Study on A Passive Solar Technique and Its Energy Saving Performance in Rural Houses in Qinghai-Tibetan Plateau

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Abstract

Solar energy is increasing essentially to fortify energy security and mitigate CO_2 emission. China committed itself under the Paris Agreement to reach carbon emission peak by around 2030 and achieve carbon neutral by 2060. Solar techniques in rural houses in Qinghai-Tibetan Plateau (QTP) are expected to be significantly developed under this background. This paper introduces a passive solar technique with aluminum frames and glass structure (AFGS), which is widely adopted by local residents in QTP. Firstly, the background for application of AFGS, including climate, economy and residents' living habit, is introduced. Secondly, the effects of this technique on indoor temperature and heating energy consumption of rural houses were discussed based on EnergyPlus simulation software. Thirdly, the impacts of AFGS on indoor natural ventilation environment were simulated by PHOENICS software. Fourthly, power generation capacity, economic cost and benefits of AFGS replaced by photovoltaic (PV) system were rough calculated, advantages and challenges regarding changing heating methods from coal to PV system were discussed. Finally, energy saving performance of AFGS on rural houses were summarized. Passive solar technique was expected to contribute more to energy conservation and reduction of CO2 emission on rural houses.

Keywords: Qinghai-Tibetan plateau, passive solar technique, rural houses, energy saving, PV system

1. Introduction

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) confirmed that human activities have an important impact on earth's climate change, particularly from energy use perspective, and that further change is inevitable. Adaptation plans need to be systematically considered by decision makers (Y.P. Cai et al., 2010). Due to the close relationship between energy consumption and climate change related to the emission of greenhouse gases, actively respond to the reduce carbon emission is imminent. As the largest national emitter of greenhouse gases, "China committed itself under the Paris Agreement to reach carbon emissions peak by around 2030 and, in the meanwhile, to increase the non-fossil share of its primary energy to 20%" (Y. Qi et al., 2020). More than that, China announced the ambition to be carbon-neutral by 2060 (Y.W. Weng et al., 2021). Low carbon development is not just a task of energy sector, most industries and departments are involved. The construction sector is one of the 3 major sectors of energy consumption (construction, transportation and industry), reducing significantly direct or indirect greenhouse gas emission from the construction sector is an important task to achieve carbon neutral (China Society for Urban Studios, 2021).

Solar energy is the most abundant, inexhaustible and clean source than other renewable energy such as wind, hydro, etc. which can substitute fossil fuels (C. Peng et al.,2011). In one day, the irradiation from the sun on the earth gives about 10,000 times more energy than the daily use from mankind. The challenge is collecting this available energy at a reasonable cost (Bjørn Petter Jelle, 2012). Although solar energy still contributes a small portion to our energy needs, a mass shift to renewable sources of power is tantamount to a healthy future. One of the most remarkable renewable energy technologies is photovoltaics, which products electricity from the sun, without concern for energy supply or environmental harm.

QTP is located in southwest of China and its altitude is between 3000-5000 meters. The region has a typical plateau continental climate, namely low temperature, little precipitation comprises the distinguished features (Y.P. Fang et al., 2002). This region receives the largest amounts of solar radiation in all of China for its high altitude, low moisture and dust content in the atmosphere (Q. Wang and H.N. Qiu, 2009), and annual total radiation amount ranges 4000–

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10100 MJ/m2 (Z.R. Zhu et al., 2006) (Fig. 1). The annual sunshine hours in most areas in QTP are more than 2500h. Xining that is located in QTP was selected as a case to study the solar energy utilization of rural houses, and field investigations were carried out. Available time for PV generation of Xining is 1460h (National Energy Administration, 2019).

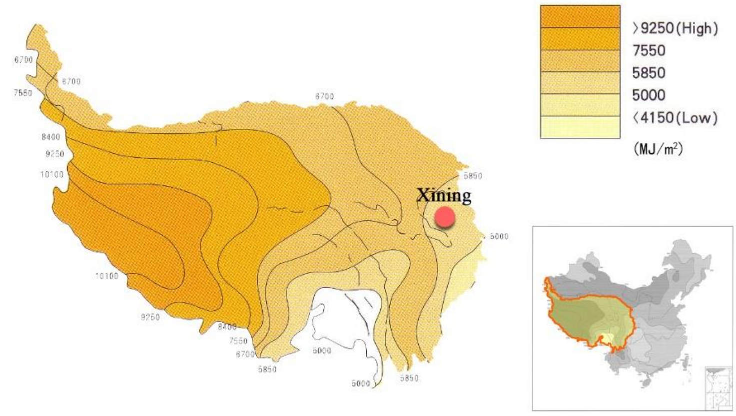

Fig. 1: Distribution of solar energy in Qinghai Tibetan-Plateau

China has implemented several policy to promote solar energy utilization in QTP. The early plan was Brightness Programme in 1999 to 2000, the plan relied on solar and wind applications to provide electricity to 23 million people located in Gansu, Qinghai, Inner Mongolia, Tibet and Xingjian by 2010, and to provide 100 W of capacity per person (Y.P. Fang, Y.Q. Wei, 2013). In 2007, China's National Climate Change Program was released, it planed to actively developing solar power and solar heating, including popularizing family-use photovoltaic power system; and popularizing household solar water heater, solar greenhouse and solar stove in rural areas (CPGPRC, 2007). In 8th September, 2021. National Energy Administration of China have published the "Notification of the Comprehensive Department of the National Energy Administration on publishing the list of pilot projects for roof distributed photovoltaic development in the whole count" (National Energy Administration, 2021). This project plan was to promote the popularization of PV technology in 676 counties and cities, 41 counties and cities of QTP were in the list. In the near future, there will be more policies to encourage the application of PV technology in buildings.

