than 45 °C, then the fan coiler will heat the greenhouse. When the temperature T_0 in the greenhouse reaches 13 °C, the fan coil system is shut down.

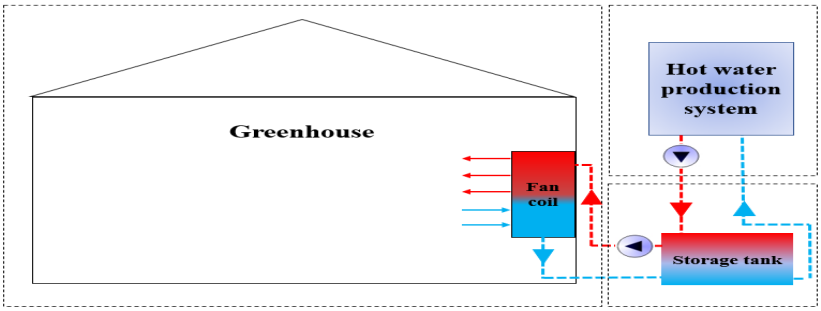


Figure 26: Greenhouse heating models

Figure 5 (a) shows the TRNSYS model of the electric boiler heating system, in which the Weather module uploads the meteorological data of Tai'an to the Greenhouse module; the heating fluid from the EB system enters the Storage Rank through water pump, and the fan coil system (type 146 and 753e) uses the heat source in the Storage Rank through water pump to provide heat for the greenhouse; the Heating control module and Temperature control module are mainly responsible for the start and stop of the EB system and the water pump and the fan coil.

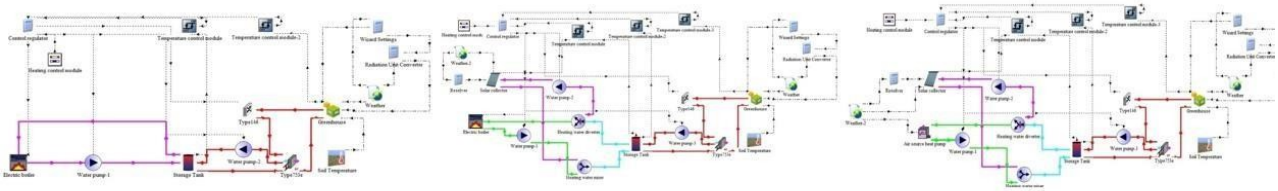
Specific working principle: during the heating season, the electric boiler (EB) heats the water in the hot water storage tank to maintain the temperature of the water in the tank above 45 °C; when the temperature of the greenhouse is lower than 13 °C, the fan coil starts, and at this time, the fan coil uses the hot water in the hot water storage tank to heat the greenhouse, and when the temperature of the greenhouse reaches 13 °C, the fan coil shuts down. The fan coil inlet and return air inlets were located on one side of the greenhouse, 1 m above the ground, and the return air inlet was located at a height of 0.1 m above the ground, with air flow speed of 2.0 $m \cdot s^{-1}$ and a temperature of 35 °C.

The TRNSYS model of solar-assisted electric boiler heating (SAEB) system is shown in Figure 5 (b), in which the Weather module uploads the meteorological data of Tai'an to the Solar collector module and the Greenhouse module; at this time, the Storage Rank is heated by both the Solar collector module and the EB system.

Specific working principle: during the heating season, when T_1 is less than 45 °C and the water temperature from the solar collector is greater than 50 °C, the water in the hot water storage tank will be heated firstly by the solar collector; when the water temperature from the solar collector does not meet the conditions, the electric boiler will start to heat the water in the hot water storage tank. Fan coil startup and EB heating system is the same as before **Error! Reference source not found.** (a).

Figure 5 (c) shows the TRNSYS model of the solar-assisted air source heat pump heating system (SAASHP), where the Weather module uploads the meteorological data of Tai'an to the Solar collector module, the air source heat pump module, and the Greenhouse module; at this time the Storage Rank is heated by the Solar collector module and the air source heat pump system together.

Specific working principle: Compared with the SAEB heating system, the equipment for heating the hot water storage tank is replaced by an air source heat pump. The other control principle is the same as SAEB heating system.



(a) EB heating system modelling. (b) SAEB heating system modelling. (c) SAASHP heating system modelling.

Figure 5: Heating system modelling

2.4. Film system

Glass greenhouses are generally specified at a height of 4 m or more, with most of the plant growing area being no more than 2 m, which results in a large blank area inside the greenhouse. In the heating season, this part of the area does not need to be heated, but currently many greenhouses are heated for this part, which leads to a lot of wasted energy. If film were placed inside the greenhouse to divide the greenhouse into upper and lower zones, heating only the area where the plants are located, this would save a lot of energy.

