194: A Field Investigation on the Energy-saving Technologies Used in the Village Housing in North China

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Abstract

This paper introduces a field investigation conducted in 13 villages in the Guanzhong and Shanbei regions of Shaanxi province (China). The study is part of a Ministry of Construction (MOC) sponsored project, the purpose of which is to develop an advisory document for the MOC to promote feasible energy-saving technologies and design strategies for village housing in the cold climate zones of north China. The influence factors are analyzed around the climate, culture and economic conditions in the two regions; and discussions are made primarily around three types of energy-saving energy technologies: (1) building envelops technology; (2) solar and wind energy technology; and (3) marsh gas technology. Besides, "Kang", a traditional clay bed, which is widely applied in the village housing in north China, is introduced and discussed. The advantages and problems of the energy-saving technologies currently been used in the village housing in the investigated regions are identified and suggestions for improving energy-saving performance of village housing in the cold climate zone in north China are provided both from technical and policy perspectives.

Keywords: Energy-saving, village housing, north China

1. Introduction

In the recent 2-3 years, to promote energy saving technologies and to improve living conditions in the rural areas, the China Ministry of Construction (MOC) has initiated and sponsored a number of research projects that are closely related to the farmers' life. The Sustainable Building and Environmental Research Institute (SBERI), an internationally collaborate research organization of Northwestern Polytechnical University (NPU) participated in one of the projects, the purpose of which is to develop an advisory document for the MOC to promote feasible energy-saving technologies and design strategies for village housing in the cold (including the cold and severally cold) climate zones of north China. As part of the research, a preliminary field investigation was conducted in the north Shaanxi province from Dec. 2007 to Jan. 2008. The results are reported in a series of five papers. This paper mainly introduces the local conditions and local village housing styles in the investigated areas; discusses the problems identified in the investigation; and provides suggestions for improving energy-saving performance of village housing in north China

2. Local Conditions

The investigated area is divided into two regions: the Guanzhong region which locates in the central part and the Shaanbei region which locates in the north part of Shaanxi province. The former one belongs to the Cold climate zone and the later one belongs to the Severely Cold climate zone, according to the China National Thermal Engineering Design Regulations for Civil Buildings (GB50176-93)[1].

The altitude of Guanzhong region is about 320-800 metres, the average temperature per annum is between 12-13.6℃[2]. It has clearly separated four seasons and generally long summers. The main physiognomy feature of the region is plain and the Weihe River lies in the middle of it.

The altitude of Shanbei region is about 900-1500 meters, the average temperature is between 8-12 ℃ per annum. It possesses a dry (annual precipitation between 350-550mm) and cold (extremely low temperature -17℃) [3] and typical seasonal climate. The annual temperature difference is close to 60℃ and daily temperature difference is usually over 20 ℃. The main physiognomy feature of the region is loess plateau.

3. Local Village Housing Styles

Literatures were first reviewed to understand the traditional village housing styles in the two regions.

3.1 Local Housing in the Guanzhong Region

People in the Guanzhogn region like to set up houses in the flat plain which is surrounded by or close to their infield. Since the land is largely fertile and the transportation is convenient, the culture and economy in the Guanzong region is relatively advanced, and the size of the villages are relatively larger. Many families (mostly relatives) live together in cluster styles in the villages, the size of which varies from tens to

hundreds of families. Houses are built in rows and closely next to each other. The whole village usually spreads out naturally alone the roads or lanes[2].

Before 1970s, houses in the Guanzhong region are usually single level, mostly made of wood structure with sun-dried brick or tamping earth walls (some with brick poles to strength the structure or brick base as water proof methods). The roofs are usually wood structure covered by clay tiles[4]. From 1980s, alone with the economic development, brick gradually replaced clay materials, reinforced concrete structures replace wood structures, and flat roof replaces slope roofs[5] (Fig. 1).

Fig 1 Typical new village house in the Guanzhong region (picture taken by YAO Jiali in the Jianjiao Village)

3.2 Local Housing in the Shanbei Region

Due to low annual perception, lack of wood and abundance in clay and stone materials, Shanbei region has a long history of building up Yaodong (cave dwelling), which uses low technology and locally produced clay or stone to create spaces that is naturally warm in winter and cool in summer. The clay materials used in the Yaodong can be totally returned to the land and be reused when the building is demolished, no construction waste is left behind, so the natural resources and environment can be largely protected [6]. Manifesting a plain natural ecological attitude, Yaodong is considered as one of the invaluable heritages of vernacular building in the China's building history. They grow out of and merged into its surrounding environment, scatter in the ravines and slopes, and spread all over the loess plateau area [7] (Fig. 2). They form part of the local culture tradition and possesses positive meaning in the contemporary eco-building development.

