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RESEARCH ARTICLE

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Regeneration of vernacular architecture: new rammed earth houses on the upper reaches of the Yangtze River

Abstract In rural areas of western China, most of the vernacular architectures are made of earth. In the process of urbanization, few residents like to build their houses with earth because the old traditional earth house cannot meet their requirement for higher standard of living. As a result, much more energy will be consumed if industrial building materials are used instead of earth. The regeneration of the traditional earth house, therefore, becomes a challenge in new village construction. This paper briefly describes a project about creating a new prototype of earth house for the migrants along the upper reaches of the Yangtze River to shed light on finding an appropriate approach for regenerating the traditional earth houses with the concept of low-energy housing. It includes an investigation of the traditional earth house and the environment condition of the new settlement, the new house design process, and the quantitative evaluation of the living quality of the new house.

Keywords earth house, low-energy housing, upper reaches of the Yangtze River, passive solar technique

1 Introduction

Earth has long been a staple building material in the history of Chinese architecture. Even to date, more than one hundred million of the rural poor across western China are still living in earth houses because of their low cost. Using earth as a construction material has many advantages in terms of environmental protection and energy saving. However, for lack of specialized construction techniques, most of the existing earth houses cannot meet the requirements for higher standards of living and have latent safety problems such as low resistance to earthquakes. As rural people become wealthier, the younger generation prefers to build concrete or burned brick houses, which entail significantly more pollution and energy use. Additionally, there is a risk of the loss of indigenous building traditions. Furthermore, valuable farm land is wasted, which affects the local natural ecosystem.

New earth house design and construction techniques have been developed based on historical vernacular traditions by the Green Building Research Center (GBRC) of Architecture and Technology at Xi'an University since 2001 in order to improve the living conditions in rural western China.

The project discussed in this paper is located in a rural region on the upper reaches of the Yangtze River, notoriously prone to earthquakes. 55.6% of the residents are non-Han ethnic minorities whose traditional houses are made of earth and wood. With the population increasing sharply in the past 25 years, the natural environment in this area has deteriorated.

In 2001, the government of Yongren County, in Yunnan Province, started the migrant plan to move 7000 low-income farmers to a new farming district in the same county before 2010 in order to decrease the pressure on the fragile environment and improve the living conditions of the farmers. Thus, 1800 new houses had to be constructed.

The main aim of the project was to create new prototypes of earth houses which not only improve the living conditions and fulfill the requirements of the modern life of the residents but also inherit the energy-efficient features of the traditional earth house and maintain the low cost, which would conserve the natural environment of the upper reaches of the Yangtze River, curb the worrisome reliance on HVAC, and avoid the degeneration of the vernacular architecture.

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2 Investigation previous to design

Before the project started some migrants had built their traditional houses in the new district. Many of them built burned brick houses instead of traditional earth ones provided that they could afford to do so. However, the climate of the new district is not quite the same as that of their hometown. The houses built in accordance with those in their hometown may have latent problems. Investigations should, therefore, be conducted as to how to improve and update the traditional earth houses while preserving the culture of the minorities and saving energy in the new design. First, studies on traditional houses and new environment conditions were conducted [1,2]. Both the merits and defects of traditional houses, especially the indoor environment, were evaluated through field survey and research. Outside environment conditions of the new district, including climate data, were collected, and the culture of the minorities and their typical living arrangement patterns were obtained [3]. The result of field measurements and analysis mainly include the local culture, environment, and typical rammed earth house arrangement patterns; the indoor environment in summer and winter including temperature, humidity, lighting, acoustic and ventilation; and the basic living requirements of the migrants.

Some indoor environment measurement results of a typical rammed earth house in summer are presented in Figs. 1–4. The earthen walls are good thermo-isolators and good moisture regulators. Moreover, they can provide people with high acoustic comfort because of their density and thickness. However, the indoor environment is not desirable because of poorly airtight envelop and poor architecture planning. The lighting and the ventilation are two obvious problems. The solar radiation in summer, as shown in Fig. 5, and winter are both relatively high, thus, solar design techniques should be applied in new house design, while the long eave as a feature of traditional houses can provide sun shading in summer.

