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Simulation and Energy Analysis of Thermal Environment of Unassisted Passive Solar House

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Abstract

The greenhouse effect it the most basic work principle of the passive solar house The passive solar house provide indoor heating relying on natural circulation, without any other mechanical power, with the excess heat stored in the walls, ceilings and ground hot body to radiate heat into the room at night, to maintain a certain temperature. It takes in, keeps, stores and distributes solar thermal energy by reasonable arrangement of building orientation and surrounding environment, smart manipulation of the inner and outer space and the proper selection of the building materials, structure and construction, so as to solve the problem of building heating. The heat collection and storage of the passive solar house mainly uses the building envelop walls or windows or the simple tablet device as a heat collector, which can be freely controlled by people, without the complex mechanical equipment and complex pipe ventilation system. The test takes a residential building as example for energy consumption simulation and from the results; we can obtain the temperature distribution in each room and the distribution of the annual heating and coldness load. Study the effect on the room temperature and reducing heating energy consumption by the different ways of thermal insulation.

***Keywords**: Passive; Solar room; Temperature control; Thermal effect; Energy*

1. Environmental Analysis of the Solar Room

Currently, China's building energy consumption accounts for about 1/3 of the social total energy consumption. The energy consumption indicator of the current newly-built buildings have a considerable degree of improvement by adopting the energy consumption measures such as wall insulation and hollow glass windows, without affecting the room comfort. But to meet the requirements on the indicators of building energy consumption and heating coal consumption of o5 version of "Public Building Energy Efficiency Design Standard" and "Shaanxi Province Implementation Details of Civil Building Energy Consumption Design Standard" (In Xian area, the building coal consumption indicator is 9.7Kg/m2 and the heating consumption indicator is 20.2W/m2), the practical assessment measures are needed. The main factors affecting the thermal performance of body building are: the envelope structure, window and wall ratio and shape coefficient of the building. Due to the building complexity and the interaction of various energy consumptions, it is difficult to determine whether a design is energy-saving. Therefore, conducting the energy consumption assessment by computer simulation has become the easiest and feasible method.

The solar room is located at north latitude of $40^0 49$, east longitude of $111^0 41$`,elevation of 1041.lm, which is the heart of the Longnan city, where the annual average temperature is 5.7℃, with the average wind speed of 1.6m/s, annual sunshine hours of 2976h and the annual total radiation of $5.63xlo^6$KJ(m'.y.

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The weather conditions of the heating season (November, 2012-March, 2013), the monthly average temperature:

Table 1. Monthly Average Temperature

November	-0.1℃
December	-10.7℃
January	-12.4℃
February	-7.3℃
March	2.3℃

The day value in each month:

Table 2. Day Values in Each Month (Calculated with the Room Temperature of 18℃)

Month	Day value	Month	Dayvalue
11	543.2	12	865.2
1	941.1	2	710.1
3	486.6	Total:	3545.7

2. Solar House Energy Saving and Economic Analysis

The investment of the solar room directly affects the promotion and development future of the solar house. The economic analysis of the solar house can be divided into two aspects, one is how to increase the investment, which largely affects whether the solar house can be promoted and developed. If the solar house investment is much more expensive than the ordinary room, that means the solar room area should be reduced with the same investment. In this regard, the analysis should be conducted according to the actual area of the built solar room, if the solar investment is 8％-15％ more than the ordinary room, which can be accepted in rural areas. If the solar investment is over 15％ more than the ordinary room, it can only accepted by the residents with the government subsides.

The other is the calculation of number of years of new investment principal, namely the solar house investment is increased over the conventional house but it saves more energy and heating costs than the conventional house. The increased investment can be offset by the energy saving costs. The shorter the time is, the better the economic effectiveness is. According to the practical experience of the solar house construction, the payback period is generally 4-8 years, which is cost-effective compared to the general masonry structures with the service life of 50 years. The solar house should be design and built according to the regional natural climatic conditions, geographical situation, economic characteristics and other local conditions and based on learning from local traditional architectural essence, with the maximum use of the local building materials, making the cost increase within 25％, not only greatly improving indoor comfort, but also receiving good economic effectiveness.

