The Effect of Passive Optimization Strategies on Interior Thermal comfort of Traditional Dwelling House in Guanzhong Region of Shaanxi Province in Cold Season

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Abstract: This paper introduces interior thermal comfort test along with simulation analysis of the target house. It is supposed to enhance the interior thermal comfort of traditional dwelling houses in Guanzhong region of Shaanxi Province in cold season, and provide reference for the research in other areas. The study was conducted in Xiaoliu village in this area by means of field test and questionnaire investigation. A brick concrete traditional dwelling house is chosen for test and research. The thermal test includes the indoor relative air humidity and air temperature. At the same time, the village residents filled in a questionnaire, which includes their thermal feeling and willingness to optimize. The test data are sorted and analyzed, the problems are found and the transformation strategy is put forward, and then the thermal simulation analysis is carried out to assess the improvement of indoor thermal comfort by the passive optimization strategy. Many existing studies describe a single factor qualitatively, lack systematic and comprehensive consideration, and can not provide accurate simulation results or quantitative results only for a certain factor. The contribution of this paper is that many factors of passive design strategy affecting building energy consumption and thermal comfort are taken into account, and the final scheme is simulated by finite element method using control variable method to quantitatively show the impact of passive design strategy on energy consumption and thermal comfort. In this study, the comprehensive passive optimization strategy is introduced into Guanzhong area for the first time. The field test and analysis reveal that thermal comfort of traditional dwelling houses in this area is poor, the spatial layout of houses is unreasonable, thermal properties of enclosure wall is not ideal and the heating mode is inefficient. Combined with the local situation, the passive design strategies such as optimizing the layout, improving the thermal insulation performance of the envelope and using solar energy are put forward according to local conditions. Through the simulation, the outcome indicates that the space division mode, the thickness of insulation layer of roof and wall, the structure of external window, the ratio of window to wall（WWR）, the depth of sunlight and other factors do affect the building energy consumption. The indoor thermal comfort of traditional dwelling houses may be enhanced by reasonably dividing indoor space, increasing the thermal insulation performance of enclosure structure, making better use of solar energy and natural ventilation. In this paper, after applying these measures, building energy consumption has been reduced by about 41%, the average temperature of the master bedroom on the first floor and the second has increased by about 4 ℃ and 4.2 ℃ respectively.

Keywords: traditional dwelling house, indoor thermal comfort, thermal simulation, passive design strategies, field measurements

Introduction

The energy problem is increasingly prominent under the background of global warming, and, therefore, sustainable development of energy is of great significance [1]. As a large energy consumption country, China's building energy consumption has accounted for about 30% of the national consumption [2]. The construction area of rural residential buildings accounts for more than half of the newly-built houses in China [3,4]. Therefore, it is high time to decrease power consumption of buildings especially in rural areas. The government proposes that the strategic goal of Rural Revitalization is to build beautiful countryside and improve rural living environment, which is a crucial approach to realize the harmonious coexistence of man and nature. As a result, there is a pressing need to study traditional dwelling house for the goal of sustainable development.

It is undeniable that traditional rural architecture contains rich ecological experience. Due to the rapid economic development, people's living standards have been continuously improved, people's requirements for indoor thermal environment are also increasing. There is a huge stock of existing traditional dwelling houses in China. Limited by the economic conditions at that time, the design standards are low and most of the existing traditional rural houses are hard to meet the thermal requirements. So far, those rural self built houses are still lack of design specifications and blindly imitate urban buildings, which leads to low thermal performance and prominent heating energy consumption problems, which is neither economic nor environment friendly.

Guanzhong region is located in Shaanxi Province with area of 55500 square kilometers together with of about 24 million. It has cold winters. The outdoor air temperature of the coldest period is approximately -1.2℃ on average(January). Most of the rural buildings in this area are three bay layout. The space layout is unreasonable, the enclosure wall is not up to standard, the heating mode is single and the indoor thermal environment is poor. There are prominent winter indoor thermal problems in residential buildings for a long time, and the research on related issues has always been a hot topic in academic circles.

From January 10, 2020 to January 14, 2020, the research group conducted research and test in Zhouzhi County, Guanzhong area. At present, the academic community has carried out some research. Liu et al. analyzed the problems existing in the spatial layout of typical rural houses in Guanzhong [5]. Hu et al. mainly analyzed the defects in thermal design of residential building envelope [6]. He et al. Put forward optimization measures such as increasing solar room from the angle of energy saving [7]. From the point of improving thermal comfort, Yu et al. put forward optimization measures such as optimization of enclosure structure and design of doors and windows [8]. The above scholars mentioned center on the causes of problems concerning thermal comfort. The optimization measures are empirical analysis from a certain aspect or angle. There are few researches on how to systematically and quantitatively study the thermal environment matching of relevant influencing factors （It mainly includes the building plane layout, enclosure structure, especially the structure of walls, roofs and windows, the depth of sunlight, and the ratio of windows to walls.）to enhance thermal comfort of traditional dwelling houses.

Paper [9] explores the effect of building orientation on improving indoor thermal comfort through CFD software simulation. Article [10] uses EnergyPlus software to study the effect of windows on indoor ventilation, and then on indoor temperature and energy consumption. In Article [11], the passive design and energy-saving simulation of external windows of existing buildings are carried out by using designbuilder software. This paper [12] points out that the window wall ratio is an important factor affecting energy consumption through software simulation. As mentioned in the summary, most of the existing studies focus on the qualitative description of a single factor, lack of systematic and comprehensive consideration, and only provide quantitative results for a certain factor. We know that these factors are not a single superposition, but a coupling effect. In this paper, many factors affecting building energy consumption and thermal comfort are considered, and the final scheme is simulated by finite element method to quantitatively present the simulation results after multiple factors are considered.

