253: A survey on energy consumption in rural households in the North Shaanxi Province (PR, China)

Gong Xinzhi[1*], Wu Nong[1], Liu Yu[1], Yao Jiali[1], Han Xiaojuan[1]

School of Civil Engineering and Architecture, Northwestern Polytechnical University, Shaanxi, China[1]*
wunong@nwpu.edu.cn

Abstract

This paper reports on a field survey of the energy use in rural dwellings in the cold region of North Shaanxi Province. The survey was undertaken during December 12th to 25th, 2007. During this survey thirteen villages and towns of Northern Shaanxi and the Central Shaanxi Plain of China are investigated. Among them, ten typical villages were selected as research objects, (including the Detached Cave Dwellings in Zaoyuan, Yan'an, and Guzui, Luochuan, the Cave Dwellings of Ravine in Gao Xigou, Mizhi, and the brick-concrete houses in Er Dejing, Jingbian, etc). The investigation was conducted by inhabitants' life visits and questionnaire surveys, through which large amount of first-hand data and information about the thermal insulation of the building stocks, the solar energy, the cases of biogas-using and other conventional energy consumption are grasped. Several energy-saving design methods of the farmhouse, such as passive design and the thermal insulation technology, which are feasible in the local area, are discussed.

Keywords: Energy utilization; Outer surface cover system; Energy-saving; Residential house

1. Introduction

The rural housing construction has been growing increasingly, Consistent with China's rapid economic development in rural areas, housing completion each year maintains at least 600 million m2, rising from about 12 m2 per capita area of dwelling structure in 1978 to 22.6 m2 in 1997 [1]. The energy-saving situation of the farmhouses plays a decisive role in accelerating the pace of overall energy-saving construction.

A survey was undertaken during the winter of 2007. During this survey thirteen villages and towns of Northern Shaanxi and the Central Shaanxi Plain of China are investigated. Among them, ten typical villages in the North Shaanxi Province were selected and discussed in this paper: Guzui Village, New Guzui Village and Gao Jiahe Village in the Luochuan area, Zaoyuan, Meng Jiawa Village in the Yan'an city, Zhouwan Village, Xiao Kouze Village, Shuang Wanjian Village in the Wuqi, Gao Xigou Village in the Mizhi and Er Dejing Village in the Jingbian. According to the existing situation of the North Shaanxi rural buildings, this paper discusses how to develop the energy and land-saving rural buildings in North Shaanxi by present building technique, from the viewpoint of energy and land-saving and ecological environment.

In previous studies energy-saving technologies applied by Chinese residential households are analyzed in macro approach, such as the statistics of the energy consumption per province.

In contrast, a micro-approach is applied in this study by undertaking a case study in the North Shaanxi Province of China. Large amount of first-hand data and information, including the rail structure in rural households and conventional energy source utilization (such as the solar energy, biogas), are grasped by questionnaires, visits to inhabitant, field measuring and mapping. Some energy-saving technologies suitable for local residents are put out, which are based on the analysis above.

The items in the questionnaire are summarized in Table 1. And the building's outer surface cover system and renewable energy utilization are the key items.

Table 1: Items of the questionnaire sheet

1. Basic circumstance
Size of household
Income
The age of building
The form of building
The form of building structure
2. The building's outer surface cover system
materials used for roof
materials used for wall
the structure of the doors and windows
3. Energy consumption
Solar energy
Biogas
Other conventional energy

2. The general situation in the local area being investigated

The geographic and climatic situations in the local area are summarized in Table 2.

Table 2: General situation of the geography, climate, and natural condition in typical villages, for Average altitude (H_a), Annual radiation quantity (R_{qa}), Annual sunshine time (T_{sa}), Annual average temperature (T_{aa}), The hottest temperature (T_h), The coldest temperature (T_c), Precipitation (P), Wind speed (v_w), and so on [3].