Most of the builindgs in QTP are rural houses, many residents there still use coal and cow dung as heating energy. PV industry in QTP has made remarkble development, but there are many challenges for promoting PV system into rural hosues. What are the challenges and advantages if PV system are adopted in rural houses. Taking Xining as an example, here we introduced a passive solar technique widely used by local residents, then discussed the changes and influence if PV system was used to replace it.

2. Methods

2.1. Investigations in Xining region

There is a thriving PV industry in QTP, mostly centered in Xining. Xining-based PV sales companies have extensive networks for selling, marketing and servicing household PV systems for rural farmers and nomads (S.J. Ling et al., 2002). At present, household PV systems for rural houses in Xining region has constant development, and that is mainly distributed in pastoral area. PV systems are rarely adapted in rural houses in urban area. This is because convenient transportation makes residents use coal as life and heating energy, instead of rely on expensive PV equipment. The investigation showed that about 4 tons of coal (worth $492) was needed in heating period for each house. The combustion of these fuels results in the emission of large amount of smoke, containing oxides of nitrogen and sulphur, inhalable particulates and carbon monoxide etc., which could pollute indoor air and hazard human health (L. Hua et al., 2016). Clean and cheap heating energy is the common need of local residents.

Weather in Xining is cold in winter and cool in summer (X.L. Wang et al., 2020). Monthly average temperature, monthly average global radiation and direct normal radiation are come from meteorological documents of EnergyPlus (U.S. DOE, 2021). It is generally considered that heating starts when outdoor average temperature is ≤ 5 °C last for 10 days. Meteorological data show that monthly average temperature lower than 5 °C are distributed from October to April of next year (Fig. 2). According to this standard, the heating period of rural houses in Xining is about 6 months, from 15th, October to 15th, April, last for 183 days. This heating period has been used for decades (J.H. Zhang et al., 2006).

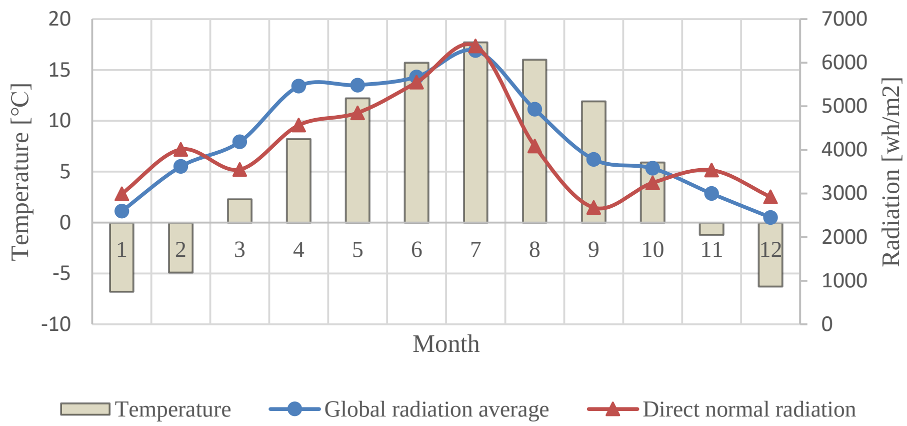

Fig. 2: Monthly mean temperature and radiation in Qinghai region

The layout of traditional rural houses in Xining generally present the Chinese character "回" (Fig. 3), which are also known as Zhuang-Ke building. The most remarkable feature of Zhuang-Ke building is the enclosed courtyard which can prevent cold wind. Nowadays, contemporary residents use aluminum frames and glass structure (AFGS) to enclose the courtyard instead of brick structure (Fig. 3). New structure can prevent cold wind, accept more sunlight, raise indoor temperature and keep the yard clean. It is popular because low cost, easy construction and good flexibility. Meanwhile, this structure is a low-cost passive solar energy technique. In the field investigation, it can be found that residents have different methods of closing their courtyard to their personal living habits and building characteristics. This paper discusses the energy saving performance of this technique in different enclosure methods. Further study will discuss the advantages and disadvantages of replacing this technique with PV system.

Fig. 3: Traditional rural houses (left) and contemporary rural houses (right) in Xining, Qinghai

2.2. Typical rural house

A contemporary rural house (Fig. 4) widely used was selected as a typical model to discuss the energy saving performance of AFGS in different enclosure methods. This building is 2 floors, building height is about 7.2 m, and floor area is 62.3 m^2 (including 1 living room, 3 bedroom and 1 bathroom). The kitchen is separated from the main building and located in a corner of the courtyard, and the courtyard area including kitchen is 47.4 m^2. 50mm XPS insulation board is adopted for the external wall and roof. The building plan is shown in Figure 5.