3. Work Principle of Entity Wall Heat Collection Wall-type Solar House

The work principle of entity wall-type heat collection solar house: when there is sunshine during the day, the heat supplied to the indoor by the heat collection wall consists of convection heating Q_k and conduction heating Q_d. Part of the sunlight irradiated to the glass is reflected and another part is absorbed by the glass cap layer, with the majority irradiated to the wall surface through the glass. And the glass temperature will increase after absorbing the solar radiation, which will release heat to the air in the heat collection wall. The majority of solar radiation through the glass is absorbed by the entity wall surface coated with paint of high absorption coefficient, causing the wall surface temperature rises, which will release heat to the air in the lamination and also conduct heat to the indoor through the wall., with part of the heat stored in the wall and the heat transferred into the room is the conduction heating of the heat collection wall Qd. And the temperature of the air in the lamination rises after being heated, which will have natural circulation with the indoor air though the upper and lower vents, with the hot air continuously into the room through the upper vent to transfer heat into the room, which is the convection heating of the heat collection wall Qk.

The area of the heat collection wall is $1.9 \times 3 = 5.7m^2$. and if the vent accounts3% of the wall, then the area of the vent is $5.7 \times 0.03 \times 10^6 = 171000mm^2$, then the vent size can be defined as 420mm×420mm.

The convection heat of the hot air and the south wall surface contact surface can be calculated by the Newton’s law of cooling:

$$q_c = hA(T_3 - T_4)$$

Where, A — The convection heat transfer area of the south wall surface and the hot air;

T_3 — south wall surface temperature;

T_4 — hot air convection temperature

h — convective heat transfer coefficient.

According to the Nusselt number in the similar criterion:

$$Nu = hd / \lambda$$

The calculation formula of the convection heat coefficient can be got:

$$h = \lambda Nu / d$$

The Nusselt number of the south wall surface can be calculated by the following formula:

$$Nu = 0.068(Gr \cdot Pr)^{0.235}$$

The calculation formula of the Graham Akio number is:

$$Gr = \frac{g\beta d3\rho 3}{\mu 2}\Delta T$$

Where, G:— Graham Akio number;

B—fluid volume expansion coefficient;

ρ — fluid density;

$$\Delta T = T3 - T4$$

The calculation formula of the Prandtl number is:

$$\Pr = \frac{\mu Cp}{\lambda}$$

Where, Pr — Prandtl number

Cp — Specific heat

Table 3. Calculation of Insulated and Strong Heat, Taking this Area as an Example

Project time	Hour angel	Azimuth angle	Elevation angle	Direct radiating heat	Scattered radiating heat	Convection heat	Heat collection wall heat
8:00	86.6	-55.2	7.50	58.7	31.4	9.30	72.5
9:00	71.5	-41.3	13.6	114	39.8	10.8	96.7
10:00	56.6	-30.9	17.9	221	48.6	21.4	121
11:00	37.9	-17.4	19.9	259	61.5	27.5	137
12:00	19.1	-5.20	21.7	273	82.7	39.8	169

4. Design of the Solar House

4.1. The Floor Plan of the Solar House

In the passive solar house, the south wall is the main part for heat collection. The greater the area of it, the more solar energy will be obtained. Therefore, the shape of the solar house is preferable the rectangular along the east to west, without too much punch changes on the surface, in order to avoid unnecessary shadows. The length of the sloping roof over eaves should not affect the duration of sunshine, taking local housing construction standards. The interior room arrangement shall be determined according to the specific application. The main room, such as the owner's bedroom,, living room and the classrooms in the school, with high requirements on the comfort, should be arranged in the south and the rest auxiliary rooms, such as the kitchens, bathrooms and the hallways of classrooms, can be arranged in the south. As for the rural housing, the south position should be given to the mainly used rooms, such as the master's bedroom and the commonly used parlors. The north position should be arranged for the kitchen and storage spaces, which plays an indispensable role in rural housing, and in some places, it even be built in front of the main house to make it have good preservation effect. From the perspective of solar energy utilization, this practice is not encouraged. Because the storage room has no significant use functions, the individual set will not only blocks the main house, but also not conducive to the need of the residential uses for taking things at any time. Therefore, it is better to find a suitable location for it.

