Energy saving performance of a combined insulation system in the rural houses of west China

Qiubo Xiao[1], Yu Liu[1], Yang Wang[2]

[1]Sustainable Building and Environmental Research Institute, Northwestern Polytechnical University, Xi'an, Shaanxi, 710072, China

[2]School of the Built Environment and Architecture, London South Bank University, 103 Borough Road, London, SE1 0AA.

Abstract. Deficiency of thermal insulation structure has caused discomfort of indoor thermal environment in the general rural houses in west China. This paper introduces a series of field investigations on the energy saving performance of a combined insulation system (CIS) in the rural houses of west China. The results show that, comparing to an ordinary rural house in the same region, CIS can reduce heating energy consumption for about 21.5 percent.

1. Introduction

The southern Shaanxi region is located in west China and in the "cold in winter and warm in summer" climate zone for building thermal design of China. Its weather characteristic is primarily sultry and damp in summer, cold and humid in winter [1]. Many villages in this region located in the mountainous valley zones [2], and their economic condition is comparatively back ward. Local rural houses are in the process of transition from traditional to modern dwellings [3]. Local residents are lack awareness of the necessity of building thermal insulation. Most of rural houses are self-designed and self-constructed [4], few of them is installed with thermal insulation material (figure 1). Therefore, the cold weather in winter has made the local residents bad experience of living in contemporary rural houses.

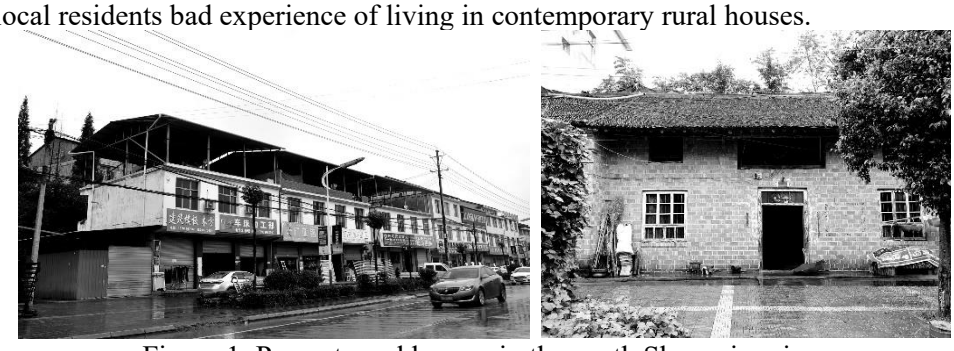

Figure 1. Present rural houses in the south Shaanxi region.

2. Analysis of field investigations

In order to clarify the needs of local people for housing improvement, a series of field investigation were carried out in eight villages in the south Shaanxi region. The main contents of the questionnaire survey mainly included the cost, structure, thermal insulation materials, comfort level and local people's expectation of rural houses. It was found that 47.1% of rural houses cost 50,000-100,000 RMB (equivalent to 8,000-16,000 USD), 41.2% of them cost more than 100,000 RMB. It also showed that

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

53.3% of the wall material was shale brick, 33.3% was concrete block and 13.4% was cork brick. Only about 8% of rural houses had uses some thermal insulation material in the roof area.

Investigates on the thermal environments were conducted based on the Standard of Test Methods for Thermal Environment of Building of China [5]. The average clothing insulation was calculated based on the Evaluation Standard for Indoor Thermal Environment in Civil Buildings of China [6]. Time of questionnaire survey was usually from 10 am to 15 pm. Results of investigations are shown in Table 1 and Table 2.

Table 1. Data of indoor and outdoor environment.

Time	Area	Air temperature (°C)	Relative humidity (%)	Black globe temperature (°C)	Air velocity (ms^{-1})
Sep.	Environment	18.8~36.6	20.8~94	17.9~42.6	0~2.7
	Indoor	19.2~26.7	50~83.8	19.3~27	0~0.3
Nov.	Environment	7.49~14.95	23.1~47.3	10.05~17.3	0~1.7
	Indoor	8.63~19.4	22.2~51.7	9.1~22.8	0~0.5

Table 2. Statistical results of field investigation.

Time	Age group	Ratio (%)	Average clothing insulation	Ratio of general thermal sensation (%)[a]							Ratio of expectation (%)[b]		
				3	2	1	0	-1	-2	-3	1	2	3
Sep.	<30	13.5	0.75	17.7	27.5	32.6	22.2	0	0	0	14.8	81.5	3.7
	30-40	27	0.66	9.4	26.2	31.2	33.2	0	0	0	5.5	92.6	1.9
	40-50	20.5	0.7	10.2	13.6	37.2	39	0	0	0	12.2	85.4	2.4
	50-60	18.5	0.75	8.5	24.3	32.1	35.1	0	0	0	27	64.9	8.1
	>60	20.5	0.83	0	30.8	35.1	24.8	9.3	0	0	19.5	80.5	0
Nov.	<30	13.6	1.56	0	9.2	8.9	27.3	36.4	18.2	0	90	10	0
	30-40	11.1	1.47	11.1	0	0	73.8	4.1	11	0	89	11	0
	40-50	28.4	1.5	0	8	17.4	43.5	21.7	4.4	5	87	13	0
	50-60	16	1.8	0	0	15.4	46.2	38.5	0	0	76.9	15.4	7.7
	>60	30.9	1.81	0	8	16	32	2	8	16	88	12	0

[a]3 means hot, 2 means warm, 1 means a little warm, 0 means neutral, -1 means a little cool, -2 means cool, -3 means cold.
[b]1 means to be warmer, 2 means maintaining the same, 3 means to be colder.