The house is in the cold region of China. It aims to provide passive design guidelines for traditional dwelling houses in the same area. Field test were performed to assess the thermal performance and their willingness towards optimization. Besides, to assess the the effect of passive strategies, simulation was performed. These passive design guidelines with regards to occupants' thermal satisfaction would lead to better thermal performance and reducing the energy consumption.

METHODOLOGY

This study adopted field measurements and questionnaires as well as simulation software. Passive design strategies were used to the simulation process, for instance, optimizing the space layout reasonably, adding thermal insulation for the envelope structure, making use of solar energy, taking advantage of natural ventilation. Later, the original building and the optimized building were compared in the software to see the effect. The control variable method was used to compare the effect of each optimization measure step by step. The simulation results told us how to enhance the thermal performance which will satisfy the occupants' need of thermal comfort by means of various passive design strategies in Guanzhong area of China. The specific research flow chart is shown in the figure below.

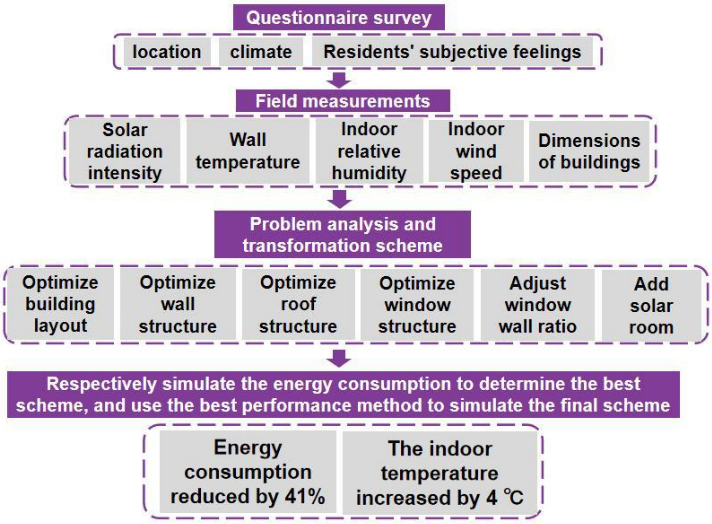


Figure. 1 Research process

Research Object

The original house is a brick and concrete house. It was selected in that its architectural style and climate are representative. In Guanzhong area, a region with a population of more than 24 million, such buildings represent most of the traditional dwellings. Therefore, the result can be used as reference for the houses in the cold region.

The house is a brick concrete structure building, which is a typical local three bay self built house. It was built in 2008 with two main floors. The first floor is 3.8m high. The second floor is 3.6m high. The depth of the bay can be seen in Figure 5. The wall is a solid clay brick wall with a thickness of 240mm. The inside and outside of the wall are plastered without thermal insulation layer. The heat transfer coefficient k=2.04W /(M^2 · K). The roof of the house is double slope roof, without ceiling and layer for heat preservation. Its shape coefficient of the house is about 0.52, the house is north-south oriented. The WWR of the south wall and north wall are both 0.27. The windows are all single glazed wood windows. There is no curtain on the door. The heating mode is carbon furnace.

Questionnaire results

From January 10, 2020 to January 12, 2020, about 100 households were visited, and information were collected concerning local building form, heating method, transformation willingness, indoor temperature and humidity feeling by questionnaire and interview. 82 valid questionnaires were received. The survey analysis results are shown in Figure 2.