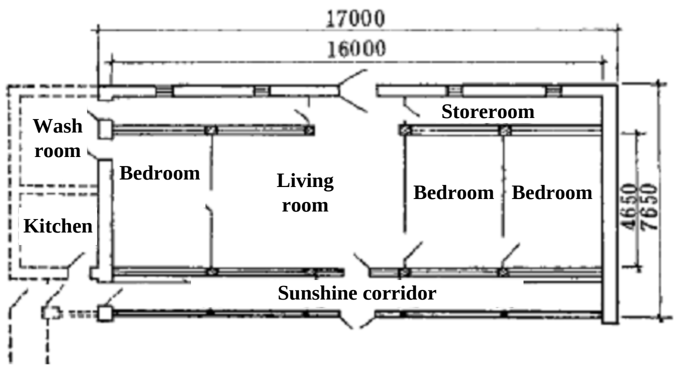

Figure 1. Passive Solar House Plan

4.2. Shape of the Building

The selection of the insulation materials can be determined according to the climate in different regions and the local materials. The appropriate insulation material plays an important role for increasing the wall insulation performance. Considering the construction operability, the final energy savings and the routine maintenance, the external insulation energy saving mode has obvious advantages. The common insulation technology used for the external wall can be divided into organic and inorganic types by major materials.

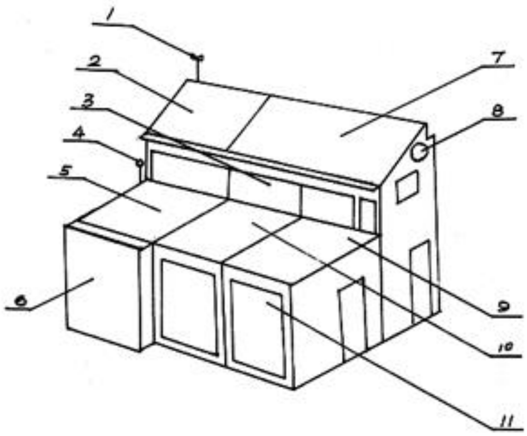

Figure 2. Architecture Model of Solar House

5. Architecture Model Building and Energy-saving Program

5.1. Architecture Model Parameter Settings:

The study object is a residential building in Xian, with the building standard floor area of 540 m^2 and the building layer height of 2.8m. Since DOE－2IN model has layer by layer and floor by floor input with the unit of floor, so after the building plan is simplified, the standard room floor configuration is shown in Figure 3.

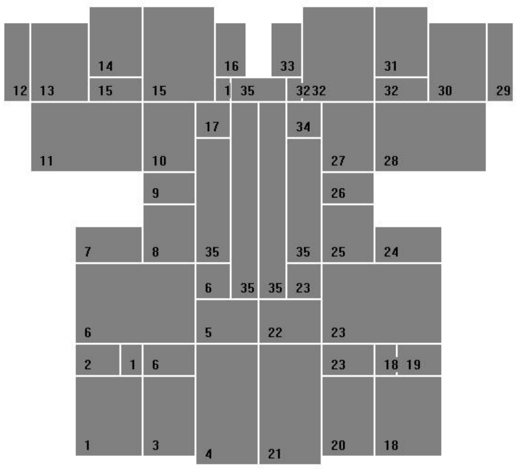

Figure 3. Standard Floor Slab Composition

The building envelope parameters are shown in Table 4.