Additionally, the properties of the soil of the new settlement were laboratory tested, with different cost-efficient additives. The appropriate additives and their proportions were derived to get the permissible compressive strength of the earthen wall. Static and dynamic structural experiments were conducted to check earthquake-resistance of the walls with reinforcement.

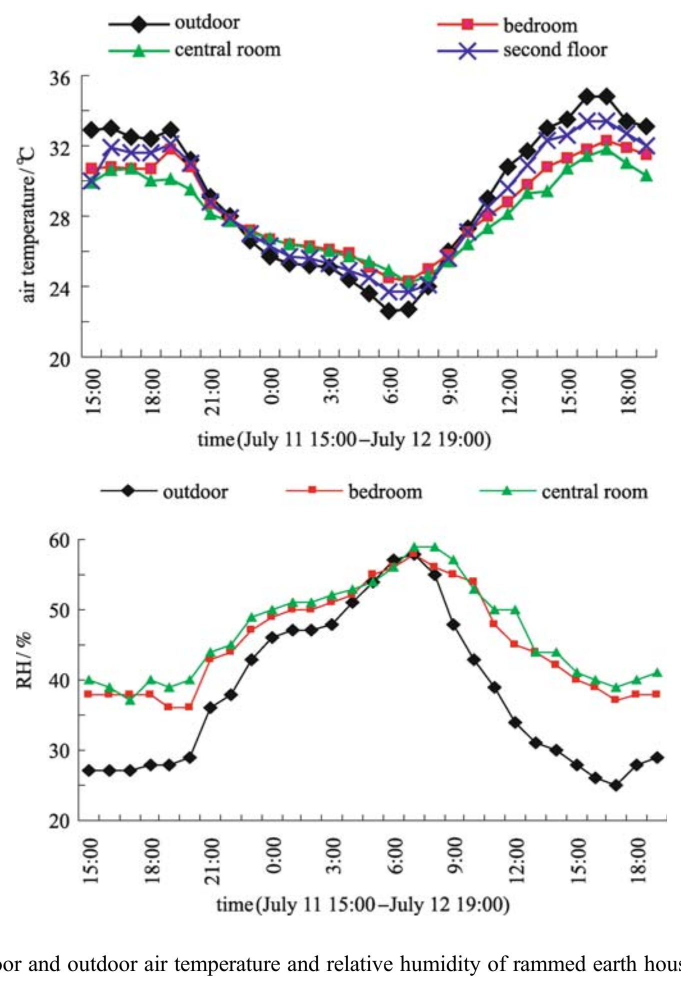

Fig. 1 Indoor and outdoor air temperature and relative humidity of rammed earth house in summer

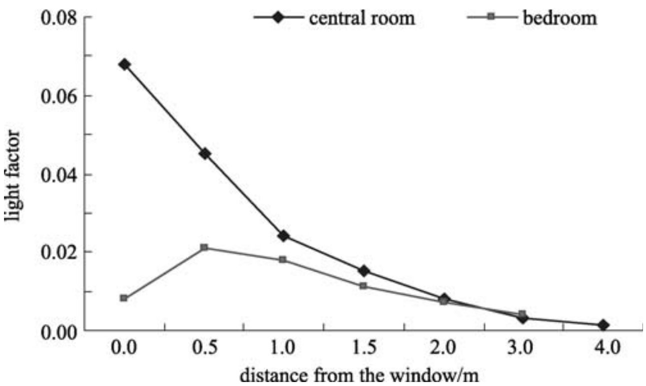

Fig. 2 Comparison of light factors between different rooms in a rammed earth house