The statistical results of investigation showed that most people feel warm and comfortable when indoor temperature was higher than 19 °C and they wanted the temperature maintain the same. Some old people and women felt cold and wanted the temperature to be warmer in the morning and at night. In general, the climate in September was comfortable for local residents. When the indoor temperature fell below 13 °C, most people felt cold and they really wanted the indoor temperature to be warmer. It also showed that the proportion of the old-age population in the investigated region was more than 23% and old people had higher requirements for indoor temperature. Therefore, it's necessary to promote building thermal insulation in this area, not only for energy saving, but also for caring of the elderly.

3. Application of combined insulation system

3.1. Conditions of a demonstration building

A rural house in the Liangjiawan village of the investigated region was selected as a demonstration of reconstruction for the improvement of thermal insulation. The house was originally built without thermal insulation. There was a country road to the south of the house and a farmland to the north of it, the east side of the building was close to another building and the west side was about one-meter distance from another building (figure 2). It had three floors and the family mainly lived on the second floor. The thermal insulation performance of the bedroom was mainly hoped to be improved, because households worked outside in the daytime and felt cold when they went to sleep. The cost of the reconstruction was expected to be reduced as much as possible and decoration of the south and north exterior wall should

not be destroyed.

Figure 2. The surrounding environment and appearance of the building.

3.2. Combined insulation system

A combined insulation system (CIS), which refers to a structural system that apply thermal insulation to a part or the whole of a building according to the conditions of the environment and the demands of the users, is applied in the reconstruction of the above mentioned demonstration building. It consists of the following:

(1) Thermal insulation of the external walls

The household identified two main bedrooms, the thermal performance of which are expected to be improved. An external thermal insulation layer was installed on the east and west wall, where there is no decoration; at the same time, an internal thermal insulation layer was installed on the north and south wall of the main bedrooms (figure 3-a, b), because the exterior wall decoration cannot be destroyed.

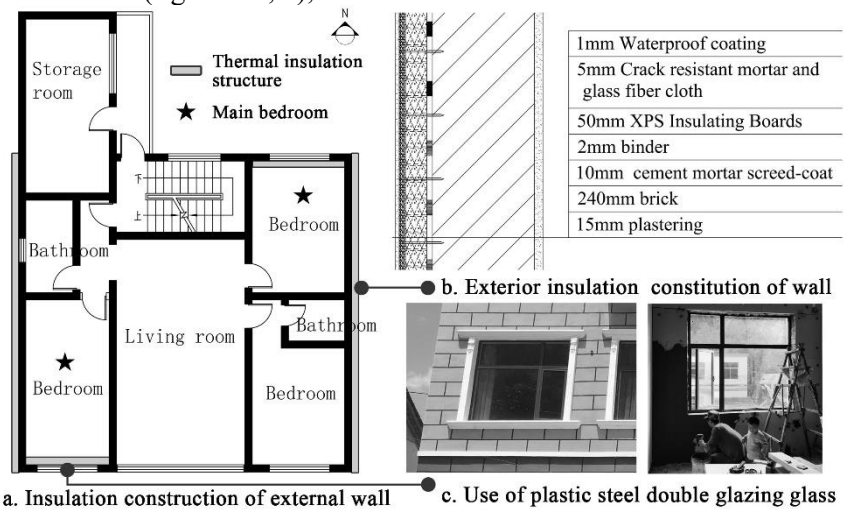

Figure 3. Thermal insulation system of external wall on the second floor.

(2) Thermal insulation of the external windows

All the external windows were also changed from aluminum alloy single glass to plastic steel double glazing glass to reduce heat loss from the window area (figure 3-c).