Table 4. Building Envelop Parameters List

Building structure	Values
External wall	240 brick facades, extruded plate, 30 external insulation, the overall heat transfer coefficient 0.68W/m^2*K
External window	Plastic steel, 3mm, ordinary float glass, without external shading, the overall heat transfer coefficient: 2.6W/m^2*K
Room surface	Reinforced concrete roof plus insulation, the overall heat transfer coefficient : 0.79W/m^2*K
External door	Compound door, the heat transfer coefficient : 1.2W/m^2*K

5.2. Heating Air Conditioning System Parameter Setting

In the software, every room must belong to an air conditioning system. Generally speaking, a household should establish an air condition system, and the public spaces such as the stairways and corridors can belong to any system, so the public places can be set to the non-air conditioning space, and the load and energy of there rooms will not be calculated in the simulation calculation. For every air conditioning system, the heating EER is 1.9 and the cooling EER is 2.3 (hot summer and cold winter area energy saving standard) (considering the heating and cooling takes the electric heating and cooling heater and air conditioning).

For the air conditioning spaces, the setting of the indoor temperature is an important factor affecting energy consumption. The software develops two modes: weekdays and weekends, under which, the temperature of 24 hours a day is set, which is the setting basis for all the air conditioning rooms in the building, and then the energy consumption of each room can be calculated. In this simulation, the heating temperature is 18℃ between 7:00 and 22:00, and 12℃ in the rest time. The cooling temperature is 26℃ throughout the day.

The energy consumption value of the air conditioning room is affected by the building factors such as the indoor and outdoor temperature and envelop, with the indirect interference of the indoor occupant density, lighting time and equipment (such as computers) use frequency. Considering these factors without accurate calculation, the software gives description by the way of internal load intensity, namely the proportion of the heat radiation every hour of the internal load such as the occupant staff, lighting and equipment in the heat radiation throughout the day. The distribution of the internal load in every time phase throughout the day is shown in Figure 4.

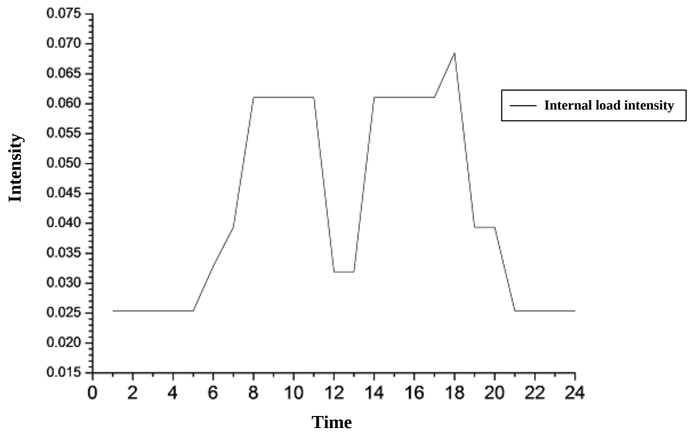

Figure 4. Internal Load Intensity

For the different building uses, the settings of the internal load intensity are different. This model takes into account the more use of the personnel and equipment use in the morning and the simultaneous operation of the personnel and lighting equipment in the evening, so it shows a bimodal distribution pattern on the curve.

6. Calculation Results and Analysis

6.1. Building Energy Consumption Indicators

The software obtained the hourly temperature distribution of each room throughout the year by dynamical calculation. Combined with the existing outdoor weather data, the energy consumption indicators of each month and the building total energy consumption in the whole year can be calculated, which can be taken as the strong basis for the evaluation of the building energy efficiency. If the building energy consumption exceeds the national standard, the designers can change some building factors in the model to meet the energy code requirements, without having to stick to the recommended standard values, so as to achieve the optimized combination of the building energy efficiency and the use of the rooms. The final results of this simulation are listed in Table 5.