The film material should be highly transmissive to the sun and have good thermal insulation. In this paper, we have chosen to use polyvinyl chloride film as the film material. Because this film is highly transparent to solar shortwave radiation, which means that most of the solar radiation can pass through the plastic and into the greenhouse. However, for terrestrial long-wave radiation, these materials are not transparent and very little terrestrial long-wave radiation can pass through them, which means that the film can block long-wave radiation from the greenhouse soil and the plants inside the greenhouse and thus reduce the temperature loss of the greenhouse. The film absorbs and also reflects back the long-wave radiation

emitted from the soil and the plants and thus reduces the loss of heat of the greenhouse. This property allows the greenhouse to be warmed by allowing a constant flow of solar energy from the outside to enter the house, while little heat is lost from the inside. The plastic film has a high reflection coefficient, so that part of the heat radiation in the greenhouse is reflected back to the greenhouse, increasing the insulation capacity of the greenhouse, and reducing the temperature transfer. In addition, the use of film reduces heat loss from the greenhouse by two other mechanisms: (1) It greatly reduces the entire volume of air heated by the heating system. (2) Reduces convection losses by not allowing the air under the film to come into contact with the very cold greenhouse roof. As shown in Figure 6, the film is placed horizontal (parallel to the greenhouse floor) at a distance of 2.5 m from the floor, the film is retractable, when the greenhouse does not need to be heated, the film is in a retracted state; when the temperature of the greenhouse is lowered, the film is opened, and the fan coil is turned on to heat the greenhouse.

After a suitable heating system has been selected, research will be carried out on the impact of the use of film on the effectiveness of greenhouse heating.

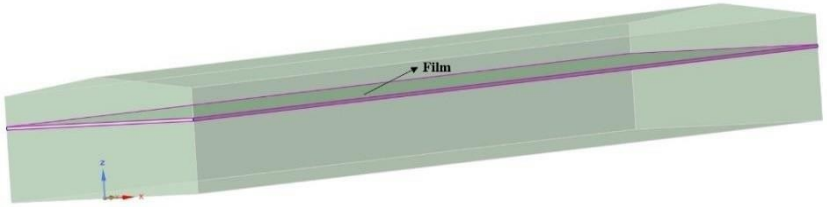


Figure 6: Numerical greenhouse modelling

2.5. Fluent numerical modelling

In order to simulate the effect of the use of a film on the fan coil when it heats the greenhouse, the computational fluid dynamics (CFD) software ANSYS Fluent will be used in this study (Kavga et al., 2023). The temperature and air velocity fields in the greenhouse heated by the fan coil with and without the use of a spacer and an outdoor temperature of -10 ^{o}C are simulated. Meshing was used to generate the grid, and a structured grid with higher quality and fewer cells was constructed for accuracy and efficiency of the calculations.

The simulation is based on the transient state, with the initial temperature of the greenhouse set at 0 ^{o}C. The DO radiation model is used to calculate the radiative heat transfer. The calculation scheme was SIMPLEC which had better accuracy and less calculating time. The spatial discretization method adopted second order upwind for the momentum, turbulent kinetic energy, turbulent dissipation energy and energy equations which satisfied the calculating requirements of flow and heat transfer.

3. RESULTS AND DISCUSSION

3.1. Economic analysis of heating systems

The EB, SAEB, and SAASHP equipment investments were 56,000 Yuan, 107,500 Yuan, and 138,500 Yuan, respectively. Table 2 shows the Operational economic analysis of heating systems. We can see that the power consumption of EB system is 62,811.4 kWh, SAEB system is 49,525.1 kWh, and SAASHP system is 43,937.4 kWh. The cost of agricultural electricity in China is 0.4 Yuan/kWh, and the cost of EB system after one year of use in the heating season is calculated to be 25,124.6 Yuan; the cost of SAEB system is 19,810.0 Yuan; and the cost of SAASHP system is 17,575.0 Yuan, and the operating cost of SAASHP system is 11.3% lower than that of the SAEB system and 30.0% lower than that of the EB system. It can be seen that the SAASHP system has the lowest operating cost, which is due to the fact that the air source heat pumps work by increasing the temperature level at which the heat is extracted from the outdoor air, consuming less electrical energy and thus saving more on operating costs.