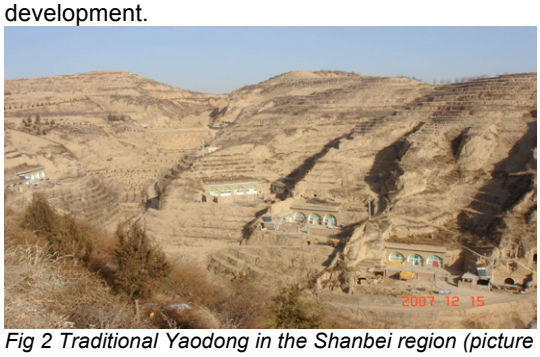

Fig 2 Traditional Yaodong in the Shanbei region (picture taken by YAO Jiali in the Mizhi County, Shanbei region)

The land in Shanbei region is largely barren. In recent year, discovery of oil, coal and natural gas in the region has greatly pushed the development of local economy. Some young people in the region moved out of Yaodong and start to build up 2-3 story new houses with brick and concrete structures. However, in the large rural areas, many old people still like to live in Yaodong rather than the new houses, since they can achieve better indoor thermal environment with much less energy consumption in Yaodong [8] (Fig. 3)

Fig 3 Typical new village house (Yaodong) in the Shanbei region (picture taken by YAO Jiali in the Gaoxigou Village)

3. Investigation on Energy-saving Technologies in the New Village Houses

To understand current situations and problems regarding four types of energy-saving technologies (building envelop technology, solar energy technology, wind energy technology and marsh gas technology) in the new village houses in the Cold and Severely Cold climate zones in the Shaanxi province, 13 typical new houses were selected from 13 villages (11 in the Shanbei region and 2 in the Guanzhong region), and three methods were used in the investigation: (1) face to face interview base on structured questionnaire; (2) building mapping on the spot; (3) measuring of thermal conditions. Following are some of the findings and discussions regarding energy-saving technologies currently been used in the village housing in the investigated regions.

3.1 Building Envelop Technology

3.1.1 Basic Situations

The earlier stage investigation was mainly conducted in the Shanbei region, the results of which are concluded in Table 1. It shows that flat concrete roofs (83.3%), solid brick walls(91.7%), aluminium alloy frame (66.7%) plus single glazed windows (66.6%), and wood doors are the major building envelop materials and elements currently been used in the new village houses in the Shanbei region. The later stage investigation shows that this situation is very much similar to that in the Guanzhogn region. The only difference is that no new Yaodong was found in the Guanzhong villages, while there are still 8.3% new houses which applied Yaodong style in the Shanbei region. One example is showed in Fig

Table 1: Building envelope structures and materials currently used in the Shanbei region

Shanbei Region			
Building Envelop Structures			Ratio (%)
Overall Type of Structure		Yaodong (cave dwelling)	8.3%
		Brick-concrete* Structure	91.7%
Roof	Form / Material	Flat roof / concrete	83.3%
		Double-pitch roof / wood & pile	16.7%
Wall	Material	Stone	16.7%
		Clay+Brick	8.3%
		Solid brick	66.7%
		Air brick	8.3
Window Frame	Material	aluminium alloy frame	66.7%
		Wood frame (double layer)	33.3% (8.3%)
Window glaze	Form	Single glaze	66.6%
		Double glaze	33.3%
Door	Material	Wood	100%

*Brick-concrete structure means building with brick walls and concrete floors.

3.1.2 Problems

Some problems regarding building envelop materials and components are identified and discussed mainly from the energy-saving point of view.

(1) The heavy clay structure of Yaodong can provide good thermal storage and insulation for the building. It is much better than the brick-concrete structure in terms of energy-saving, thermal comfort and environmental protection; however, this type of building structures is difficult to be promoted today even in the Shanbei region, where cave dwellings have been dominated building structures for hundreds even thousands of years. The investigation reveals that this is mainly because that Yaodong usually takes longer time to build (usually 3 months for construction of 3 standard caves with about 90m^2 construction areas); occupies more structure space (the construction width of the "side leg" is between 800-1200 mm, "middle leg" between 400-500mm); is less flexible in plan arrangement; and cost similar to or even more than the brick-concrete structure (cost 12,000RMB per standard width with about 30m^2 of construction areas). The plan and section of one investigated Yaodong in the Gaoxigou village is shown in Fig. 4.