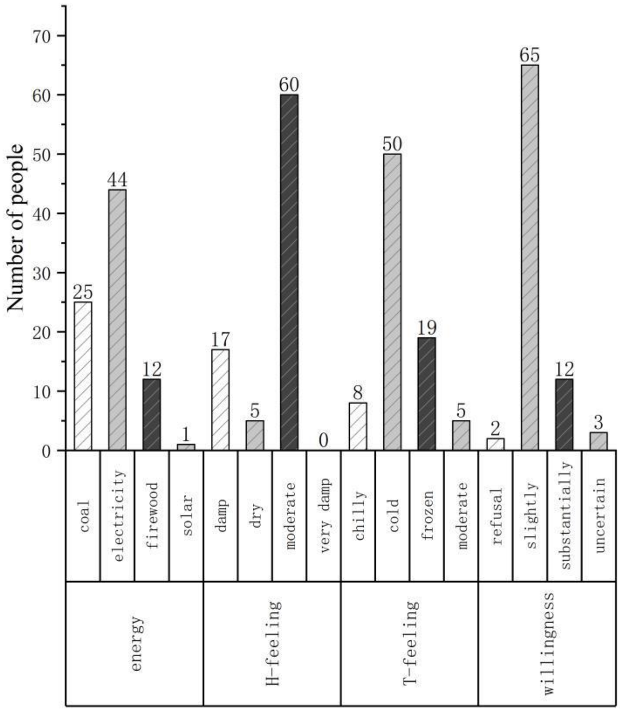


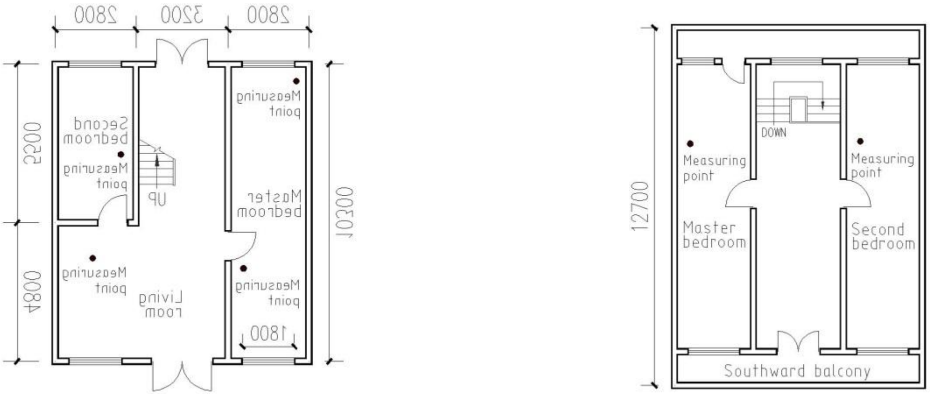
Figure. 2 Survey analysis results

The survey results show that only 2% of the residents are willing to maintain the status quo. Although these residents are not pleased with the indoor thermal performance, some people do not know the cost of renovation, and some people are unwilling to carry out renovation because they do not want to destroy the decoration. However, 94% of the residents are more willing to optimize their houses, which shows that there is little resistance to optimize the indoor thermal environment in Zhouzhi County. Research shows that only 1% of the residents have used solar heating equipment, and the vast majority of residents rely on non renewable energy or even high pollution energy for heating. In addition, the government's demand for greenhouse gas emissions has been increasing in recent years, so the use of firewood for heating has been restricted. This has led to the elderly who are in poor economic conditions to give up heating. The results of indoor humidity can be seen that the local indoor humidity is relatively high, 21% of the residents think that the humidity is humid, and 73% of the residents think the indoor humidity is moderate. The analysis of indoor temperature perception shows that only 4% of the residents think that the indoor temperature in winter is acceptable, which indicates that the subjective feeling of residents is that the indoor thermal performance is poor and needs improvement.

FIELD MEASUREMENTS

Measurements Plan

During the test period from January 13, 2020 to January 14, 2020, the weather was sunny. The test contents include indoor temperature, relative humidity and outdoor solar radiation intensity in winter. The 175-h1 self recording temperature and humidity meter with measurement accuracy of ± 0.2C was used for 24h continuous test, and the data acquisition interval was 1 h. The measuring point is set in the first floor bedroom. The height of indoor measuring point is 0.9m from the ground, and the distance from the wall is more than 1.0m. The solar radiometer is set in the open space without any shelter around, and the data acquisition time interval is 1h. The plan of brick concrete building together with measuring positions are illustrated in Figure 3.



(a) Space division of the first floor (b) Space division of the second floor

Figure. 3 Original space division scheme （mm）

Intensity of Solar Radiation

The test lasted for about 9h, from 09:00 to 18:00. The summit of solar radiation intensity is 500W/m2. The average intensity is 237w/m2. The direct intensity has a proportion of 77.8%.

We can concluded from the results that the solar radiation intensity is considerable in winter in this area, which is promising for the development of passive solar heating. The hourly variation curve of solar radiation intensity is illustrated in Figure 4.

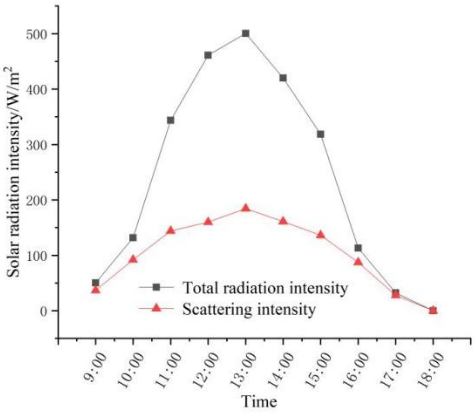
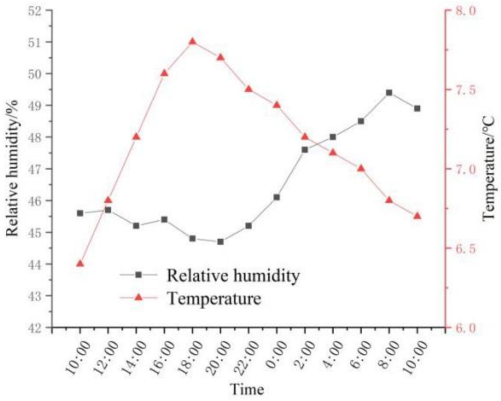


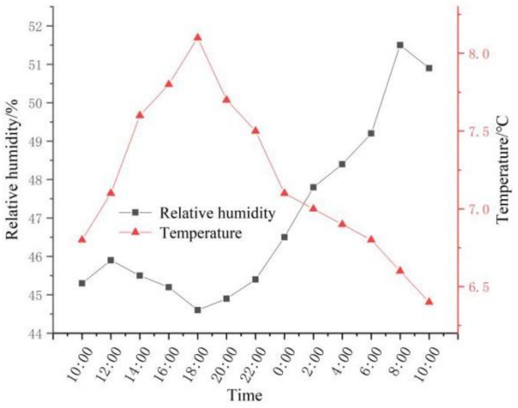
Figure. 4 Variation curve of solar radiation intensity

Indoor Humidity and Air Temperature

The hourly variation curve is given in Graph 5. Fluctuation range is large as we can see, relative humidity decreases as temperature increases. The average temperature of the first floor master bedroom is 7.2 ℃, the maximum temperature is 7.9 ℃, The temperature variation range is 1.5 ℃. The data of the second is 7.2 ℃, its maximum is 8.3 ℃ while the amplitude is 2.0 ℃. The humidity distribution on the first and second is 47% and 46.5% respectively. The difference is not big. From the second floor room according to the test results, its maximum temperature is slightly higher, but with the lower average temperature. The fluctuation range comes to be larger, which shows that the thermal stability of the second layer is worse than that of the first layer.The hourly variation curve of temperature and humidity in the first and second floor master bedroom is given in Graph 5.



