Ecological building design based on the optimization of thermal performance of stilt houses in Guangxi Province

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Abstract. Traditional stilt houses in Guangxi Province are ventilated and breathable in summer with good dehumidification and heat insulation performance. In winter, however, their airtightness and thermal insulation abilities are relatively poor. In order to analyze the advantages and disadvantages of the thermal performance of stilt houses in Guangxi Province, this study designs four ecological buildings: Building A is a traditional stilt house with a sloping roof and wooden fences; Building B is a reinforced concrete structured house with a flat roof; Building C is a reinforced concrete structured house with a sloping roof and surrounding self-insulating blocks; Building D has the same conditions as C, except its louvers. Through the Swire energy consumption simulation, we can obtain an ideal multi-layer ecological civil building with a thermal-insulation top layer that can be opened as well as louvers and self-insulating blocks used for the outer wall.

1. Introduction
The stilt houses with an elevated ground floor in Guangxi Province are well and flexibly arranged according to the local terrain. At present, they are mostly distributed in the mountainous areas of North Guangxi, Northwest Guangxi, and Northeast Guangxi, and are widely used by Zhuang, Dong, Yao, Miao, and Maonan nationalities. These houses have overhead bottoms that are conducive to drainage and heat insulation, high tops that are conducive to ventilation, and protruding eaves that act like sunshades and rain protectors. North Guangxi, including Guilin, Liuzhou, Hezhou and Hechi Cities (covering near half of Guangxi), is a region with cold winters and hot summers. Therefore, the house shall have good moisture transfer and heat insulation capabilities in summer and good heat preservation performance in winter. The stilt houses in North Guangxi can make full use of its own conditions to meet the requirements of shading, ventilation, moisture removal, and thermal performance in summer. However, they fail to perform well in winter in terms of cold defending, as shown in Figure 1.
Figure 1. Ventilation and thermal insulation effect of the existing traditional stilt houses in North Guangxi

How to reasonably use their advantage of heat insulation in summer to solve the shortcomings in winter, so that they can provide an indoor thermal environment that is warm in winter and cool in summer? This is a topic worth researching. To probe further, this study aims to develop a new type of ecological building model that is passively energy-saving and adapts to hot summers and cold winters by improving the thermal performance of traditional stilt houses in North Guangxi. At the same time, this paper explores low-tech energy-saving technologies suitable for residential buildings in North Guangxi, thereby opening a new path for the development of green ecological residential buildings in Guangxi. The structure can be applied to the reconstruction of existing residential buildings and new residential buildings in North Guangxi as well as the residential buildings in other part of China with hot summers and cold winters.

Thermal insulation of buildings is an important topic in the research related to energy conservation of buildings. Countries around the world have formulated policies, regulations and standards in terms of thermal performance. The United States began to incorporate the effective temperature index ET into the ASHRAE (American Society of Heating, Refrigerating, and Air conditioning Engineers) in 1967 to determine the range of indoor thermal comfort zones. Germany promulgated the Regulations on Thermal Protection of Buildings in 1976. In 2000, France proposed measures to improve the thermal performance of buildings. In 1972, Professor Fanger with the University of Science and Technology of Denmark established the thermal balance equation for the human body, based on which he proposed the thermal comfort theory and formed the evaluation indexes called “predicted mean vote (PMV)” and “predicted percentage of dissatisfaction (PPD)” for determining indoor thermal comfort zones. China has also promulgated the Energy-Saving Design Standards for Residential Buildings in Hot-Summer and Cold-Winter Areas and Calculation Rules for Thermal Performance of Building Doors, Windows, and Glass Curtain Walls (JGJ / T 151-2008). In 2017, Guangxi promulgated the Regulations on Energy Conservation of Civil Buildings in the Guangxi Zhuang Autonomous Region, which clearly stipulated the energy conservation of new and existing buildings and the promotion of green buildings.

Thermal performance analysis software is developed at home and abroad for conducting simulation tests and analysis of data and for optimizing the design of building thermal performance. Software commonly used abroad are the Optics, THERM, WINDOW developed by the US Lawrence Berkeley National Laboratory, Informind Ltd. by Switzerland, BISCO by the Belgium Physibel laboratory, and
ENVI-met by Germany, etc. In China, common software includes the MQMC developed by the Guangdong Academy of Building Research, the DeST developed by the Institute of Environment and Equipment, Department of Architectural Technology, Tsinghua University, and the PKPM developed by the Institute of Architectural Engineering Software, China Academy of Building Research.