Fig. 4: Typical rural house in Xining region

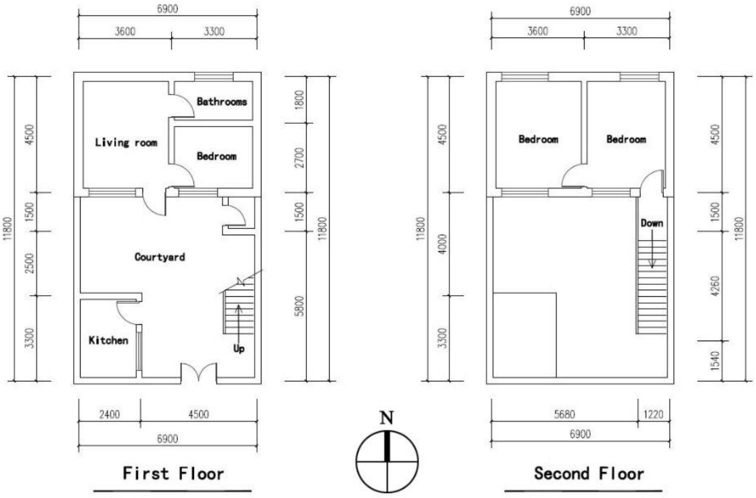

Fig. 5: Building plan of the typical rural house

2.3. Temperature and energy consumption simulation based on EnergyPlus software

4 main courtyard closure models were established by using Open Studio based on typical rural house. Model 1 did not close the courtyard, which was a reference model. Model 2 to 4 were adopted different way to enclose courtyard, they were experimental models (Fig. 6). Model 2 represents rural houses that do not enclose the entire courtyard, but the outer corridor is closed and large-area windows are opened. Model 3 represents buildings that enclose the courtyard on the 1st floor and outer corridor on the 2nd floor. Model 4 represents rural houses that enclose the entire courtyard with a height of 2 floors. There are more than 4 methods of closure courtyard actually,the most popular methods were selected as examples in this paper.

Indoor temperature of 4 models under non-heating state was simulated to compare the insulation performance of different enclosure methods of AFGS. Meteorological data of Xining region were from the official website of EnergyPlus (U.S. DOE, 2021). The running time of indoor temperature simulation in non-heating state was the whole year. 4 people were set in the building, operating time and efficiency of equipment and lighting were set with reference to the actual situation of local residents. Building envelope of simulation models was referred to the actual construction of rural houses. U factor of exterior wall and roof of models was set as 0.457 W/m^{2}K. U factor of exterior window was set as 2.686 W/m^{2}K, solar heat gain coefficient (SHGC) of glass was set as 0.764. Air change rate was set as 1 time per hour.

Energy consumption of 4 models in heating period were simulated to compare the energy-saving performance of different enclosure methods. The heating temperature was set to 18 °C, and heating was only set for bedrooms and living room. The run period of heating ventilation and air condition (HVAC) was from 15th, October to 15th, April of the next year. Cooling energy consumption in summer was not be considered because residents did not use air condition in summer. The setting of building envelope and air change rate of models were the same as that of non heating simulation.

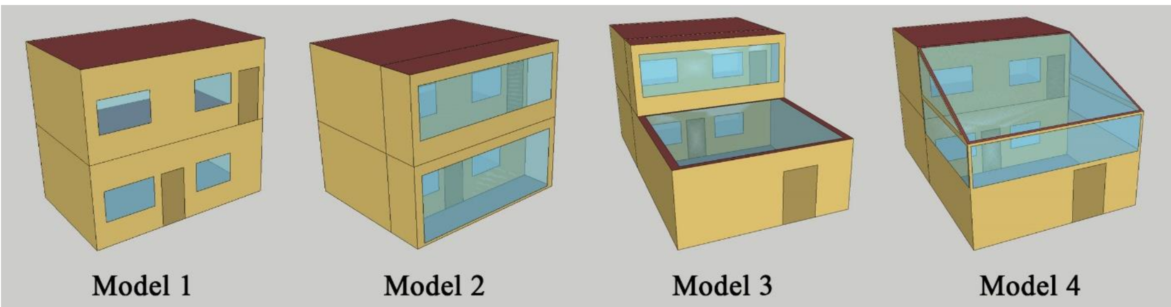

Fig. 6: 4 rural house models for EnergyPlus simulation

2.4. Ventilation simulation based on PHOENICS software

Indoor ventilation environment can be affected by enclosing the courtyard, local residents set some windows on the AFGS to adjust indoor air environment. The investigation showed that the risk of soot poisoning and allergic rhinitis will be increased for those who living in a poor ventilation house. In order to compared the impact of different practices on indoor wind environment, PHOENICS software was used to simulate the indoor ventilation environment of 4 models (Fig. 7). The date was set at 2 p.m. on July 15th. Meteorological data of wind and sun were come from EnergyPlus (U.S. DOE, 2021). The simulation interests focused on livingroom's indoor wind speed and air age.

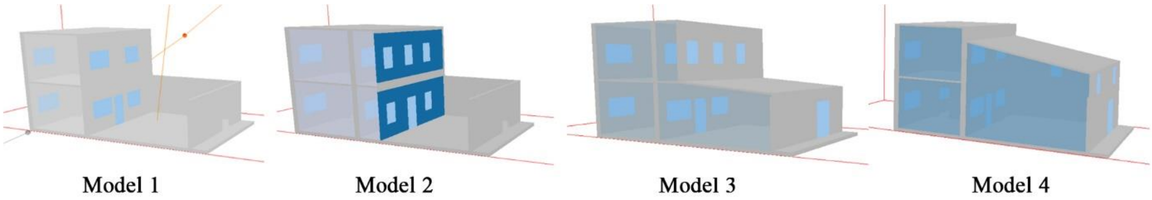

Fig. 7: Four rural house models for ventilation simulation

2.5. Comparison of aluminum frames and glass structure and solar PV technique

2021 is the first year for China to achieve the goal of carbon emission peak and carbon neutral. Boosted by impressive technological innovation and cost reductions, photovoltaic (PV) technology is widely used in the QTP as an important way to reduce carbon emissions (Y. Huang et al., 2021). According to relevant research, the cost of distributed PV system in QTP will be $ 6.2 per 1 kW in 2025(CEPPEI, 2019), low cost of PV system enables it to be popularized in the rural houses in QTP.