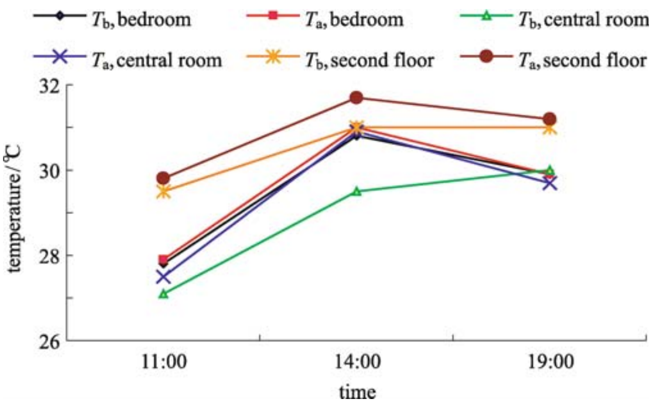

Fig. 3 Indoor air temperature and black bulb temperature

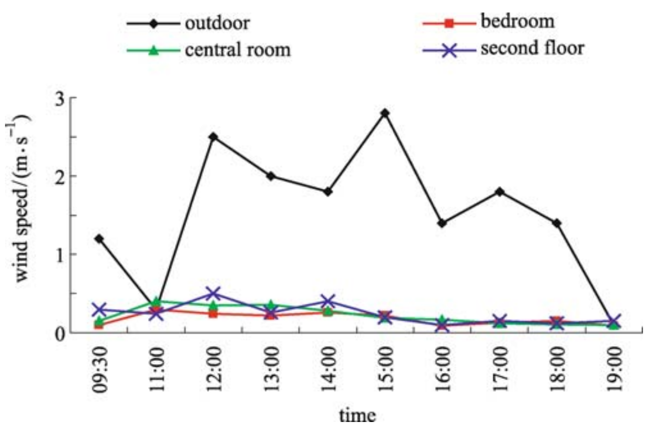

Fig. 4 Indoor and outdoor wind speeds in summer

3 Design process

Based on the survey and test results analyses, several house design alternatives were proposed [4,5]. Considering environmental protection, sustainable aspects of the design include selection of natural building materials, use of

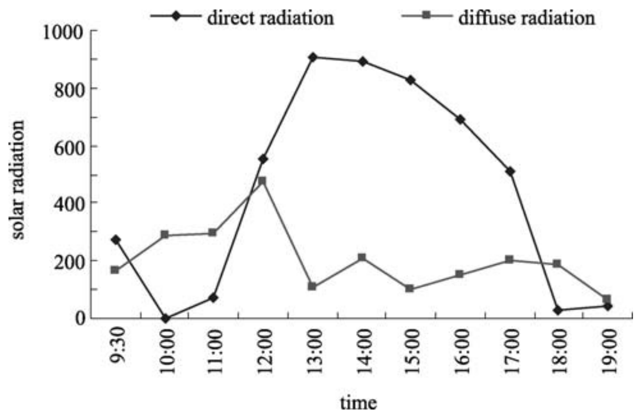

Fig. 5 Outdoor solar radiation intensity in summer

passive solar and climate-conscious design techniques and respect for local culture and living arrangement patterns. Some residents have been involved in the design and construction processes. Consensus agreement has to be reached on every design proposal.

The main features of the design are as follows:

1) Based on ecological and sustainable habitat idea, both the layout of the village and the house design are environmentally-responsive. Climactic conditions and natural landscape are fully considered.

2) Natural materials, such as earth, are used as a main building material to get good thermal mass considering energy saving, and to reduce CO_2 emission.

3) Passive solar techniques are applied, and solar energy is widely used for natural cooling and heating, solar hot water heating, lighting, sunrooms and natural ventilation. The new houses have inherited traditional stylistic features, but the quality of life of the residents has been greatly improved, including day-lighting, natural ventilation, indoor thermal environment and building safety.

4) A simple family sewage-purge-pool and marsh-gas-well system were designed for each house to reduce pollution and get energy from wastes, instead of using lumber to fuel cooking and water heating as before.

5) Traditional housing techniques and principles have been applied and upgraded to make the buildings seismically stable and to meet local building codes.

6) Some residents have been involved in the design and construction processes. They speak highly of both the house style and the construction technique.