Abroad, Giulio Allesina et al. analyzed a model of energy-saving renovation of building elevations in Easy to Implement Ventilated Sunspace for Energy Retrofit of Condominium Buildings with Balconies. Along the periphery of the balcony, there is the transparent plastic film that can be removed in the hot season to facilitate ventilation and installed in the cold season, thereby forming a greenhouse environment. In Assessing the Energy and Daylighting Impacts of Human Behavior with Window Shades, a Life-cycle Comparison of Manual and Automated Blinds written by Amir Nezamdoost et al., six different louver systems, including four manual ones and two automatic ones are designed. Through data analysis, it is found that the energy saving effect of the four manual louver systems and the two automatic ones are similar, and sometimes the manual ones are even more effective. In the article titled Comparative Investigation on Building Energy Performance of Double Skin Facade (DSF) with Interior or Exterior Slat Blinds, Dongsu Kim studied the energy consumption of three louvered building models (with external louvers, internal louvers and no louvers). EnergyPlus simulation analysis shows that the external louvers of the building contribute more to reducing the heat load and lighting energy consumption. Therefore, the energy saving effect of the outer shade is better than the inner shade. He et al. introduced a porous sunshade with a water spray device in the article named Development of a Sunshade Device with Evaporative Cooling. The louvers made of porous materials can absorb the sprayed water in summer to effectively reduce their own temperature so as to achieve a good shading effect.

In China, Sun et al. used CFD software to conduct a ventilation simulation study on Houba Township of Qianjiang River in Simulation Study on the Summer Monsoon Environment and Summer Thermal Environment of Typical Tujia Settlement in Southeast Chongqing, pointing out the overhead bottom, ventilated attic, and eaves are helpful for natural ventilation, dehumidification and cooling. Wu et al. conducted an on-site test of the indoor thermal environment of the Miao people's stilt houses in Taijiang, Guizhou in winter in the article named Survey of Indoor Thermal Comfort in Residential Buildings of Miao People's Stilt Houses in Guizhou, pointing out the advantages and disadvantages of stilted houses compared to common farm houses. The advantage is that the relatively open peripheral structure increases the number of air changes, leading to lower indoor humidity and pollutant concentration than ordinary farm houses. The disadvantages lie in the thermal insulation, heat preservation and airtightness, leading to lower average indoor temperature in winter and the need for intermittent fire heating. Xue et al. used Design-Builder software to model the internal thermal environment of the building and the indoor temperature throughout the year in Study on the Thermal Comfort of Stilt Houses in Longsheng District, Guilin, Guangxi Province, and calculated the annual thermal comfort index inside the building. Through comparison, it is concluded that the internal thermal environment and thermal comfort index of the stilt building are significantly better than those of ordinary residential buildings. Although the accuracy of the conclusion about the thermal comfort of the stilt house in winter requires further research, it is a consensus that modern buildings can learn from the traditional stilt houses in Guangxi in terms of thermal comfort.

In summary, there are many studies on energy-saving technologies for buildings at home and abroad, such as the analysis on how to use a closed balcony to form a greenhouse to achieve the insulation effect in the cold season, the analysis on the energy-saving effects of internal and external shading, manual and automatic shading, etc., providing some energy saving models for reference. Although China has conducted research and practice on the thermal performance of stilt buildings in many areas, we lag behind in terms of the research on the thermal performance of stilt buildings in Guangxi Province. In addition, the analysis of the ventilation performance in summer and the insulation performance in winter of stilt buildings in North Guangxi is not deep enough. Their comparative advantages that are worth popularizing and applying as well as the disadvantage in need of specific analysis. Therefore, it is particularly necessary and urgent to conduct analysis in this
respect and apply the results to modern residential buildings in Guangxi Province so as to develop low-technical-requirement and low-cost passive green building energy-saving technologies that adapt to the local climate.

2. Thermal performance analysis of traditional stilt buildings in Guangxi

The traditional stilt houses in Guangxi are known as "breathable building" as they are cool indoor without an air conditioner in summer. How do the stilt houses use their own conditions to achieve the requirements of shading, ventilation and moisture removal? The causes are analyzed through its plane, facade and profile as follows.

2.1. Plane analysis of traditional stilt houses in Guangxi

The buildings are mostly three-story with an overhead bottom floor for raising livestock and stocking tools. The second floor is the main function space, which is equipped with a central room, a fireplace, a kitchen, a dining room, bedrooms and a utility room. The third floor is used for stacking cereals and sundries as well as some bedrooms usually for the young when there are many children in the family. From the layout of the second floor, it is found through on-site surveying and mapping that the second floor is conducive to ventilation.