This study assumes that in the future, with the incentive of policies, solar PV system is widespread used in rural houses as the only source of energy, and coal was abandoned. Based on the current conversion efficiency of solar PV system, carrying area, energy generation capacity and cost of PV system for 4 rural houses' models were discussed. Purpose of this discussion is to explore the possibility and difficulty of carbon neutral in rural houses in Xining region.

3. Results and discussion

3.1. Indoor temperature of rural houses in natural state

Indoor monthly average temperature of 4 models in natural state were simulated (Fig. 8). Results showed that, 1) indoor monthly mean temperature of 4 models changed synchronously with outdoor temperature without heating. 2) Monthly mean temperature was the highest in July and the lowest in January. 3) Indoor temperature in Model 1 and Model 2 in summer (Jun.-Aug.) was lower than that of the other two models for about 2 °C. 4) The time when monthly indoor temperature was higher than 18 °C was distributed from mid-May to mid-September. 5) The maximum monthly mean temperature of 4 models was lower than 25 °C, therefore, rural house did not need refrigeration in summer. 6) Temperature change trend of 2 floors in 4 models had almost the same trend. 7) Monthly mean temperature of 1st floor was lower than that of 2nd floor from January to July, and high than that of 2nd floor from August to December.

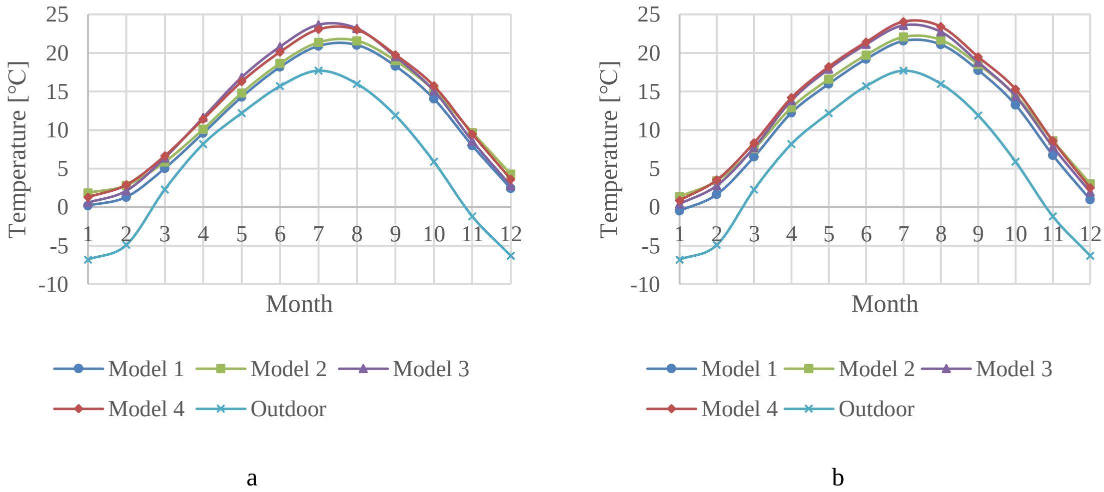

Fig. 8: Indoor monthly mean temperature on the 1st floor (a) and on the 2nd floor (b) of 4 models

15 °C is the cold feeling turning point of human body (J.H. Zhang et al., 2006). Monthly mean temperature is lower than 15 °C of 4 models is distributed from October to April of next year, which is consistent with the heating period

of Xining region. Indoor temperature could be improved by enclosing courtyard with AFGS. But it can not change the heating demands of rural houses. High indoor temperature of enclosed courtyard in model 3 and model 4 may occur in summer according to the field investigation and simulation (Fig. 9). Appropriate cooling measures need to be applied for these practices. Indoor temperature of rooms and enclosed courtyard in model 2 is higher than that of model 3 and model 4 in winter, which means model 2 has better insulation performance than other 2 models.

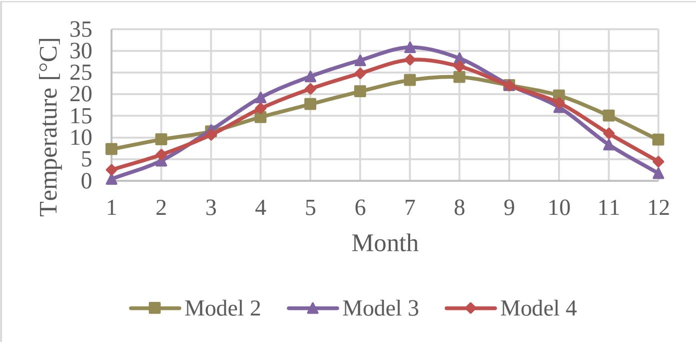

Fig. 9: Indoor monthly mean temperature of enclosed courtyard of 3 models

3.2. Heating energy consumption and carbon emission in different models

Energy consumption simulation is an important way to compare the energy saving performance of different construction. Simulation result of heating energy consumption from 15th, October to 15th, April was shown in figure 10. Results showed that, 1) Monthly energy consumption of 4 models showed a single peak distribution, which was the highest in January and the lowest in October. 2) When outdoor temperature was lower, heating energy consumption was higher. 3) Annual energy consumption of model 1 was the largest and that of model 2 was the smallest, annual heating energy was model 1 > model 3 > model 4 > model 2.