(a) Hourly temperature and humidity change curve of room on the first floor



(b) Hourly temperature and humidity change curve of room on the second floor

Figure. 5 Hourly variation curve of temperature and humidity

Analysis of Existing Problems

The original building is a typical three bay building, which lacks reasonable space separation in space division, and there is no North-South Division for bedrooms; the opening and depth of rooms are very large, and the floor height is very high. Under the same conditions, it is more difficult to reach a comfortable temperature.

In terms of enclosure structure, 240mm clay brick wall is adopted for the external wall, and the inside and outside of the wall are plastered, without thermal insulation, and the wall structure is simple; the double slope roof without ceiling is used, and the wood and tile materials have poor thermal performance; the external window adopts single glass window, with poor air tightness and thermal insulation performance; The residents are accustomed to open the door, and do not set up cotton curtain; The heat transfer coefficient of each link of the enclosure wall in cold areas is far less than the standard requirements, there is a lot of heat lost through the wall, which is very unfavorable to the thermal insulation in winter.

The heating mode in this area is single, and can not be good at using solar energy for passive heating under the premise of conditions. It relies heavily on electric energy, coal and firewood. It consumes a lot of energy, which is neither economic nor environmental protection.

Optimization Simulation Analysis

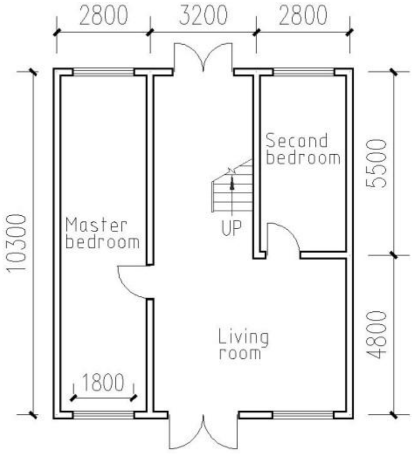
Energy Saving Optimization Scheme

The optimization scheme can not be divorced from the reality. We should treat the existing rural economic situation correctly and put forward optimization measures according to local conditions. In view of the existing problems, this paper puts forward the corresponding optimization strategies from three aspects: space division, thermal insulation performance of enclosure structure, and adding additional sunlight room.

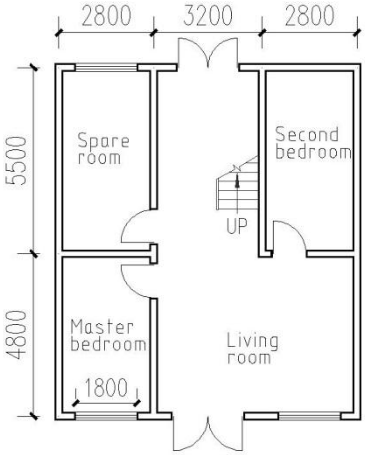
The simulation software adopts the mainstream thermal calculation software ecotect 2011. Based on the control variable method, the advantages and disadvantages of the scheme are compared step by step, to make sure the simulation results are reliable.

Optimization of Spatial Layout

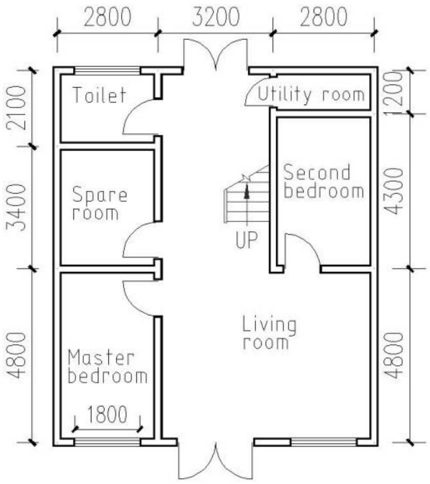
According to the research group's investigation on the basic space division of existing buildings in Guanzhong area, three suitable spatial division modes are determined, as shown in Figure 6. Condition a is the original layout of the building. Condition B divides the west main bedroom on the first floor into North and south parts on the original basis, while condition C adds more auxiliary rooms in the North-South dimension. When three schemes are simulated, the second layer is set according to Fig. 3 (b) to compare the three schemes.



Condition A



Condition B



Condition C

Figure. 6 Division scheme of the first floor space

The simulation time set by the software is consistent with the test time, and the meteorological conditions in Xi'an, Shaanxi Province are selected. According to the clothing situation of villagers and the reference [13], the average clothing thermal resistance value of indoor personnel in winter is 2.5 clo, the indoor humidity is set as 47%. The indoor air change frequency is set as 0.5 times / h. Under the default conditions of weather tool, the human activity is set to sit still, the WWR is set as 0.5, the thermal insulation of enclosure structure is set to low, and the solar heating efficiency is set to low. The specific operation process and parameter settings are combined [14]. The simulation results of building energy consumption under different space division modes are shown in Figure 7.

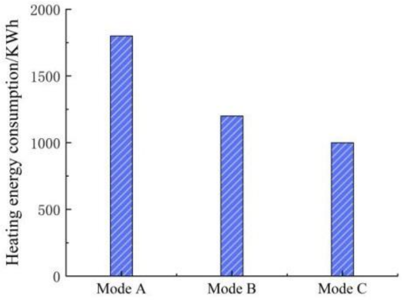
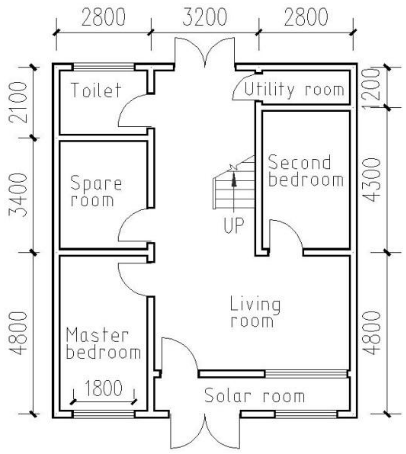


Figure. 7 Heating energy consumption simulation under various space division schemes

The simulation results reveal that the Heating energy load can be significantly decreased by multi space division. Reference [15] points out that the indoor temperature of main rooms can be improved by setting partition walls. The south facing wall receives solar radiation, so the main room is set in the south direction. The secondary room is arranged in the north to form a temperature buffer zone. The temperature of the main rooms in the south direction is kept at a high level. The change of condition a to condition C can increase the average hourly temperature of the first floor master bedroom by about 1.2 ℃. The simulation results show that condition C has the best effect.