Table 5. Building Energy Consumption Statistics

Month	*Cooling*		*Heating*	
	Cooling energy consumption MWH	Maximum cooling load KW	Heating energy consumption MWH	Maximum heating load KW
1	0	0	23.63	202.31
2	0	0	14.97	201.96
3	0	0	4.56	156.96
4	0	0	0	0
5	11.71	121.5	0	0
6	17.62	140.73	0	0
7	24.05	151.52	0	0
8	18.63	143.74	0	0

Month	*Cooling*		*Heating*	
	Cooling energy consumption MWH	Maximum cooling load KW	Heating energy consumption MWH	Maximum heating load KW
9	10.6	121.99	0	0
10	2.65	66.62	0.342	8.622
11	0	0	7.23	140.1
12	0	0	19.2	201.19
Total	85.21		69.92	
Max		151.52		202.19

Unit construction area cooling capacity: 27.85kWh/m^2
Unit construction area heating capacity: 22.85kWh/m^2

For the building energy consumption, the external walls and windows are the main factors. We can find the contribution to the building energy saving of the different insulation effects from the above modeling process and calculation results.

6.2. Effect of Changes in the External Walls to the Energy Consumption

The wall is the largest part of the building envelop. In the case without considering the heat storage capacity, the wall heat transfer coefficient is the decisive factor affecting energy consumption. This simulation re-calculates the energy consumption value after wall change and finds the contribution of the different insulation materials to the total energy consumption, as shown in Figure 5.

In the simulation, 240 brick walk is insulated by the wood fiber board and polystyrene board and the wall heat transfer coefficient is respectively is 1.57 W/m^2•K and 0.98 W/m^2•K, and the building energy consumption after change can be obtained by the simulation.

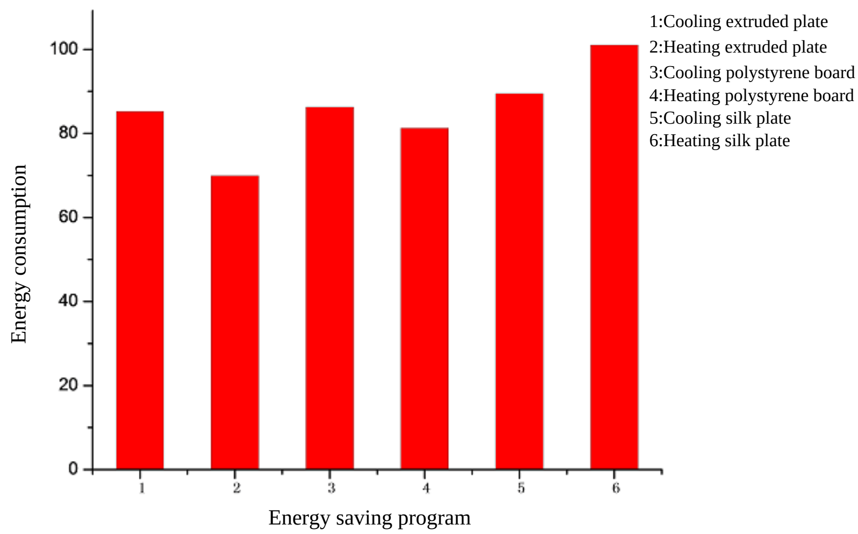

Figure 5. Annual Cooling and Heating Energy Consumption Values under Different Wall Insulation

As can be seen form Figure 3, the change of the insulation layer has little effect on the cooling load in summer, from 89.48 to 85.21, with limited energy saving. While the winter insulation layer significantly reduces the heating energy consumption, and then we can get the linear equation of the heating energy and wall heat transfer coefficient: y=4.9x+81.7. When the external wall heat transfer coefficient varies from 1.57 to 0.98, the heating load is reduced by 19.6％The difference of the energy consumption between heating and cooling relies on the difference of the heat transfer modes: winter heating is the steady heat transfer, with the indoor temperature higher than the outdoor temperature, so the relationship between the energy consumption value and the heat transfer coefficient is linear; while in the summer, in the sun radiation during the day, the envelope structure is heated up to transfer heat to the room, with heat radiation at night, namely the heat transfer of alternating direction day and night. Therefore, with respect to the heat transfer coefficient, the thermal storage properties of the wall are more important [5]. Because the simulation is set to 240 brick wall, the energy consumption values has little difference.