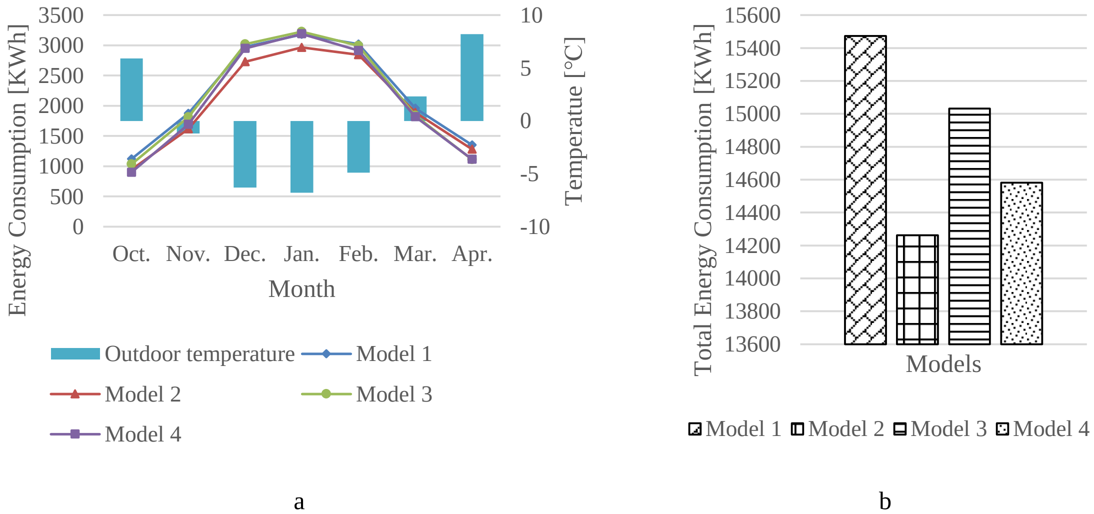

Fig. 10: Monthly energy consumption (a) and annual energy consumption (b) of 4 models for heating

Outdoor temperature varies the same trend with the solar radiation intensity (Fig. 2), In heating season, when outside environment goes colder, solar radiation intensity goes lower, but heating energy demands become higher. Uneven time distribution of solar energy resource increases the difficulty of utilizing it to reduce heating energy consumption in winter. Annual heating energy consumption can be reduced by enclosing courtyard with AFGS, and model 2 performs best. This is because construction of model 2 is more conductive to using solar energy to raise indoor temperature.

Results from non heating simulation showed that passive solar technique can not change the situation that indoor temperature of rural houses in winter was low and local residents still needed using coal for heating. On the other hand, heating energy consumption can be reduced by improve passive solar technique. In order to achieve the goal of carbon emission peak in residential building, adaptation plans need to be systematically considered by decision maker, and more efficient passive solar techniques needed to be discovered.

3.3 Indoor ventilation environment in different models

Local residents use AFGS to enclose the courtyard is to prevent cold wind, but it will also increase the risk of soot poisoning and allergic rhinitis in winter. According to field investigation and news (QHNEWS, 2011), a large proportion of residents in Xining region suffer from allergic rhinitis, and many people have experienced soot poisoning. Natural ventilation result is shown in figure 11 to figure 13.