The space division scheme of subsequent analysis adopts condition C, and on this basis, internal partition wall is set. The final scheme is given in Graph 8. The original bedroom has no North-South Division. The original master bedroom is divided into three parts in scheme C. The first floor retains the original function and adds kitchen, toilet and storage room to enrich and improve the use function. To achieve more differentiation of small space to achieve thermal insulation effect, which uses the concept of "room in room", plays the role of temperature transition zone to prevent heat loss. Therefore, reasonable indoor space division can improve the temperature of the room. In the architectural layout, the kitchen and Kang room are adjacent to each other in the form of stove and Kang. Kang room is used as heat source to radiate and convection heat [16]. This kind of space division scheme does not change the shape coefficient of the building, and strives to keep the architectural shape regular and avoid concave convex changes due to the layout. The subsequent analysis is optimized on the basis of the spatial division scheme in Figure 8.



(a) Plan of the first floor

(b) Plan of the second floor

Figure. 8 Optimized space division scheme（mm）

Optimization of Enclosure Structure

The enclosure structure includes exterior wall, roof, doors and windows.

External Walls

Wall is the main component of building envelope, and its thermal performance has huge influence on heat loss and indoor temperature. According to reference [17], to simplify, equal heat transfer coefficient method should be used for exterior wall structure design.

SchemeA, B, C and D gradually increase the thickness of insulation layer. See Table 1 for the calculation model information of exterior wall structure.

Methods	Material	Thickness mm	Thermal conductivity $W/(m\cdot K)$	Dry density kg/m^3	Specific heat $J/kg\cdot K$	Thermal resistance K/W	Heat transfer coefficient $W/(m^2\cdot K)$
Method A	cement mortar	20	0. 930	1800	1. 05	0. 022	2. 04
	clay brick	240	0. 810	1800	1. 05	0. 296	
	cement mortar	20	0. 930	1800	1. 05	0. 022	
Method B	EPS	50	0. 041	20	1. 38	1. 220	0. 59
	clay brick	240	0. 810	1800	1. 05	0. 296	
	cement mortar	20	0. 930	1800	1. 05	0. 022	
Method C	EPS	60	0. 041	20	1. 38	1. 463	0. 52
	clay brick	240	0. 810	1800	1. 05	0. 296	
	cement mortar	20	0. 930	1800	1. 05	0. 022	
Method D	EPS	80	0. 041	20	1. 38	1. 951	0. 41
	clay brick	240	0. 810	1800	1. 05	0. 296	
	cement mortar	20	0. 930	1800	1. 05	0. 022	

Table 1 information of external wall construction model

Note: The thermal parameters of materials are selected from reference [18]; The heat transfer coefficient is obtained according to reference [19].

With the model parameters unchanged, the four wall materials are input into Ecotect 2011 in turn. The results of different wall structures are illustrated in Figure 9.

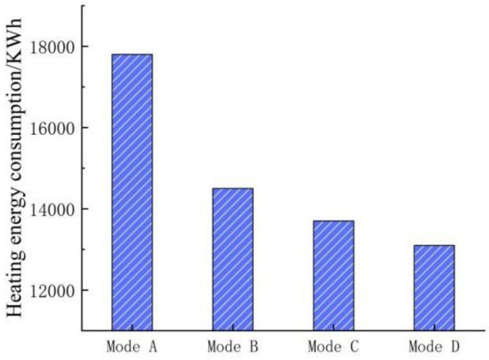


Figure. 9 Simulation results of energy consumption under different wall structures

It can be seen that from no insulation to insulation, the energy load is greatly reduced while the energy-saving rate is getting smaller and smaller. This indicates that the primary task should be to increase the insulation, rather than not do the insulation at all.

When selecting the structure, the cost should be considered at the same time, so method B is selected for subsequent simulation calculation.

Roof

Based on the original roof, energy consumption is simulated by changing the thickness of thermal insulating layer. The parameters is given in Table 2. The results is shown in Figure 10.

Table 2 information of roof insulation thickness model

Roof insulation thickness/mm				
0	20	40	60	80

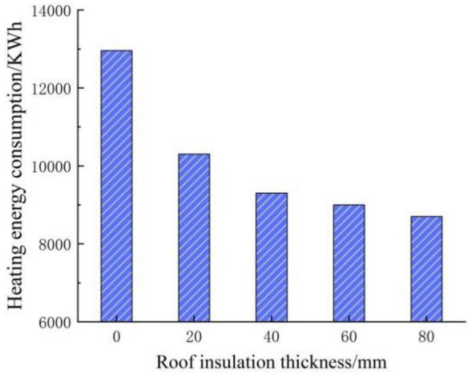


Figure. 10 Simulation results of energy consumption under different roof insulation thickness

The results indicate that increasing the thickness of roof insulation layer has lower and lower gain for energy saving rate. The final roof insulation method is: flat tile surface + 40mm XPS extruded board + waterproof layer + cement mortar leveling layer + roof panel. The heat transfer coefficient of the roof is about 0.590. The slope roof panel can be combined with light ceiling to form a closed air interlayer, which is more conducive to winter insulation.