Figures 6–10 show one of the design proposals. The planning of the new house with the courtyard not only respects the traditional living pattern of the residents but also provides a more comfortable living space, as shown in Figs. 6 and 7. The wall is made of earth, which can save around 19% of energy for winter heating and around 85% of processing energy consumption compared with burned brick. Passive solar design such as winter solar heating, nature lighting, and ventilation are used [5]. Figure 8 shows the natural ventilation induced by pressure

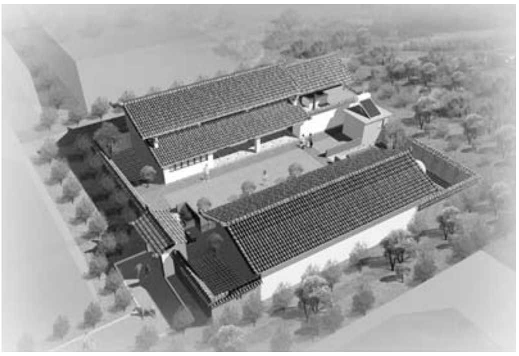

Fig. 6 Design of a new rammed earth house and courtyard

Fig. 7 A proposal separating the residence from the livestock

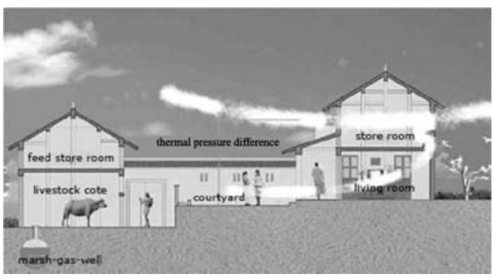

Fig. 8 Natural ventilation design in summer

difference in summer. The long eave (overhang) of the traditional house is adjusted to meet the requirement of passive solar cooling and heating. The appropriate overhang to the south-facing windows prevents the high-angle sunshine of the summer from penetrating the house, as shown in Fig. 9(a) but permits the low-angle sunshine of the winter, as shown in Fig. 9(b). The family

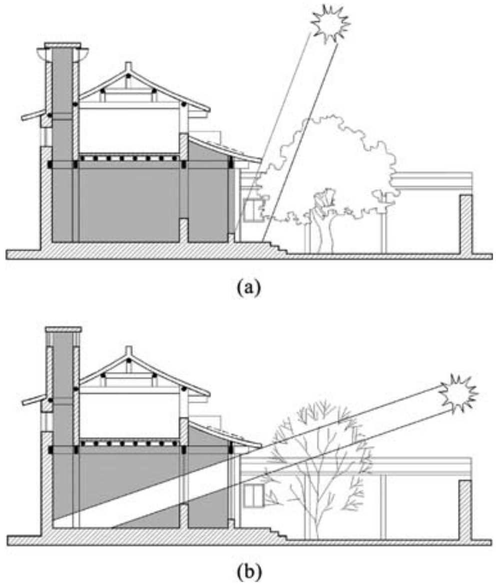

Fig. 9 Design of the overhang
(a) In summer; (b) in winter

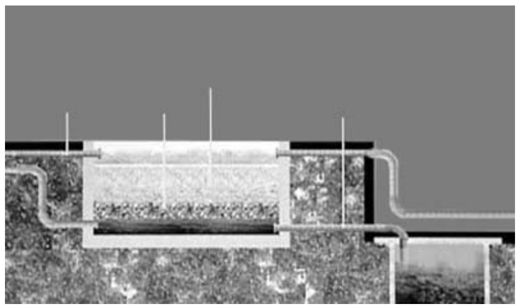

Fig. 10 Design of family sewage-purge-pool

sewage-purge-pool and marsh-gas-well system, very simple but effective, as shown in Fig. 10, are warmly welcomed by the residents.

4 Result

More than 400000 square meters of new earth housing was constructed. A subjective response survey showed that most of the residents were satisfied with the new earth houses. The application of modern science and environmental protection measures to traditional houses has improved the durability and the comfortability of the houses. Figures 11–15 show the construction process and the completed new houses.

5 Evaluation of the house

To evaluate the improvement of the houses compared to the old traditional ones, thermal simulation and other

Fig. 11 Building with earth

measurements were made and questionnaires were given, which included thermal performance test and analysis; solar energy utilization evaluation; comparison of the lighting environment; comparison of the indoor air quality (IAQ); comparison of the indoor air temperature, relative humidity, air velocity and MRT; simulation and testing of natural ventilation efficiency; and subjective responses of the residents.