Village	Luochuan	Yan'an	Wuqi	Jingbian	Mizhi
H_a (m)	1159	960	1331.1	1336	1049
Longitude	109.42°E	109.47°E	108.22°E	108.79°E	110.23°E
Latitude	35.76°N	36.6°N	36.93°N	37.61°N	37.78°N
R_{qa} ($\times 10^9$J/㎡)	5～5.25	5～5.25	5～5.25	5.5～5.75	5.5～5.75
T_{sa} (h)	2400～2500	2400～2500	2300～2400	2700～2800	2700～2800
T_{aa} (℃)	8～10	8～10	6～8	6～8	8～10
T_h (℃)	38～40	36～38	34～36	36～38	38～40
T_c (℃)	-22～-24	-24～-26	-24～-26	-28～-30	-22～-24
P (mm)	600～700	500～550	400～500	350～400	400～500
v_w (m/s)	2.0～3.0	2.0	2.0	3.0	2.0～3.0
Zonal landforms	Loess plateau	Loess plateau	Loess plateau	Loess and the shifting of sand dunes plateau	Loess plateau
Landforms	Loess tableland	Loess hill ridge	Loess long ridge	Loess ridge hill	Loess ridge hill
Climate	North warm temperate semi-damp climate with summer cool	North warm temperate semi-damp climate with summer cool	North warm temperate semi-arid climate with summer cool	Temperate semi-arid climate with summer cool	North warm temperate semi-arid climate with summer cool
Hydrogeologic condition	Loose rock with hole and aqueous, weak water-rich degree	Cataclasite with aqueous, medium water-rich degree	Cataclasite with aqueous, medium water-rich degree	Cataclasite with aqueous, medium water-rich degree	Cataclasite with aqueous, weak water-rich degree

Towards the Table 2, the five Regions, Luochuan, Yan'an, Wuqi, Jingbian and Mizhi are located between longitude between 108°E and 111°E, latitude between 35°N and 38°N [2], altitude between 960m and 1336m. And global average elevation is about 800m. From the zonal landforms, they are all situated in the loess plateau. Among them, the most Precipitation is only 700mm, while the least is 350mm [3]. In a word, as the regions are featuring deep soil, high elevation, an arid climate, a shortage of forest, most local rural residents use local materials, and pay more attention to Cave Dwellings.

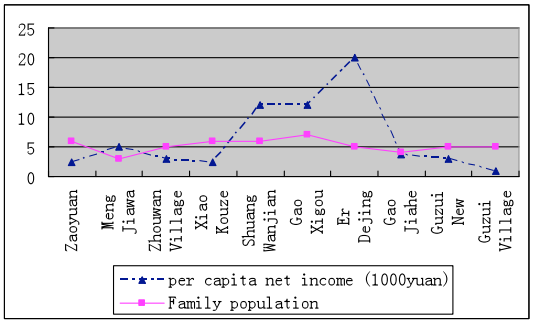

Fig.1. Family population and per capita net income

3. Survey results

3.1 Features of households

The average size of the surveyed households is 5.2 persons per household, with a minimum of three persons and a maximum of seven persons. The most common size is five persons per household. The form of household size and the income level of the surveyed area are showed in Fig.1.

The highest income reaches 20,000yuan per person every year, while the lowest just reaches 1000yuan per person every year. This clearly indicates that the economic development is not uniform in North Shaanxi Province.

Because of the poverty of soil and backward economy in the past, most rural households in this area are Cave Dwellings. The recent discovery of petroleum, coal and natural gas in this region, has given rise to rapid economic development. One-story houses, and even larger house built of brick or concrete are gradually replacing the traditional cave dwellings. However, due to their good thermal (insulation) and heat storage properties, as well as based on their low-cost, low environmental-impact features, cave dwellings still make up a large proportion of construction in Northern Shaanxi. According to the survey released by the Architectural Society of China in 1985, nearly 40,000,000 people are still living in various forms of cave dwellings [4].