(2) Majority (91.7%) of the external walls in the investigated regions are built with single layer solid bricks (240mm thick), no additional insulation method is applied. This obviously can not satisfy the thermal insulation requirements in the Cold and Severely Cold climate zone in China[9].

(3) Traditionally, Yaodong is built without waterproof method. Although they are mostly built in dry regions, a relatively concentrated rainfall may cause infiltrate of water into the indoor space and any heavy storm may severely damage the whole structure.

(4) Windows and doors are the weakest points of the building envelop. In the investigate regions, only 8.3% of the houses uses double layer windows and another 33.3% uses double glazed windows. Most of the houses use only single glazed and single layer windows with no additional insulation methods. Cold wind leakage through windows and doors can cause large amount of heat lose in winter time.

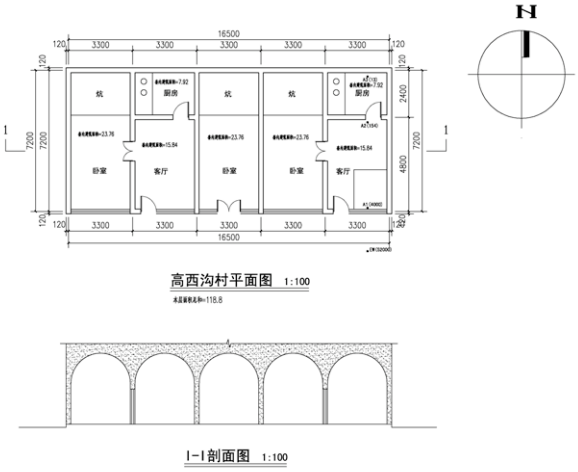

Fig 4 The plan and section of an investigated Yaodong in the Gaoxigou Village, Shanbei region (drawn by Gong Xinzhi)

3.2 Solar and Wind Energy Technology

3.2.1 Basic situations

In the north Shaanxi province, the annual solar radiation is usually more than 5020MJ/㎡ and sunshine hours more than 2500h[7], so is considered suitable for developing solar technology. Currently, solar thermal technology, photovoltaic technology, and passive design strategy are applied in the investigated regions to use solar energy and to reduce the consumption of conventional energy in buildings.

(1)Solar thermal technology for water heating is the major active solar technology been used in the investigated region. Considering as a reliable and easily available technology in the market place, it is applied in 50% of the investigated houses, mainly for providing hot water for bathing and cooking (Fig. 5).

Fig 5 Solar thermal technology for water heating (picture taken by YAO Jiali in the Gaoxigou Village, Shanbei region)

(2)Photovoltaic technology (PV system) is applied in two demonstration projects to provide

electricity for road lighting system and provide electricity to the family. According the local farmers, in the first case, the road light can work for 3-4 hours in clear days, and no more than 1 house in cloudy or raining days; in the second case, the PV system can provide electricity for one night lighting and TV watching per clear day (Fig. 6).

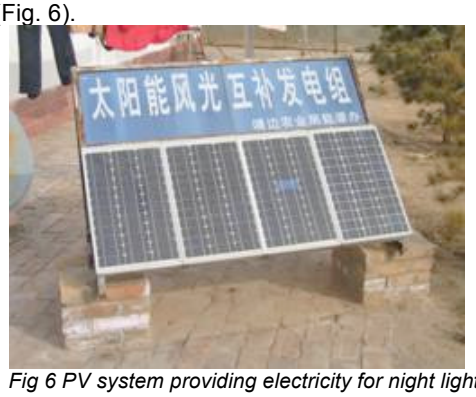

Fig 6 PV system providing electricity for night lighting and TV operation (picture taken by YAO Jiali in the Erderjing Village, Shanbei region)

(3)Passive design strategies were applied in a new Yaodong demonstration project in the Zaoyuan Village of Yanan city. An additional solar space is attached to the living space of the village house. The occupants were very pleased about the thermal performance of their new house (detailed case study of this building is introduced in other report paper).

3.2.2 Problems

Some problems are identified in the investigation regarding application of the solar energy technologies in the village housing:

(1) Tap water is not supplied to the village housing in some of the investigated regions. This restrains the application of solar thermal water system.

(2) Most of the local residents are aware of the advantages of solar thermal water system; however, only half of the families can afford the addition costs for applying the technology at current stage (the other 50% explicitly expressed that they expect to apply this technology as soon as they could afford it).

(3) There is a lack of instructions to the village residents regarding how to apply passive design strategies when constructing and/or operating their homes. In a demonstration project, it was found that some lighting and ventilation channels were blocked or discarded in the construction process since the builders and users are lack of knowledge about their functions. The consequence is that the indoor thermal performance of the house was far less comfort than what was predicted in the design stage.