Figures 16 and 17 show the indoor temperature of a new house in winter and summer, respectively. It can be seen from Figs. 16 and 17 that the indoor environment is improved without additional energy consumption. According to the subjective response survey, as shown in Fig. 18, 80% of the residents do not feel cold indoors in winter, without applying any heating measures, while 89%

Fig. 12 The first new rammed earth house built as a demonstration

Fig. 13 View of the courtyard

Fig. 14 Shutter for ventilation and day lighting

Fig. 15 New settlement of rammed earth houses

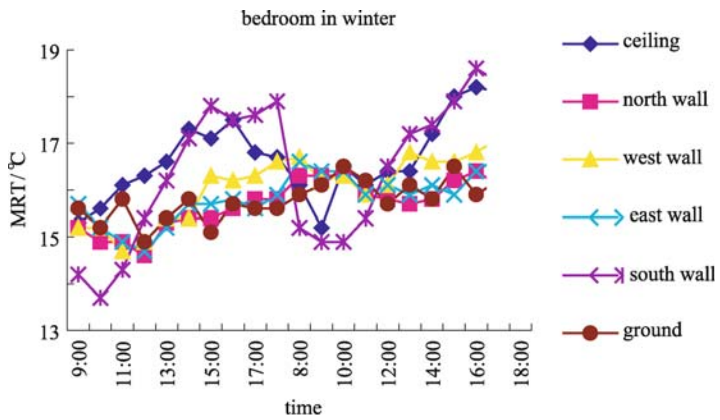

Fig. 16 Indoor radiation temperature of the new house in winter

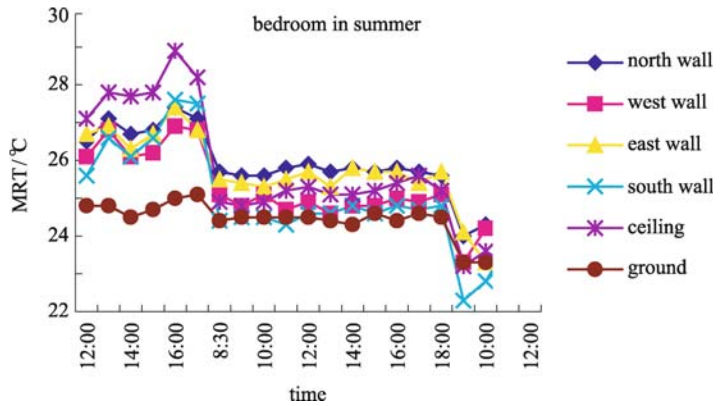

Fig. 17 Indoor radiation temperature of the new house in summer

of the residents do not feel hot in the house in summer, without air-conditioning.

6 Conclusions

The concept of low-energy housing with environmental compatibility is used in the design of traditional earth houses for migrants along the upper reaches of the Yangtze River with efficient use of renewable local materials.

1) Best use were made of natural resources to provide light, heat, waste disposal and gas for cooking and heating.

2) The energy consumption of house heating and cooling is near zero by virtue of passive solar design.

3) The use of simple family sewage-purge-pools and marsh-gas-well systems reduce pollution and save more than 50% more energy for cooking and heating water.

4) By using natural materials such as earth as a main building material, instead of concrete or burned bricks which are widely used in rural areas in China, around 2 tons of cement are saved and 2 tons of CO_2 emissions are reduced in the construction of the project.

5) Using earth walls as thermal mass, the yearly energy needed in running the house is reduced (predicted as the energy produced by 5500 tons of coal), and CO_2 emission is decreased by about 1 ton per year.

In this project, applying modern science and environmental knowledge to the earth house design while respecting the wisdom of traditional techniques achieves a more stable basis for future sustainable development of rural areas. The new earth house model and construction techniques in this project have a wide range of adaptability

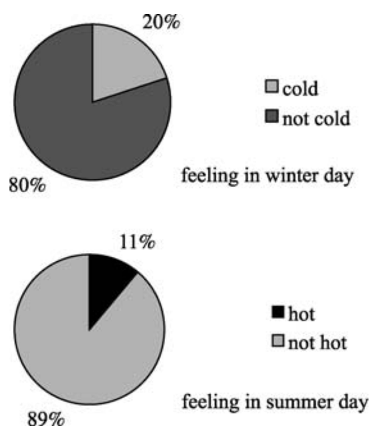

Fig. 18 Subjective response survey of the residents in winter and summer

and can be transferred to other areas in western China where most of the vernacular houses are built with rammed or adobe earth walls.

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