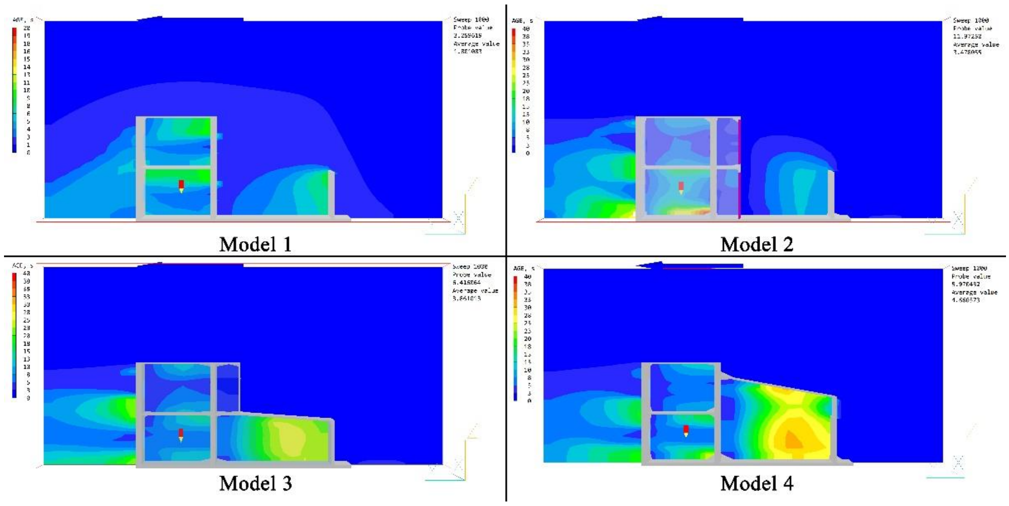

Fig. 11: Air age distribution in summer of 4 models

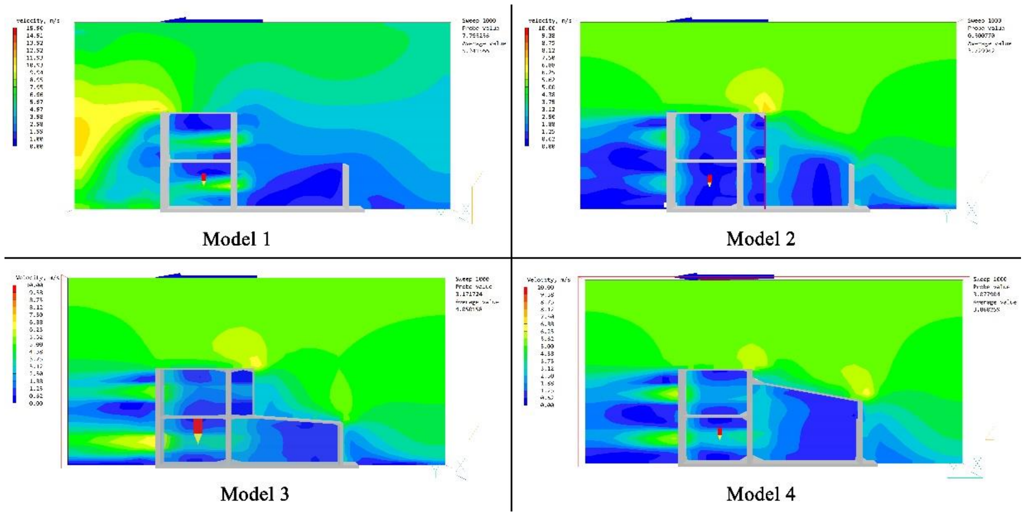

Fig. 12: Wind speed distribution in summer of 4 models

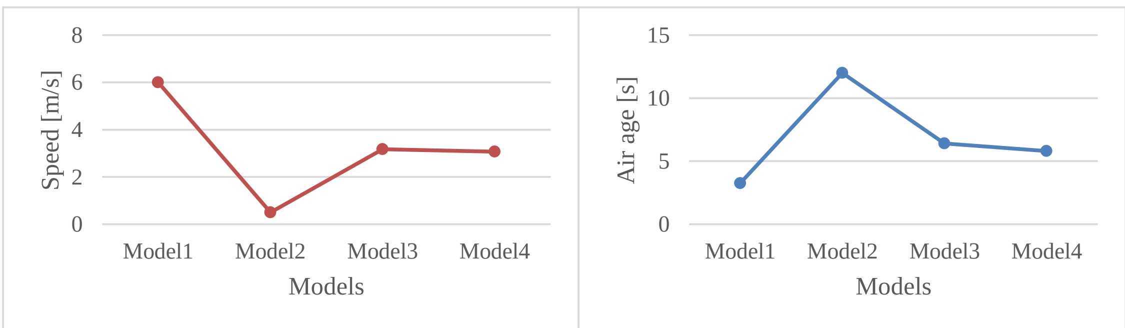

Fig. 13: Indoor wind speed value (left) and air age value (right) in summer of living room in 4 models

The test point was located 1.5m high in the middle of the living room on the first floor of 4 models. Ventilation simulation results showed that, 1) Indoor wind speed of living room under natural condition was Model 1 ＞ Model 3＞ Model 4 ＞ Model 2, when the indoor wind speed was higher, the air age was lower. 2) When outer windows were opened, indoor ventilation environment at the height of less than 2 m could meet the living demand. 3) Indoor air environment was generally good because the building depth was small.

Indoor wind environment simulation of enclosed courtyard in summer is based on the ideal condition. In fact, residents can not adjust opening status of window in time in summer, which may cause over high indoor temperature. Indoor ventilation environment is poor in winter, because residents usually close the window to prevent cold wind from outside.

3.4 Comparison of AFGS and solar PV technique

There is general consensus among future energy studies that solar energy will gradually substitute fossil fuels and become the solution to a sustainable energy supply of the world (BP Energy Economic, 2021). In 2021, National Energy Administration of China has selected a number of counties and cities to develop roof distributed PV system as pilot projects. 41 counties and cities of QTP were in the list, and 5 counties of them located in Xining region (National Energy Administration, 2021). The notice required that at least 20% of roof area of rural houses required to installed solar PV system by 2023. In the near future, solar PV system will be widely utilized in rural houses in Xining region. Under this situation, it is necessary to discuss the advantages and challenges of the widespread use of PV systems in rural area. As an application of the PV technology, building-attached photovoltaic (BAPV) systems have attracted an increasing interest in the past decade, and have been shown as a feasible renewable power generation technology to help buildings partially meet their load. BAPV are considered an add-on to the building, not directly related to the structure's functional aspects. They rely on a superstructure that supports conventional framed modules (S.F. Barkaszi, J.P. Dunlop, 2001). This paper assumes BAPV systems will replace the AFGS technique in these 4 models, energy generation capacity and cost of this change are discussed.

Firstly, Surface area of models which PV panels can installed should be estimated. PV panels should be attached on reasonable building surface. Shadowing effect, ambient temperature, the direction of the building and the slope of the PV have a significant effect in order to achieve higher power output and efficiency in the building applications. (Emrah Biyik, 2017). Thus, roof and south exterior wall are ideal installation area for PV panels. For 4 models in this paper, roof and south exterior wall above 2nd floor are ideal area, because the side wall of rural houses is adjacent to other buildings, and there will be shadows of enclosing wall on the south wall in the 1st floor. Building surface area (blue area) of 4 models that can PV panels be install is shown below (Fig. 14). Effective installation area of model 1 is 60 m^2, that of model 2 is 70.5 m^2, that of model 3 is 109 m^2, that of model 4 is 103 m^2.