Guzui Village (Fig.2) is one of the 3 villages surveyed in the Luochuan area. The building in the picture is a one-story flat-roof soil cave dwelling completed in 1978. Since then its exterior has

been upgraded with ceramic tiles, as well as with arched doors and windows built from brick and concrete. The interior structure remains unchanged.

Fig.2. Guzui Village

Zaoyuan Village (Fig.3) is one of the 2 villages surveyed in Yan'an area. The building which was constructed in 2000 and covered a square of 170 m2, combines the modern technologies and the conventional style of the cave dwelling.

Fig.3. Zaoyuan Village

Zhouwan Village (Fig.4) is one of the 3 villages surveyed in Wuqi area. The building constructed in 2007 is a one-story flat roof brick cave dwelling.

Fig.4. Zhouwan Village

The building in the Er Dejing Village (Fig.5) was constructed in 2004, covering a square of 270m2, belonging to the type of two-story double-pitch roof villa of the brick and concrete structure.

Fig.5. The building in the Er Dejing Village

The building in the Gao Xigou Village (Fig.6) in the MiZhi area was constructed in 2003, which is a stone cave dwelling with a hill at the back.

Fig.6. Gao Xigou Village

3.2 The country house's outer surface cover system in the survey

Table 3 shows the situation of the thermal insulation in 10 households in the survey. Some analysis can be attained from the statistics in Table 3.

There are mainly three types of materials for roof in the local area, such as clay for cave dwelling, concrete for flat roof constructions, tile for double-pitch roof building. Among them, the flat roof constructions account for 80%. Solid bricks used for walling are applied in the brick and concrete structure, with a proportion of 70%. Stone and clay are applied in cave dwellings, with a proportion of 20% and 10% respectively. New walling air bricks are not used in the farmhouses in the survey. In addition, as to doors and windows, the use of aluminum alloy window is up to 50%, and 50% of the farmhouses use single glass with two windows or double glass windows to maintain the temperature inside. Wood doors are popular in the local area, with a proportion of 80%.

Table 3: The basic statistics of the thermal insulation of the farmhouses in Northern Shaanxi Province for the number of villages in use (N), percentage (P).

Project			Classification		N	P
The form of building			Cave dwelling		5	50%
			One-story house		4	40%
			Building		1	10%
Roof	Form		Flat roof		8	80%
			Double-pitch roof		2	20%
	Whether use facilities of heat retaining	Yes	Covered with soil		8	80%
			Others		0	0
			No		2	20%
Wall	Material		Stone material		2	20%
			Loam wall		1	10%
			Solid brick		7	70%
			Air brick		0	0
	Whether use facilities of heat retaining	Yse	Air brick		0	0%
			Sun-dried mud brick or stone		3	30%
			Solid brick		2	20%
			No		5	50%
and Doors windows	Material		Aluminum alloy		5	50%
			Wood		3	30%
			Iron		2	20%
	Whether use facilities of heat retaining	Yes	single glass		1	10%
			double glass		4	40%
			No		5	50%

3.3 Conventional energy utilization

According to Table 4, conventional energies used by 10 farmhouses in the survey include: electricity, coal, straw, natural gas, and so on. The dominant energy for daily life is coal. As the electricity is applied to illumination in every farmhouse, its further investigation is not specified.

Table 4: Utilization of the conventional energy for different end-uses, number of villages in use (N), and percentage (P)

Energy	Purpose	N	P
Coal	Cooking	9	90%
	Heating, cooking	1	10%
Straw	Cooking	4	40%
Natural gas	Prime energy	1	10%
Electricity	Mainly used for illumination in farmhouses, which is not the focus of the project		

The task of the project summarized in Table 5 is to investigate the utilization of the renewable energies, such as solar, biogas and wind power.

Table 5: Statistics of the utilization of renewable energies for the number of villages in use (N), percentage (P), and so on.