The yield of greenhouse-grown tomatoes in the heating season is about 5 tonnes, and the selling price of tomatoes in winter is about 7000 Yuan/tonne, minus the costs of seeds, fertilizers, pesticides and other costs, resulting in an income of about 34,000 Yuan. After calculation, the annual profit of the EB system is 8875.4 Yuan, the annual profit of the SAEB system is 14,190.0 Yuan, and the annual profit of the SAASHP system is 16,425.0 Yuan. The payback cycles of the three types of equipment are 6.3, 10.5, and 8.4 years, respectively, and the profits of the three types of systems after ten years of operation are 32,754.0 Yuan, -7600.0 Yuan, and 25,750.0 Yuan, and the profits of the three systems after fifteen years of operation are 77,131.0 Yuan, 63,350.0 Yuan and 107,578.0 Yuan, respectively. The decision to use the SAASHP system for greenhouse heating was made from the standpoint of operating costs, payback period, and profit at a later date.

Table 25: Economic analysis of heating systems

Typology	Electricity (kWh)	Price of electricity (Yuan/kWh)	Total cost (Yuan)
EB system	62,811.4	0.4	25,124.6
SAEB system	49,525.1	0.4	19,810.0
SAASHP system	43,937.4	0.4	17,575.0

3.2. Impact of film on SAASHP heating system operation

Greenhouse heat load

After the selection of the greenhouse heating system, a study was carried out on the impact of the use of film on the operation of the SAASHP heating system.

The heat load diagram of this greenhouse was obtained after simulation by TRSYS software, Figure 7 (a) shows the annual heat load of the greenhouse without a film and Figure 7 (b) shows the annual heat load of the greenhouse with a film. The annual heat load of the greenhouse without film is 66,720.7 kW, with a maximum heat load of 61.0 kW, and the annual heat load of the greenhouse with film is 38,140.9 kW, with a maximum heat load of 41.7 kW. Comparing the annual heat loads of the two types of greenhouses, the annual heat loads of the greenhouse with film are significantly smaller than the annual heat loads of the greenhouse without film, which is reduced by 28,579.8 kW, or 42.8%. This is due to the fact that the heat supply space becomes smaller after the greenhouse is equipped with a film, so the required heat load is also reduced, and the film is a kind of thermal insulation material, which reduces the overall loss of heat.

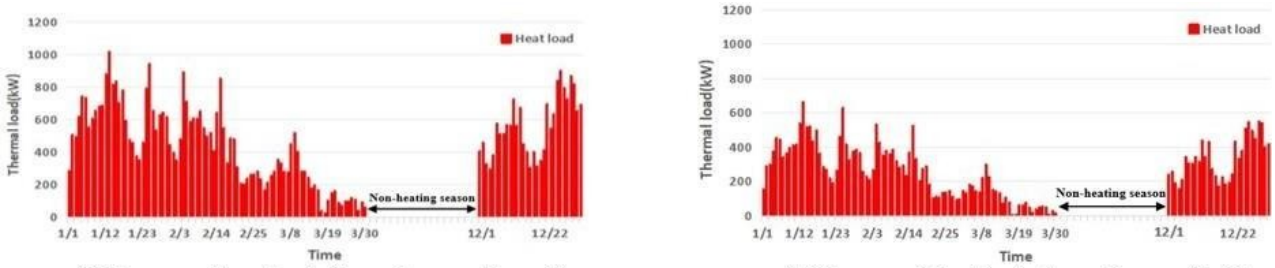


Figure 7: Year-round heat load of greenhouse

Power consumption analysis

Power consumption affects the availability of a system. A comparison of the energy consumption of the water pump and air source heat pump in the greenhouse with and without film is shown in Figure 8, where the heating system consumes 43,937 kWh of energy during the heating season before the film is used, and after the film is used, the heating system consumes 35,211 kWh, which is a reduction in power consumption of 19.9%. The reduction of power consumption is related to the change of heating area. The original glass greenhouse space that needs to be heated is 1350 m^3, while after the use of film, the greenhouse space that needs to be heated is 900 m^3, i.e. he heating space is reduced by about 33%. The reduction in the heating area of the greenhouses also led to a significant reduction in the use of the heating system, resulting in higher energy savings.