The lap joint of the ceiling is provided with an opening that can be opened and closed.In summer, ventilation can be improved and indoor heat can be taken away. The subsequent optimization is based on the above contents.

Transparent Enclosure

The transparent envelope in building envelope is an important source of solar radiation for buildings, and also the main way for buildings to lose heat, so its thermal performance is very important [20]. The thermal performance of three typical external windows is given in Table 3. Single glass window is adopted in most of local houses. The energy load of three kinds of external windows is simulated in Ecotect. The WWR of south is set as 0.5 and the north is still set as 0.27. In terms of exterior window material, considering the comprehensive performance, plastic steel window is selected among wood, plastic steel and Bridge breaking alloy. The cost of plastic steel is much lower, and its excellent heat preservation and air tightness performance can be achieved with a relatively small cost. The calculation model information under different external window structures is given in Table 3. The simulation results of energy consumption under different external window structures are shown in Figure 11.

Table 3 Calculation model information under different external window structures

Methods	Single glass	Double Glass	Low-E window
Methods	6mm glass	6mm glass	6mmLow-E glass （Radiation rate 0.25, arranged inside）
		10mm air layer	10mm air layer
		6mm glass	6mm glass
Heat transfer coefficient	5.70	3.00	2.30

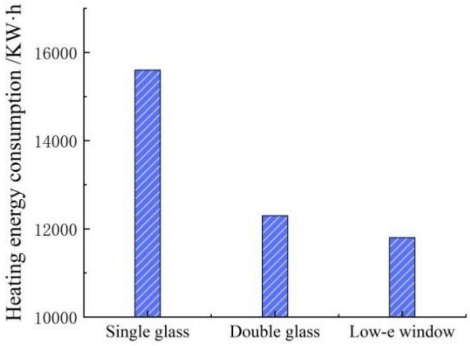


Figure. 11 Simulation results of energy consumption under different external window structures

Single glass window has the worst thermal performance and the highest energy consumption. This is because the single glass window has large heat transfer coefficient and poor air tightness. In winter, the indoor heat loss through windows is large. The energy consumption of double glass window is significantly lower than that of single glass window, and the energy consumption difference between double glass window and Low-E window is small so the thermal performance of windows can be improved to significantly reduce cold air penetration and heat loss and the hollow structure can also improve the sound insulation performance. Therefore, the first step of energy-saving strategy for external windows is to replace single glass windows with double windows. In winter, we can also consider hanging cotton curtain at the door. Through the above methods, the heat loss can be effectively reduced in the door and window, which is a part of indoor and outdoor heat exchange.

Window to Wall Ratio

The original WWR is 0.27. Refer to the references [21] on rural residential buildings in cold areas, the south facing window to ground ratio is set to 0.5. In order to simplify the working condition, the WWR of north is set as 0.27. The results of energy load under various WWR are shown in Figure 12. The results show that increasing the ratio of south facing windows to ground can significantly reduce energy consumption, and large area of south facing windows can increase the temperature of main rooms facing south.

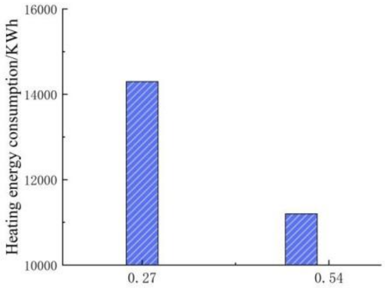


Figure. 12 Simulation results of energy consumption under different window to wall ratio

Passive Solar Heating

The test outcome indicates that it is promising to develop solar heating in this area. Taking advantage of solar energy can reduce the dependence of residents on firewood and significantly reduce the consumption of non renewable energy[22,23]. But the survey results also show that only 1% of the local residents use solar heating equipment.Considering the local economic situation, the development of passive solar heating is the best choice. Adding additional sunlight room is the first choice to develop passive solar heating [24,25].The additional sunshine room is set in the living room, and the architectural shape is regular without changing the shape coefficient of the house. In addition, the depth of sunlight will not only affect the heat collection effect of the room, but also affect the use function of the residents. In this paper, the energy consumption of different sunlight depth is simulated.The section diagram of the model is shown in Figure 13, and the marked position in the figure is the sunlight room. The calculation model information under different sunshine depth is given in Table 4. The simulation results are shown in Figure 14.

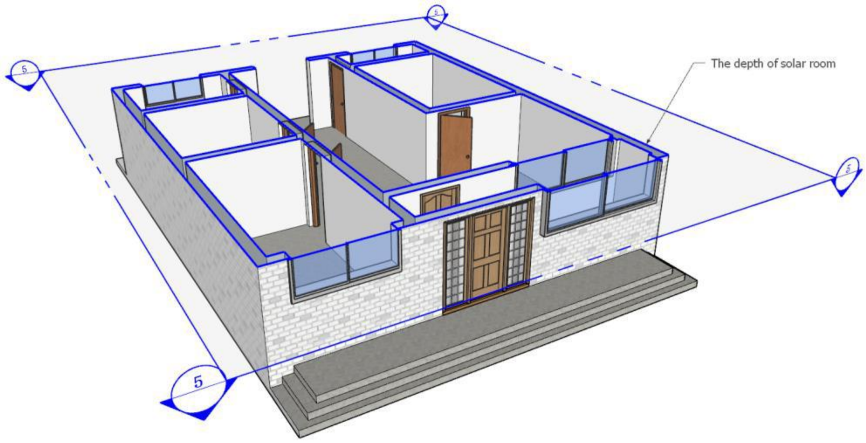


Figure. 13 Location of additional sunlight in section

Table 4 Model information under different sunshine depths

Window	The depth of solar house/m				
Plastic steel double glass window	0	0.6	1.2	1.8	2.4