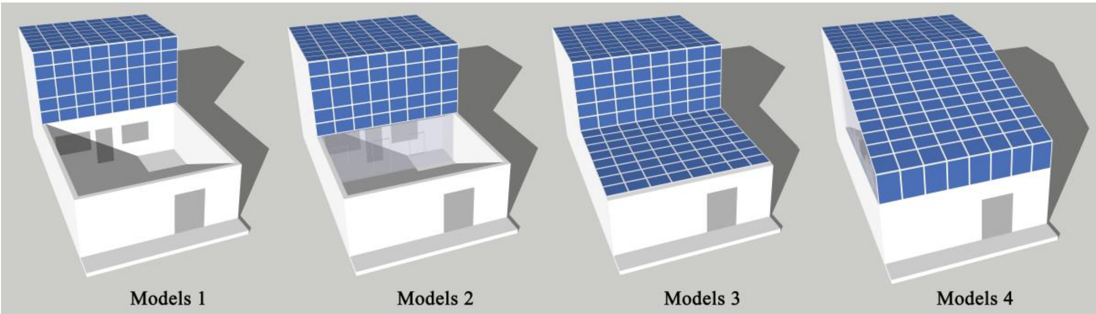

Fig. 14: Building surface areas of 4 models that can install PV panels (blue area)

Secondly, power generation capacity of 4 models is estimated. Power generation capacity of stand-alone photovoltaic system is related to effective installation area, total amount solar radiation, conversion efficiency of PV array and comprehensive system efficiency. Annual power generation of PV system can be estimated by the following formula (H.X. Wang, G.Z. Wu, 2012.).

$$E_p = H_A \times S \times \eta \times K \quad \text{(eq. 1)}$$

E_p - Annual power generation ((kWh);

H_A - Total annual solar radiation per unit area (kWh / m^2);

S - Total area of PV module (m2);

η - Conversion efficiency of PV array (%);

K - Comprehensive system efficiency.

D.K. Hu assessed the solar energy resource of Xining city in nearly 50 Years, the result showed that the total mount of annual solar radiation is 1450 – 1774 kWh / m^2. 1700 kWh was taken in this paper in order to facilitate the calculation. The output of passivated emitterand rear cell (PREC) in China accounted for 70% of the total output of crystal silicon solar cell in 2019. The average conversion efficiency of product of most enterprises has reached about 22% by the end of 2019 (China Photovoltaic Society, 2020). Although conversion efficiency of p-type PREC monocrystalline silicon solar cell of Longi has broken the world record and reached 24.03% in 16th January, 2019, and there will be higher efficient solar cells in the future. This paper use 22% for calculation. Effect of angle for installation photovoltaic arrays on conversion efficiency was not considered in order to simplify the calculation. Comprehensive system efficiency K is related to conversion efficiency of the subassembly and inverter, energy losses coefficient, grid power system efficiency, annual utilization rate of system. Comprehensive system efficiency in this calculation is 0.784 base on consider all factors (X.Y. Ma, Y. Zhao, 2019). Annual power generation of PV system of 4 models can be calculated and the result was shown below (Fig. 15).

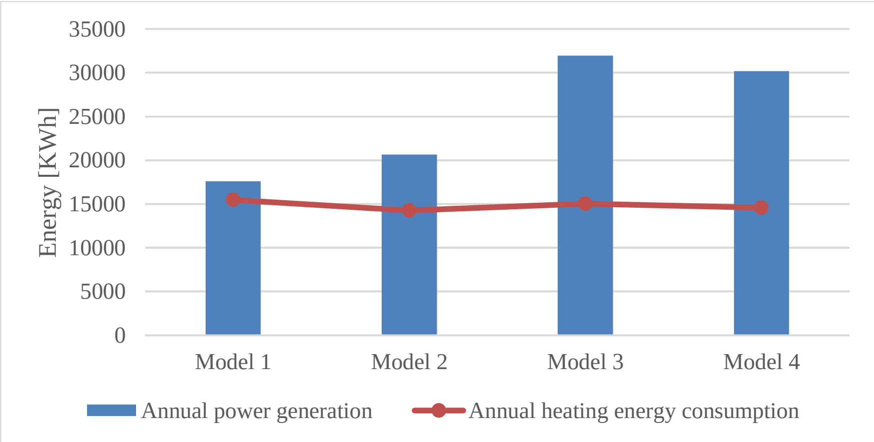

Fig. 15: Annual power generation and annual heating energy consumption of 4 models

The results showed that, annual power generation of 4 models were larger than their heating energy consumption. Solar power generation of model 1 and model 2 could cover their heating demands in an ideal condition, but they had weak potential to resist risks. Power generating capacity of model 3 and model 4 was more than twice their heating energy demands, which means these 2 models is more capable to ensure power supply and resist risks. That is, rural houses may achieve carbon-free through appropriate design.

Thirdly, one of the most important issues with solar panels is cost. Solar cells in the early 1950s cost 286 USD/W and reach efficiency of 4.5-6% (J.H. Yong, 2011), with the greatly increased demand and development of industrial technology, the price of PV panels has declined a lot (B. Sun et al., 2021). Based on the current cost of PV system in Xining, economy cost and benefit of PV system were compared.