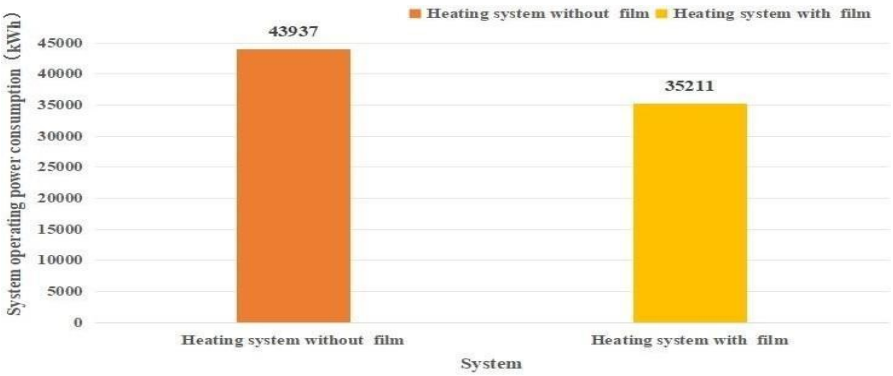


Figure 8: Power consumption for heating system operation

Environmental analysis

Heating systems that heat greenhouses by consuming electrical energy, which is obtained by the power plant in the form of coal consumption. Since the energy efficiency of electric heating is much lower than that of the solar collector-assisted air source heat pump heating system, and the corresponding standard coal consumption is inevitably higher than that of the coupled heating system, only the environmental benefits of the heating system operation modes before and after the use of the film are compared here.

From Figure 8, electricity savings of approximately 8726.0 kWh per year from the use of the film greenhouse heating system, and the corresponding reduction of each pollutant is shown in Table 3, and the electricity saved corresponds to the saving of 3490.5 tonnes of standard coal per year, and the reduction of carbon dioxide emission is about 8691.3 tonnes/year, which shows that the thin-film heating system has considerable environmental benefits.

Table 26: Energy savings and emission reductions in the heating system after the use of film

	Savings in standard coal	CO_2	SO_2	NO_x	Dust
Emission reductions (tonnes/year)	3490.5	8691.3	261.7	130.8	2373.5

Fluent temperature and velocity field analysis

Figure 9 show the temperature field in a glass greenhouse without film and with film, respectively, located in the area midway between the two fan coil outlets. It is clear from Figure 9 (a) that the temperature distribution in the greenhouse not covered with film is not uniform. The fan coil outlet (hot air blowing from the right side to the left side) is located on theright side of the greenhouse, and the hot air collects on the left side of the greenhouse. At this time, the temperature at 0.5 m above ground is 13.5 ºC, 1 m above ground is 15.3 ºC, 1.5 m above ground is 14.6 ºC, 2 m above ground is 13.9 ºC, 2.5 m above ground is 11.3 ºC. The temperature in the tomato growing area in the greenhouse was 15 ºC in some areas and 10 ºC in others, and the temperature in the upper right part of the greenhouse reached 8 ºC, with a large variation in the temperature gradient. Parts of the plant growth area were around 10 ºC which is below the minimum temperature requirement for tomato growth and will affect normal tomato growth. In the area near the glass wall, the temperature was lower, and the cold outdoor air intrusion was severe. Figure 9 (b) shows the greenhouse covered with film, and it can be seen that the temperature shows the same temperature variation as when no film was used, with the temperature concentrated on the left side of the greenhouse. However, this time, the temperature distribution of the plant growth area in the greenhouse is more uniform, and the temperature from 0.5 m to 2 m from the greenhouse floor is between 14.5 ºC - 16.0 ºC, with a small temperature gradient change. The upper part of the film showed an obvious temperature gradient due to the factor of heat transfer, the temperature near the film reached 3 ºC from the initial value of 0 ºC, and the area near the top of the greenhouse reached -8 ºC due to the influence of the cold outdoor air.

Figure 10 show the velocity field distributions in the glasshouse without and with film, respectively. Figure 10 (a) demonstrates that the air velocity flow in the greenhouse without film is mainly concentrated in the direction towa rds the fan outlet, and at a height of 1 m from the ground, the air flow velocity near the outlet reaches 1.3 $m \cdot s^{-1}$,and the air flow velocity away from the outlet at the same height is also 0.3 $m \cdot s^{-1}$, but the air flow velocity in the upper part of the greenhouse is 0.06 $m \cdot s^{-1}$, which is a slow flow velocity. The air flow was slow in a large part of the greenhouse, which made the temperature diffusion slow and the greenhouse heating slow, which explains why the upper right part of the greenhouse was only 8 ºC without the film, and the slow air flow led to the fan running for a longer period of time, which increased the unnecessary energy consumption. With the film the area heated by the greenhouse was reduced and partsof the upper part of the film did not need to be heated, so there was no need for human intervention in air flow. As can beseen in Figure 10 (b), air flow was faster in most of the tomato growing areas, resulting in a more even temperature distribution in the greenhouse.