(4)PV system is still too expensive to be used in the villages. The PV technology been used in the demonstration projects were all sponsored by the local governments. Therefore, it is more of a figure than a feasible technology at current stage.

3.3 Marsh Gas Technology

3.3.1 Basic situations

March gas technology has been used in 57% of the investigated houses. It is widely considered as a convenience, relatively affordable and attractive new technology, which can be used in the villages.

3.3.2 Problems

(1) Most marsh gas pool produces few gases in winter time, sometimes only enough for cooking one meal, even less. If gas production during winter time can not be guaranteed, its application in the Cold and Severely Cold climate zone must be largely limited.

(2) Normal farmers do not have sufficient knowledge about marsh gas technology. This also restrains the application of it.

(3) The construction cost for an 8 stere marsh gas pool is about 3000 RMB. According to the economic conditions of the investigated villages, it can be financially difficult to apply this technology for many families in the short term.

3.4 Kang—a traditional energy-saving technology

3.4.1 Basic situations

"Kang" is a traditional clay bed, which has been widely applied in the village housing in north China. It is usually set up next to the cooking space and is heated up by the waste heat carried by smoke/hot air exhausted from the stove. Existing research shows that, in winter time, when the outdoor temperature reached -30℃, the surface temperature of Kang can maintain at above 30℃ thus form a relatively comfortable micro environment around it[9] (Fig. 7).

Fig 7 Kang in the new village (picture taken by YAO Jiali in the Xiaokouze Village, Shanbei region)

3.4.2 Problems

(1) Setting up a "Kang" is much more complex and takes longer time than putting a bed in the space. It requires specific knowledge and skills that few young people in the villages possess.

(2) "Kang" is considered as a symbol of old style in young people's concept. They would rather bear cold indoor temperature in winter time, but not set up "Kang" in their new homes anymore. Therefore, although many old people still like to use "Kang", it is gradually replaced by bed in the new village houses.

4. Suggestions

4.1 Technical Perspective

4.1.1 Building envelope technology

The thermal insulation of the overall envelop (including roofs, external walls, windows and doors) of village housing need to be strengthened. Considering that the brick-concrete buildings are spread out quickly both in the Guanzhong and Shanbei region, they require more attention in the future research. Some specific suggestions for improving the thermal performance of this type of building are provided as following:

(1)Roof

A number of methods can be taken to improve the thermal performance of flat concrete roofs, such as putting additional insulation materials in the roof structure or adding a planting layer on top of the roof. One special method learned from the experience of Yaodong housing is to put 400-500mm clay on top of the flat roof. This method has been applied in the Zhouwan village in Shanbei region and gained positive results, according to the local residents' reports.

(2) External wall

To improve thermal performance of the external wall of village housing and save land resources, 370mm air brick wall are suggested to replace the 240mm solid brick wall. Beside this, additional insulation lay should be added to the inner side of the external wall of existing buildings and to the outer side of the external wall in new constructions.

Considering the economic level is relatively low in the region, further researches are recommended to develop relatively cheap insulation materials and simple construction details that could use the local farm products in the villages, like corn straws and wheat straws.

(3) Windows and doors

To improve thermal performance of windows, plastic-steal window frame is suggested to be used instead of wood (the investigated region is dry and lack of wood resources) or aluminium alloy window frames. Besides, door and windows should be better sealed to prevent heat loss in winter time.

4.1.2 Solar energy technology

According to the results of the preliminary investigation, following two solar energy technologies/strategies are suggested to be promoted in the village housing in the researched region:

(1) Passive design strategy

In China, lots of researches have been done to integrate passive design strategies into residential buildings; however, few have been transferred into real practice in the village housing. This paper suggests that more attention and efforts should be given to implement passive solar technology and passive design strategies in the village houses in the Guanzhong and Shanbei regions.

(2) Solar thermal technology for water heating

Solar thermal technology has been a mature technology in China. To better promote this technology in the villages, water supply system should be made more stable and reliable (PV system is not suggested to be promoted in the villages in the short term).

4.1.3 Marsh gas technology

Villages in north China normally have abundant raw materials (e.g. corn straws, domestic animal excrement, etc) for producing marsh gas. However, to promote the marsh gas technology in north China, more research still need to be conducted especially to improve the amount of gas production in the cold winter time.

4.1.4 Other suggestions and comments

(1) Traditional village houses in the Shanbei region are mostly scattered among large areas in the loess plateau. Increase the density of these houses would largely reduce the need of infrastructure and help cutting down energy consumption.