6.3. Effect of Changes in the External Windows to the Energy Consumption

Another important impact of the energy consumption is window heat transfer. With the increase of the building window and wall ratio, its importance in building energy consumption has constantly been studied [6]. For the hollow double-glass external window in this simulation, 3 comparison programs are set: ordinary plastic steel window, with the heat transfer coefficient of 4.7 W/m^2•K; hollow glass window of 6mm and ordinary float glass, with the heat transfer coefficient of 3.04 W/m^2•K; low radiation coated glass window, with the heat transfer coefficient of 2.06W/m^2•K. The changes of the cooling and heating energy consumption are compared.

The window heat transfer property is similar to the wall, with the large change of heat transfer coefficient in winter heating, fit to a linear relationship. The equation of the heating energy consumption and the window heat transfer coefficient is : y=7.4x+50.33, as shown in Figure 6.

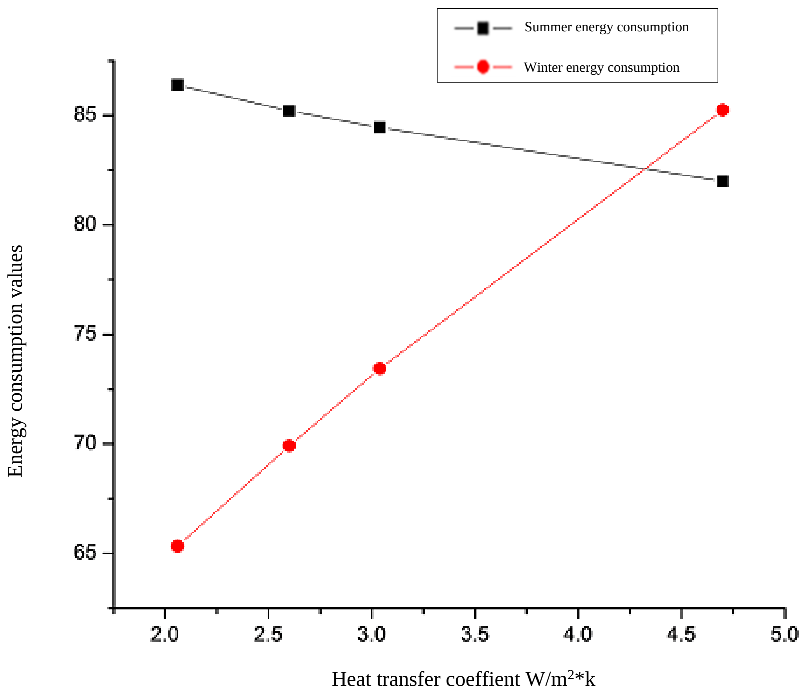

Figure 6. Relationship between Window Heat Transfer Coefficient and Energy Consumption

It is worth being noted that, in the figures, in the summer, with the window heat transfer coefficient increase, the energy consumption is reduced. Its change trends and heat transfer law are different, because of the sun shading coefficient difference of the different glasses, while in the summer, due to the strong solar radiation, the energy change law is difficult to be analyzed effectively just by the heat transfer coefficient. Comparison between window and external wall energy saving ratio: in winter, the reduction of the external wall and windows heat transfer coefficient is conducive to the building energy saving, but through the equation of the energy consumption and heat transfer coefficient of these, we can know that window heat transfer reduction is better for the reduction of the energy consumption. In the case that the heat transfer coefficient of the external wall and window is decrease by 20%, the energy consumption of the building in winter for heating is respectively reduced by 7.5% and 10%.

7. Summary

The promotion of the passive solar energy utilization technology needs the cooperation with the architects and owners, which can not be achieved just relying on either side. Currently, the main problem in the promotion of the passive solar house in China's rural area is the limited understanding of the passive technology, without understanding of the success stories in this aspect, causing the owners do not trust the architects, without as correct perception on the relationship between the investment and return., which has a negative impact on the passive solar house construction. In this case, strengthening the government's propaganda is very important, to deepen the concept of environmental protection in the thought of the people, taking energy saving as a premise, to raise the awareness of the disadvantaged of the existing residential houses and development space, which is the key to solving this problem. Only people are subjectively awareness of the necessity of passive technology, will it be possible to further promote the passive solar house in the countryside.

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