PV combined with electric heating equipment is a feasible technical solution for rural houses. R.D. Zhang et al. have compared 3 PV methods of clean housing heating including PV + electric heating, PV + air source heat pump and PV + phase change thermal storage for rural area in Xining region. Economic and environment benefits of the 3 methods were analyzed (R.D. Zhou et al., 2020). D.H. Chang et al. did an economic benefit analysis on PV power generation in a poverty alleviation project in rural area of China (D. H. Chang et al., 2020). It could be found that equipment with high electrothermal efficiency had a higher price. This paper discussed economic cost and benefit of utilizing PV systems and passive technique (AFGS + coal heating) on rural houses represented by model 4 based on the research result of relevant studies.

The information of PV systems came from the data combination of relevant studies (R.D. Zhou et al., 2020; E. Gul et al., 2022). The initial cost of PV + equipment system was about $ 6,000 to $ 9,000. It is assumed heating for 12 hours a day, heating period is 183 days, the annual heating energy for different heating equipment was distributed from 6,000 to 19,000 kWh. Annual PV power generation of model 4 was calculated above and it was 30,200 kWh. Time of cost back of PV + equipment system in rural houses was about 6 to 8 years.

The cost of AFGS in model 4 was about $600 according to the local market price. Unit price of high-quality coal is $ 170.5 per ton, and 4 tons of coal were needed for heating in most rural houses. So that initial cost of AFGS with coal heating is about $ 1282. However, an annual additional cost was needed because residents should buy coal for heating every year. According to the field investigation, most of the coal burned by residents in Xining was lignite coal, whose carbon content was about 70%. Most combustion of coal was insufficient because residents used household coal stoves to burn coal, and there was little treatment for the carbon emissions from burning, but emit them into the outdoor. It is estimated that burning a ton of coal produces about 3 tons of carbon dioxide (CO_2) and burning 4 tons of coal could cause about 12 tons of carbon emission a year. Economy cost and benefits of PV + equipment system and AFGS + coal heating was show in Table 1 (Tab. 1).

Tab. 1: Economy cost and benefits of PV + equipment system and AFGS + coal heting

Contents	PV + equipment system	AFGS + coal heating
Initial cost / $	6,000~9,000	1,282
Annual additional cost / $		682
Annual power generation / kWh	30,200	
Annual heating energy need / kWh	6,000~19,000	1,4581.2
Annual carbon emission / ton		12
Time of cost back / year	6~8	

There was a higher initial cost for using PV + equipment system than using coal for heating. Although utilization of PV + equipment system can eventually recover the cost by selling electricity to national grid and become a part of residents' income in the useful life (R. M. A. Domingos, F.O. R. Pereira. 2021). It was still a difficult decision for most people in rural area to pay more than 10 times price for a new heating system in a short time. More than that, the problems of degeneration and maintenance of PV panels, lack of knowledge of PV system for residents, inadequate infrastructure etc. are hinder the population of PV system in rural area of Xining region.

There are more than 10 million residents live on the QTP and most of them live in rural houses. Coal is still the main heating and cooking energy for residents at present, family coal combustion across this region is an important source of carbon emission. QTP is considered to be the ideal place for promotion of PV technology for its rich in solar energy resources and cold climate (Y. P. Fang, Y. Q. Wei, 2013). PV system will be adopted widely in rural houses of QTP in the future, which is supported by the carbon neutral commitment of China, national incentive policies and decrease in PV system cost. Fossil fuel will be eliminated because of excessive greenhouse gas emissions, which do not meet the requirement of sustainable development.

4. Conclusions

Residents enclose their courtyard with AFGS can improve thermal insulation performance of rural houses, although this technique is initially intended to prevent cold wind and keep the courtyard clean. Model 2 of 4 models in this paper has the best energy-saving performance because the small sunroom can transfer better the heat of solar energy into living area than a large one. There is an impact on indoor ventilation environment by closing the courtyard, but the indoor air quality of 4 models is good because the depth of building is small. Courtyard ventilation conditions of model 3 and model 4 need to be improved. Heating energy are required if only using passive technology in Xining region. Coal is the main fuel for heating, its burning process will emit greenhouse gases and have negative impact on resident's health.

Fossil fuel can be replaced by PV system for heating in rural houses in Xining region. Model 3 and model 4 can provide a larger installation area for PV panels, so that they have a higher power generation potential if adopt PV system on them. There is a higher initial cost of PV system than using coal, but this cost can be recovered in several years, taking model 4 as an example. Promotion of PV system into rural houses is still subject the resistance from the high cost of system, weak awareness of residents and inadequate infrastructure. Incentive policies from the government and technology upgrading from enterprise for solar PV technique will change this circumstance. Fortunately, rural houses in QTP, which is rich in solar energy, can not only achieve zero carbon emission thorough utilization of PV system, but also increase residents' income by selling electricity to nation grid.

It is an overall trend to develop PV technique on building's surface for reducing carbon emission. Rural houses in QTP are ideal place to implement this technique. But insufficient infrastructure and low awareness of residents for new technology still obstruct the promotion of PV technique. Promotion of the advantages of PV technique, heightening the electricity sales subsidies, perfecting infrastructure construction and providing residents with technical services for installation and maintenance of PV system for free could make local residents accept PV technique better. Residents have built diversified courtyard enclosure methods based on their houses' characteristics and personal habits, which provides a rich reference sample for building integrated photovoltaics (BIPV) form. This also avoids the potential problems of BIPV looked like a cookie-cutter.

There were some limitations in this study. For example, power generation capacity of PV system was estimated by formula instead of comprehensive evaluation. Economic cost and benefit of PV system came from a simple calculation without scientific computing. Hopefully, this paper helps in providing an overview of a new version for passive solar technique and development trend of rural houses in QTP, as well as useful reference for the relevant studies.

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