According to the temperature and velocity fields, it can be concluded that the temperature distribution is more uniform after the use of film, and this part of the upper part of the film does not need to be heated, which will lead to a reduction in the fan coil running time, and the film will be part of the heat radiation of the greenhouse reflected back to the greenhouse, reducing the loss of some of the temperature in the greenhouse, and only a small portion of the tempera ture is lost to the top of the greenhouse, which leads to a significant reduction in the amount of heat required to reduce the use of the heating system to lower the energy consumption for operation. It was calculated that the fan coil running time was reduced by approximately 25% when the film was applied compared to the fan coil running time without the film.

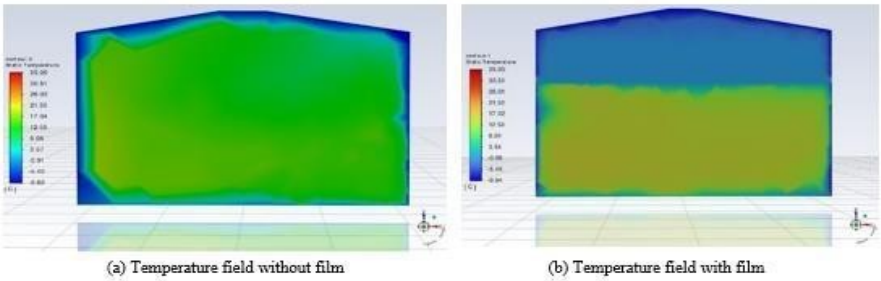


Figure 9: Greenhouse temperature field

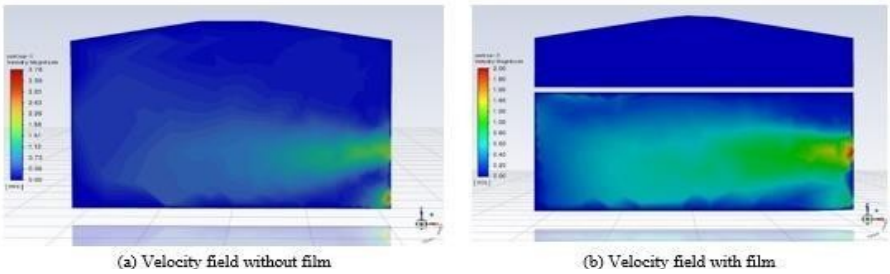


Figure 10: Greenhouse velocity field

Economic analysis after the use of films

The cost of film as shown in Table 4, more than no film investment of 3600 Yuan, after adding the film, will reduce the annual consumption of 8726 kW of electricity, will save the annual electricity bill of 3490.4 Yuan. The use of film heating systems relative to the use of film heating systems can be used in the year back to the capital, so the use of plastic film greenhouse heating system has a good economic result.

Table 4: The amount of investment in the film

Component	Quantity (m^2)	Unit Price (Yuan/m^2)	Cost (Yuan)
Film	360	10	3600

4. CONCLUSION

The use of this film was investigated by simulating a glass greenhouse in a cold region of China with the addition of a film in a greenhouse with solar collectors and an air source heat pump as the heating system. The following are the main scientific and valuable conclusions:

After analysing the operating economics of the EB system, the SAEB system and the SAASHP system, after heating the greenhouse for one year, SAASHP has the lowest operating cost, and the SAASHP system's operating cost is 11.3%lower than that of SAEB and 30.0% lower than that of the EB system. And the payback cycle of the SAASHP system is 8.7 years, which is the best return for long-term operation.

With the addition of insulating film, the annual heating heat load of the greenhouse was significantly less than the annual heat load of the greenhouse without spacers. With the film, the greenhouse heat load was reduced by 28,579.8 kW or 42.8% from the original. Therefore, the addition of film will reduce heating energy consumption and also create a better microclimate inside the greenhouse.

The heating system saves 8726.3 kWh of energy a year and reduces CO_2 emissions by 8691.3 tonnes a year, so the heating system with film has considerable positive environmental benefits.

The investment in the film is 3600.0 Yuan, and after using the film will save money on electricity costs of 3490.4 Yuan/year, with a payback period of about 1 year. With the passage of time, it has a greater value of use.

After the use of film, fan coil heating of the greenhouse, the greenhouse velocity field is more complex to make the air flow more quickly, speeding up the temperature distribution and diffusion in the greenhouse, making the temperature distribution more uniform. At the same time, the film reduces temperature loss and allows some of the heat radiation to be reflected back to the tomato growing area, resulting in less temperature loss. The addition of the film reduces the running time of the fan coils by 25%, saving more energy.

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