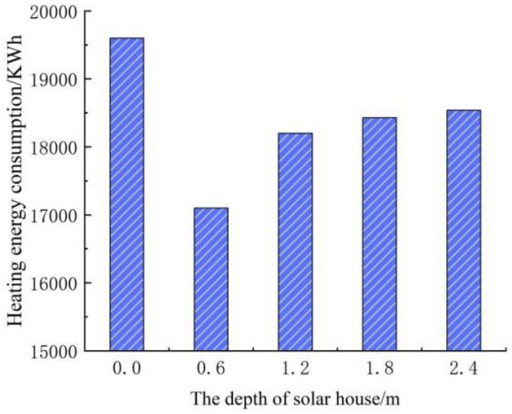


Figure. 14 Simulation results of energy consumption under different depths of sunshine room

The simulation results show that the energy load tends to be the lowest when the depth is 0.6m. increasing the depth of sunlight, the heating energy consumption is no longer reduced, showing an increasing trend. When the depth is set at 1.2m, it can not only keep low energy consumption, but also meet the requirements of function and cost.

The wall between the additional sunlight space and the living room can play the role of heat storage. Trombe wall be used, and openable vents are set at the bottom and top of the wall. The air in the sunshine room is heated. The ventilation hole is opened during the day. When heated, the air is lifted and flows into the room through the air port above. The cold air in the living room flows into the sunlight room through the lower vent, forming a cycle. The vents are closed at night, and the stored heat is released to heat the room.

To cope with the problem of overheating in the sunlight room in summer, the glass in the sunlight room can be opened as a vent. In summer, pebbles can be removed, and louvers can be shaded to prevent overheating. The relative position of doors and windows in the optimized scheme is also conducive to natural ventilation and take away indoor heat. It can be considered to set the openable vent on the external wall under the cornice at the same time, which can be opened in summer and closed in winter.

As the height of the first floor of the building is up to 3.8m, a 3.0m high 10mm PVC ceiling can be considered in the master bedroom to reduce the room volume and reduce the heating difficulty. The section diagram of the optimized brick concrete residential building is shown in Figure 15.

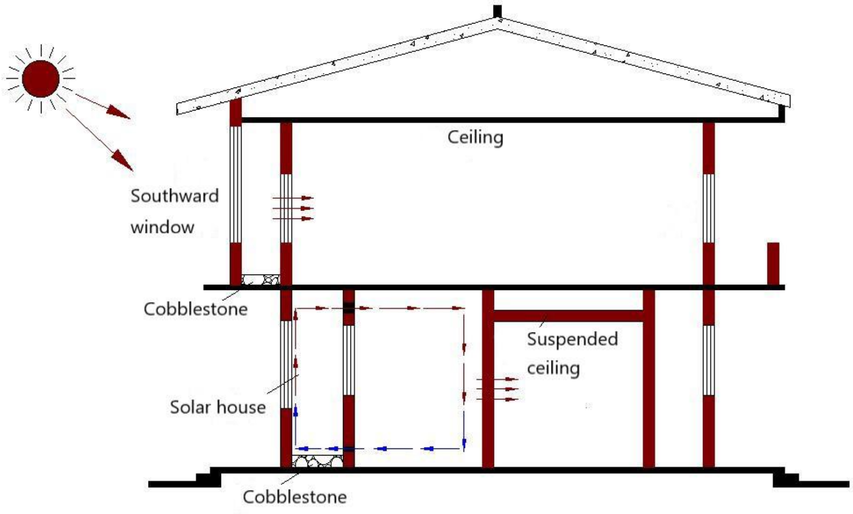


Figure. 15 Sectional view and indoor ventilation of the residence after optimization

Simulation of Final Scheme

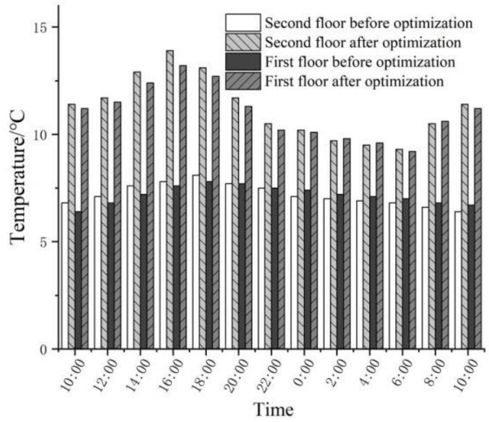
The summary of the improved model practice information is given in Table 4; the final rendering image is illustrated in Figure 16.

Table 4 information of improved model

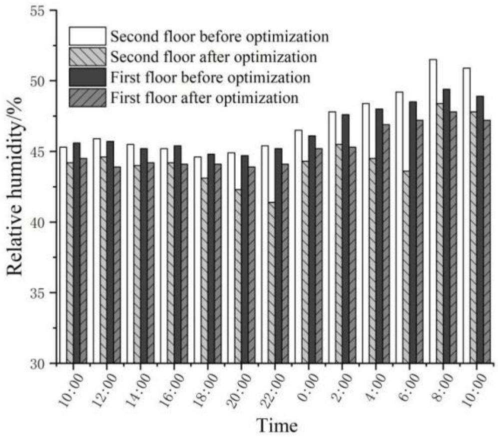
Position	Summary of model setting information after optimizing
space division	multi space division mode C / the main rooms are set in the south and the secondary rooms are set in the north / "Stove with Kang"(A traditional heating method in North China)
exterior wall	50 mm EPS+240 mm clay brick+20 mm cement mortar, Heat transfer coefficient is 0.59
window	6mm glass+10 mm air layer+6mm glass plastic steel double glass window, Heat transfer coefficient is 0.30
window to wall ratio	South: 0.5; north: 0.3
roof	plain roofing tile+40 mm XPS+waterproof layer+cement mortar leveling course+roof slab, Heat transfer coefficient is 0.59/ light weight suspended ceiling under sloping roof slab
door	add cotton curtain
solar house	depth:1.2m / add Trombe wall / heat storage materials / set blinds
master bedroom	10 mm PVC ceiling is set at 3.0 m