The flat layout centered on the semi-open central room is conducive to cross ventilation. The North Guangxi region is located at the junction of Guangxi, Hunan and Guizhou. The climate is cold in winter and hot in summer. In order to adapt to the hot summer, most stilt houses in this area have semi-open central rooms, which is arranged in the center of the room, with one side open, forming a plane integrating the central room and the balcony. It is ventilated, airy, spacious and comfortable, and can adapt well to the sultry summer climate. The central room, as the most important functional space in the house, is also used for meeting guests, family gatherings, children playing, manual labor, etc. Along the central room, there is a kitchen, bedrooms and a utility room, as shown in Figure 2. This kind of layout centered on the semi-open hall can help with cross ventilation.

![Figure 2. Plane layout centered on a semi-open central room](image)

2.2. Facade analysis of traditional stilt houses in Guangxi

The overhead ground floor, the balcony and the windows form a ventilation system. The elevated ground floor, the balcony, and the walls closed by wooden boards provide a beauty of shadows and many other important functions. For example, the overhead bottom floor can remove the humidity and
keep the second floor dry. The balconies connected to the open hall are made into a whole row of long balconies. The eaves on the upper part of the balconies can protect the house from the sun and rain, and the balcony is good for ventilation. The triangular roof truss at the junction of the top of the gable and the eaves is pierced, forming a high ceiling window for ventilation, as shown in Figure 3. The exposed roof trusses also show the building structure clearly.

![Figure 3. The facade of the building](image)

**2.3. Profile analysis of traditional stilt houses in Guangxi**

The cavity formed by the patio and top-level storage space, which is conducive to lighting and ventilation, as shown in Figure 4. This profile uses the chimney effect to form convection throughout the house. The open windows at the top take away the hot air gathered at the top of the house, and the fresh cold air outdoor flow in through the windows and balcony, as shown in Figure 4. The cool and comfortable stilt houses in northern Guangxi in summer shall owe to the perfect indoor ventilation system of the building. This is also a passive energy-saving method worth learning and promoting.

![Figure 4. Profile of building with chimney effect](image)

Through the above analysis, the main reason for good ventilation in stilt houses in North Guangxi in summer are:

2.3.1. The plane layout centered on the semi-open central room helps to form cross ventilation;

2.3.2. The overhead ground floor, the balcony and the windows form a ventilation system;

2.3.3. The cavity formed by the patio above the central room and the storage space on the top floor helps with ventilation by taking advantage of the chimney effect.

**2.4. Thermal performance analysis of traditional stilt buildings in Guangxi in winter**

Although traditional stilt houses in Guangxi are good at ventilation in summer, they are not good at insulation in winter. According to on-site surveying and mapping, the traditional stilt houses in Guangxi are wet and cold in winter indoors, and need to be heated with fire facilities. The main causes are as follows:
2.4.1. The outer walls of traditional stilt houses in Guangxi are mostly surrounded by wooden slats, and the cold monsoon will take a lot of indoor heat through the gaps between the slats;

2.4.2. The gable windows on the top floor are open all year round, or poorly closed only with wooden strips. In winter, the wind will take away a lot of hot air indoor, therefore delivering a poor insulation effect.

Based on the analysis, this paper makes two countermeasures:

- Self-insulation masonry is adopted for the outer wall.
- A manually adjustable louver system is added to the top gable windows.

The scheme based on the optimized thermal performance of traditional stilt residential houses in Guangxi is shown in Figure 5.

![Figure 5. Optimization plan of the thermal insulation performance of the traditional stilt houses in North Guangxi](image)

3. Analysis of thermal performance of four residential buildings

This paper takes a single residential building in Nongtuan Village of Sanjiang Dong Autonomous Region in Guangxi as an example for analysis. The building covers an area of 136 m². The land is flat and the surrounding environment is beautiful. The base has a village-level highway in the south, a scenic mountain forest in the north, a small stream in the east, and a 3-storey house in the west. The surrounding environment of the building is shown in Figure 6, and the red dotted frame is the research object. Four types of buildings are designed, namely, Building A (a traditional stilt house with insulation in Guangxi), Building B (a modern new rural house without insulation in Guangxi), Building C (a new residential house with insulation but without an adjustable louver system), and Building D (a new residential house with insulation and an adjustable louver system).
3.1. Four architectural designs

3.1.1. Plane and facade drawings of four buildings. The plane and facade views of the four buildings are designed according to the on-site data, as shown in Figure 7.

3.1.2. Calculation of indoor ventilation. The population in each house is taken as 5 persons. According to the per capita living area, the minimum ventilation per hour = 0.5, so the minimum ventilation for buildings B, C, and D is 0.5. Since there is an unclosed opening on the top floor of Building A, the ventilation is taken as 5 with the prevailing wind direction and building orientation taken into consideration.