(2) While the construction areas of city residential buildings are targeted for 18m^2/person in 2010, the village houses have already been built much larger than that. For example, the investigation shows that the construction areas of normal village houses in the Erdejing village, Jingbian county (Shanbei region) are usually between 40-50m2/person. Their indoor floor to ceiling heights (usually over 3 metres) are also larger comparing to that of the city residential buildings (usually between 2.7-2.8 m). Control the construction areas and floor to ceiling height will be helpful in reducing energy consumption of these buildings, especially in the winter time.

(3) Although many young people in the Shanbei region have discarded Yaodong style, none of them really deny the advantages and benefits of Yaodong from the energy-saving and thermal comfort point of view. Therefore, this paper takes the view that if the disadvantages of Yaodong, as described in the previous section, can be overcome through innovative design (some have been partially tested in a couple of demonstration projects) and be accepted by the local young people, there are still large possibilities for revival of Yaodong style in the Shanbei region.

(4) Similarly to Yaodong, the advantage of "Kang" is undeniable in the energy-saving and thermal comfort point of view. Literature review shows that an improved "Kang" constructed with prefabricated elements have been set up in demonstration projects in another province in north China. It would be interesting to explore later to see whether this improved technology can be applied in the north Shaanxi province or not.

4.2 Policy Perspective

4.2.1 Provide financially incentive policies

According to the statistical data from the Shaanxi Information Centre (2007), in many parts of Shaanxi province, the net annual income of village residents in 2007 is less than 3000RMB/person. To promote energy-saving technologies in a region with such a low economic level requires strong financial support to be provided and effective financially incentive policies to be implemented.

4.2.2 Set up energy-saving codes and standards for village housing

Currently, there is no energy-saving building code or standard for the village housing in China. Village residents normally build up their houses either according to traditional experience or learning from whatever styles they happen to know in their life. Setting up energy-saving codes and standards for village housing (e.g. the thickness of brick wall should be no less than 370mm) would guide and help local residents to build up more energy efficient buildings.

4.2.3 Other suggestions

(1)Improve awareness through education

Many people in the investigated regions are neither aware of the necessity of energy conservation nor the effectiveness of energy-saving technologies and design strategies of buildings. Local people, especially those in the Shanbei region (where there are lots of coal mines), use to burn tons of coal to heat their houses in winter time rather than applying the new energy-saving technologies. Therefore, it is suggested to set up education programs to improve local people's awareness of the importance of energy conservation and increase their demands for energy-saving technologies.

(2) Provide life-time technical assistance

In the investigation process, many local village residents asserted that effective technical assistant could be crucial for them to implement and continually use any new energy-saving technology. Therefore, to promote energy-saving technologies, it is suggested to develop effective policies to make sure that life-time technical assistants be provided to their users in the villages.

5. Acknowledgements

This research was made possible thanks to the Village and Small Town Division of the China Ministry of Construction for offering funds for conducting the investigation; to the local governments in the investigated regions; and to all the people who have assisted in different ways.

6. References

1. Ministry of Construction, National Thermal Engineering Design Regulations for Civil Buildings (GB50176-93). 1993: China.
2. Jia, L.L., Exploration of village inhabitancy culture in the Shaanxi Guanzhong region. Sichuan Building Science, 2007(2): p. 160-163.
3. Zhu, L.B., The ecological thought of cave-dwelling. Journal of Zhengzhou University of Light Industry (Social Science), 2007(4): p. 12-14.
4. Shaanxi Vernacular Building Writing and Editing Group, The Vernacular Building in Shaanxi ed. B.T. Zhang and Z.Y. Liu. 1989, Beijing.
5. Zhao, J.W., The organic renewal of the countryside dwelling in Guanzhong Champaign region of the Loess Plateau. Journal of Northwest Institute of Architecture and Engineering (Natural Science), 2001(4): p. 153-157.
6. Hou, J.Y. and J. Wang, China Yaodong. 1999, Zhengzhou: Henan Science and Technology Publishing Company.
7. Lu, Y.H. and Q. Ji, Thoughts on origin green view of traditional cave dwelling. Shanxi Architecture, 2007(2): p. 35-36.
8. Wang, Y., et al., The study on indoor environment of old and new Yaodong dwellings. Journal of Xi'an University of Architecture and Technology, 2001(4): p. 309-312.
9. Jin, H. and L.L. Zhang, Continuity and Development of Energy-saving Spirit in Traditional Rural Housing. New Architecture, 2002(2): p. 17-19.