Figure. 16 Optimized rendering effect

The Ecotect thermal model is established to verify whether the reconstruction scheme can significantly enhance thermal performance. Simulation and comparison are carried out before and after optimization. The simulation time set by the software is consistent with the test time, and the meteorological conditions in Xi'an of Shaanxi Province in the database are selected; the average clothing thermal resistance value is set as 2.5clo, the indoor humidity is set as 47%, the indoor wind speed is set as 0.5m/s, and the indoor air change frequency is set as 0.5 times / h. Under the default conditions of weather tool, the human activity is set to sit still, the south WWR is set as 0.5 while the north is set to 0.27, the envelope insulation is set as medium, and the solar heating efficiency is set to high. The simulation results are shown in Figure 17.



（a）Temperature comparison chart of master bedroom



（b）Humidity comparison chart of master bedroom

Figure. 17 Comparison of temperature and humidity of master bedrooms before and after optimization

Thermal comfort will be greatly improved by adopting reasonable space division, excellent thermal performance of enclosure structure and proper solar passive heating. According to the reference, it can be seen that this actually forms the pattern of direct benefit solar house Kang room and additional sunshine room living room. After calculation, the average temperature of the first floor and second floor master bedroom reaches 11.0 ℃ and 11.2 ℃, respectively, which increases about 4 ℃ and 4.2 ℃ respectively, and the promotion effect is remarkable. The room comfortable temperature in winter varies from 18 ℃ to 28 ℃, and the above simulation results show that there is a certain gap between the above simulation results and the comfortable temperature. If passive solar heating is used and heat source is supplemented, such as considering the contribution of stove and Kang, it will be easier to reach a comfortable temperature range. According to reference [26], the relative humidity for indoor comfort is 30% to 70%, so the relative humidity is in the comfortable range.

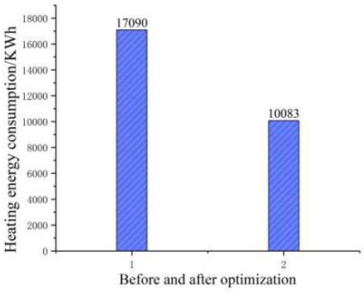


Figure. 18 Comparison of energy consumption before and after optimization

After applying all the methods in Table 4, the simulation results show that the energy consumption is reduced by about 41%, as shown in Figure 18.

Final Discussion

In order to explore the effect of the design scheme, the control variable method is used to compare the effect before and after improvement. According to the field test and questionnaire results, the passive design strategy is adopted, and the best factors are obtained from the passive design strategy of analysis, including space layout, enclosure structure, window wall ratio, sunshine room, ventilation, etc. according to the specification, it is known that the main problem in this area is the problem of heat preservation in winter, so the problem of ventilation in summer goes by without special discussion, Only the ventilation optimization measures are added to the passive design, taking into account the heat protection in summer. The above measures are to improve the comfort of the house on the premise of acceptable transformation willingness of residents. In the process of national new rural construction, the above scheme can provide reference and test.

Conclusion

The questionnaire results show that the residential space division is simple, the envelope structure performance is poor, the heating mode is single, the room thermal comfort can not meet people's requirements. The residents have strong desire for optimization.

Test field investigation results show that the solar radiation intensity is considerable in Guanzhong area in winter, and it has the conditions to develop solar passive heating. The results also reveal that building envelope is poor, its thermal storage performance is not satisfying. During test period, the indoor temperature is still far from the comfortable temperature range of rural residential living room in cold areas under the operation of heating furnace.

Based on the control variables, the energy consumption simulation gradually verifies that the strategies of multi space division mode, realizing the insulation of exterior wall and roof from scratch, changing single glass window to double glass window, adding Trombe wall type additional solar room can not only significantly reduce energy load but improve room temperature.

The final scheme is simulated by computer software, the data applied to the final scheme are presented in Table 4. The results suggest that the average temperature of the first floor and the second floor is increased by about 4 ℃ and 4.2 ℃ respectively. The energy consumption is reduced by about 41%. The simulation results fully verify that the thermal performance of the envelope and reasonable space division have positive effect. Combined with active heat source, it will be closer to the lower limit of the comfortable temperature range.

The simulation results can provide guidance in the energy-saving and comfort transformation of both existing and new buildings, that is, the comparison of the effects before and after the transformation can show that the passive design strategy plays an important role in reducing energy consumption and improving thermal comfort, specifically in optimizing the building layout, optimizing the envelope structure and optimizing the window wall ratio, adding the sunshine room to make rational use of solar energy resources. Future generations can also continue this method to simulate more working conditions, and apply the transformation strategy to specific buildings and obtain actual data when conditions permit.

Acknowledgements: This reaserch was founded by the NSFC (No. 52078419).

Author Contributions: Funding acquisition：Yiyun Zhu; Methodology：Yiyun Zhu and Guochen Sang; Investigation：Lu Liu; Software：Lu Liu and Xiaoling Cui; Writing – original draft：Lu Liu; Validation：Yiyun Zhu.

Conflicts of Interest: The author states that there is no conflict of interest.

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