Based on the formula \( n = \frac{Q}{V} \), we can get \( Q = nV \).

In the formula: \( n \) is the frequency of ventilation (unit: times/h); \( Q \) is the ventilation volume (unit: \( m^3/h \)); \( V \) is the room volume (unit: \( m^3 \)).

Based on the plane, facade, and profile of the four buildings, the author calculates their respective ventilation rates:

- **Building A**: According to the drawing, \( VA = 1341.94 \ m^3 \), \( QA = nVA = 5 \times 1341.94 = 6709.70 \ m^3/h \).
- **Building B**: According to the drawing, \( VB = 1243.87 \ m^3 \), \( QB = nVB = 0.5 \times 1243.87 = 621.94 \ m^3/h \).
- **Building C**: According to the drawing, \( VC = 1581.33 \ m^3 \), \( QC = nVC = 0.5 \times 1581.33 = 790.67 \ m^3/h \).
- **Building D**: According to the drawing, \(VD = 1581.33 \ m^3 \), \( QD = nVD = 0.5 \times 1581.33 = 790.67 \ m^3/h \).

3.1.3. Heating and cooling conditions. In order to compare the energy consumption of heating and cooling in Buildings A, B, C, and D under the same conditions, it is necessary to use room air conditioners with the same energy consumption in all the four buildings. Building D has louvers. In order to obtain the maximum natural wind in summer, the opening angle of the louvers is designed to
be 90° (maximum); in winter, the opening angle of the louvers is designed to be 0° (minimum) to form a greenhouse space for insulation.

3.2. Thermal performance analysis of four buildings
For the above four buildings, Swire software is used for energy consumption stimulation.

3.2.1. Test results. Based on the plane and elevation of four buildings in Figures 7, the author establishes a three-dimensional model, as shown in Figure 8.

The year-round load of the four buildings is shown in Figure 9.

The annual energy consumption based on computer simulation analysis is shown in Table 1.

|             | Cooling Power Consumption | Heating Power Consumption | Total Building Energy Consumption |
|-------------|---------------------------|---------------------------|----------------------------------|
| Building A  | kWh/m²                    | 16.77                     | 3.90                             | 40.28                           |
| Building B  | kWh/m²                    | 27.35                     | 2.66                             | 45.21                           |
| Building C  | kWh/m²                    | 15.83                     | 1.44                             | 27.95                           |
| Building D  | kWh/m²                    | 11.87                     | 3.75                             | 26.30                           |

3.2.2. Analysis of test results. Through the data analysis, the annual cooling energy consumption of the four buildings is ranked as: Building D (best), Building C, Building A, Building B. The heating energy consumption of the whole year is ranked as: Building C (best), Building B, Building D, Building A. The total energy consumption of the buildings throughout the year is ranked as: Building D (best), Building C, Building A, Building B.

It can be seen that the cooling energy consumption and the total energy consumption of Buildings A, C, and Building D with insulation layers are significantly better than those of buildings B without insulation layers. Surprisingly, though Building B without insulation is inferior to Building C with insulation, it is better than Buildings A and D with insulation. Based on this, the electricity consumption of building heating is related to the construction materials and louver settings.
Figure 7. Plane and elevation views of four buildings
Figure 8. Swire three-dimensional model of four buildings
4. Conclusion

Based on the design of four energy consumption models and comparison analysis of energy consumption simulation, this paper draws the following conclusions:

4.1.1. Based on the comparative analysis of Buildings A, C, D and B, the energy consumption of buildings with heat insulation layer is significantly better than that of buildings without heat insulation layer.

4.1.2. Based on the comparison analysis of Building A and Buildings B, C, and D, it is found that the energy consumption of buildings with traditional wooden surroundings is significantly inferior to that of reinforced concrete buildings with thermal insulation exterior walls, but is slightly better than reinforced concrete building with thermal insulation exterior walls.

4.1.3. Based on the comparison and analysis of Buildings C and D with Buildings A and B, it is found that the energy consumption of buildings with thermal insulation exterior walls is significantly better than that of wooden or reinforced concrete buildings without thermal insulation exterior walls.

4.1.4. Based on the comparison and analysis of Building D and Building C, it is found that the energy consumption of buildings with louvers is slightly better than buildings without louvers and that the energy consumption is closely related to the location, orientation and opening angle of louvers.

In summary, an ideal multi-layer ecological civil building is featured with:

- A thermal insulation top layer.
- An insulation layer at the top with louvers. The recommended opening angle of louvers in winter is 0º, and that in summer blinds is 90º.
- Self-insulation blocks are adopted for the outer wall.

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