Items		Classification	N	P
Solar Energy	solar thermal Technology	Solar water heater	5	50%
		Solar energy stove	2	20%
	solar PV technology	Street lamps for lighting	1	10%
		Power supply	1	10%
	passive solar energy	Passive solar houses	1	10%
Biogas	Trinity	Pen, restroom, pit	5	50%
		Orchard, restroom, pit	1	10%
	Quaternity		1	10%
Wind Power			1	10%

There are three main applications of solar technologies in the local area: solar photovoltaic (PV) technology for power generation, solar thermal technology for water heating, as well as passive solar energy for space heating.

50% of homes in this area use solar thermal collector for domestic hot water (DHW) generation. Typically a solar collector with an area of 1.5 to 2 m2 can meet the hot water demand of a family of 5 people, and the capacity of the hot water tank is usually 100 l. A typical initial investment for a solar hot water system is 600yuan to 2500yuan. The rural population, with an annual income of 3500 yuan to 6000 yuan per person per year, can afford the facility.

There are two prime applications of the solar PV technology in the countryside in Shaanxi Province, first of which is using solar street lamps for lighting at night, second of which is power supplies for farmhouses. Only 2 villages in the 10 villages surveyed make use of the technology. Among them, Xiao Kouze Village of the Wu Qi County in Yan'an city provides power for street lighting by the equipment of light-electricity conversion, so does farmhouses power supply in Er Dejing Village of Jingbian County, Yulin city. According to local information, the solar energy collected and stored during a sunny day, can power the street lighting for ca. 3~4 hours, whereas lighting is provided for only 1 hour on rainy days. Generating capacity of the solar light-electricity equipment per day meets one day's consumption, which only contains power for lighting and electricity for television. The two equipments are invested by the government.

PV panels are only used in the Zaoyuan village, Yan'an city during the survey. Farmhouses with Passive solar houses enjoy better performance in heating in winter.

Application of biogas in Shaanxi Province can be mainly classified into 2 types according to different purposes of raw materials and by-products. The first type, called the Trinity, can be specified into two kinds: one possesses domestic animal's pen, restroom, methane-generating pit; the other possesses orchard, restroom, methane-generating pit. Villages using the former are Meng Jiawa Village, Zhouwan Village, Xiao Kouze Village, Shuang Wanjian Village and Gao Xigou Village, which occupy a ratio of 50%. Village using the latter is Gao Jiahe Village, with a ratio of 10%. The second type, called the Quaternity, is an integrated construction mode with greenhouse, methane-generating pit, domestic animal's pen and restroom, which means that rearing cattle,

constructing methane-generating pits and restrooms in the greenhouse. The feces are flowing automatically to the methane-generating pits to make biogas. Er Dejing Village makes use of it, with a ratio of 10%.

Only Er Dejing Village Jingbian County, Yulin City uses wind power to generate electricity in the survey. However, the annual wind speed has decreased as local significant effects in sand controlling, so wind power generation equipments are working less time than before.

4. Conclusion

4.1 Existing Problems

Though significant energy-saving technologies are coming into use in rural areas of Northern Shaanxi Province, a number of issues still need to be addressed:

Although the cave dwelling is a better construction in energy-saving, it is rather difficult to promote its application, considering its high cost, larger area, longer construction time. At the same time, it's important to improve several performances in the insulation against heat of external walls, doors and windows, roofs, and water-tight of roof.

And it's difficult to promote new technologies like positive solar energy technologies, because of the poor economic conditions. Farmers lack the knowledge how to build and use the biogas-generating pit, particularly in lack of knowledge of using biogas in winter.

4.2 proposals about future improvements

According to the survey, facilities with lower construction cost and higher energy-saving effect , such as passive solar houses, ground Kang, should be applied, so is construction format which takes advantage of nature materials. As a result, energy consumption in heating per year will reduce and energy-saving effect in farm-houses of the cold area will soar. Energy consumption in heating is high in China's constructions. Beginning with the huge number of rural households, enhancing consciousness of the rural residents in energy saving, increasing the energy utilization in China's rural areas will bring profound impacts on environmental protection and sustainable development.

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