(3) Thermal insulation of the roof and the floor

To further enhances the thermal performance of the main bedrooms, roof insulation and floor heating system with a thermal insulation layer were installed. The 50 mm thickness XPS insulating board was used in roof and wall insulation

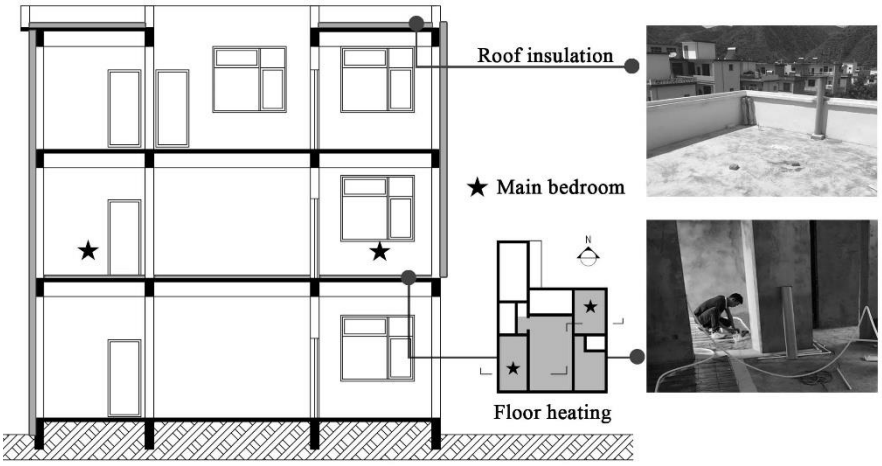

Figure 4. Roof insulation and floor heating system with a thermal insulation layer.

On the one hand, the CIS applied in this building is different from a normal insulation system in the city areas in two aspects: 1) not the whole building, but only the selected main bedrooms were insulated according to the needs of the users; 2) not a single type of insulation, but two different types (internal or external) of insulation, was applied on different external walls according to their specific conditions. On the other hand, it is same as a normal insulation system in the city areas in that a combination of different insulation structure is apply for the external walls, windows, roof and floor of the building.

4. Field survey on the energy saving performance of CIS

In order to test the energy saving performance of CIS, a typical normal rural house in the same village, was selected as a contrast building. It had a similar plan and orientation as the demonstration building. A qualified third party, the SCEGC Research Institutes of Shaanxi Province, was invited to survey and measure the thermal performance of the demonstration building (refereed as building A) and the contrast building (refereed as building B). The testing time was November 27th to December 3rd, 2017. The main bedrooms of building A and the same position rooms of building B were tested. The purpose of the measurement was to identify the energy consumption and thermal comfort performance of the two buildings under the same conditions. Results of the survey is shown in Table 3.

Table 3. Energy consumption under the same temperature condition.

Time	Outdoor temperature (°C)	Indoor temperature (°C)	Energy consumption (kWh)		Energy consumption per unit area (Wm^{-2})	
			Building A	Building B	Building A	Building B
Nov. 27th	7.36	15	28.81	58.9	37.17	47.75
Nov. 28th	7.77	16	33.37	70.37	43.04	57.04
Nov. 29th	8.57	18	45.35	90.77	58.5	73.58
Nov. 27th	7.54	18	43.54	86.25	56.17	69.92
Dec. 1st	6.9	18	42.86	85.52	55.29	69.33
Dec. 2nd	7.57	17	36.11	76.38	46.58	61.92
Dec. 3rd	6	17	35.79	70	46.17	56.75

The data in this table was provided by SCEGC Research Institutes of Shaanxi Province.

Frequency control heater was used to warm indoor temperature and maintain the specified temperature from 15 °C to 18 °C, every specified temperature was kept for 24 hours. Then, the energy consumption of this time period were recorded (table 3). The energy consumption per unit area was calculated based on the recorded data. It showed that, to maintain the same indoor temperatures, energy consumption per unit area of building A is about 21.5% less than that of building B.

5. Conclusion

Research of this paper shows that, for rural house in the researched region, CIS is effective on improving their energy saving performance. It not only can enhance the thermal insulation performance of the building, but also can adapt to the complex conditions of existing buildings and different needs of the users. Results of the field third part survey also indicate that, comparing to normal house in the same region, building with CIS is able to maintain a relatively stable and comfortable indoor thermal environment with about 1/5 less energy consumption.

Acknowledgments

The research of this paper was supported by the 2016 International Science and Technology Collaboration and Communication Program of Shaanxi Province (No.2016KW-031) and the 12th Five-Year Science and Technology Support Program of China (2015BAL03B04-2).

References

[1] Peng J 2015 Southern Shaanxi mountain settlement climate adaptation of the tradition settlements environment space characteristics *Xi'an University of architecture and technology*.
[2] Yan J 2009 *Sichuan Building Science* **03** 226-229.
[3] Rongrong H, Feng S, Wengfang H, Wan peng L 2009 *Xi'an Univ. of Arch. & Tech. (Natural science edition)* **41** 841-845.
[4] Yu L, Jin W, Juan R 2017 A preliminary study on the climate adaptive design of green rural houses in west China *Procedia Engineering* **180** 735-740.
[5] Standard 2014 Standard of test methods for thermal environment of building (JGJ/T 347-2014) (Beijing: China Architecture &Building Press).
[6] Standard 2012 Evaluation standard for indoor thermal environment in civil buildings (GB/T 50785-2012) (Beijing: China Architecture &Building Press).