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Low energy characteristics and low carbon strategies for traditional timber framing in the full life cycle -The case studying on Tujia hanging foot in southwest Hubei

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Abstract: The issue of carbon emissions has attracted a great deal of attention in recent years, both at home and abroad. There are also more and more people engaged in related research. In the field of architecture, more people are starting to look at the whole life cycle of buildings to explore energy saving and emission reduction of buildings. It is not just about exploring how to reduce the energy consumption of a building during its use. This paper will analyze the advantages of traditional wooden buildings and modern buildings in terms of low carbon from five perspectives: material selection, transportation, construction, use, transportation and demolition, and summarize the related strategies from a whole life cycle analysis of buildings.

Keywords: Traditional wooden building; Whole building life cycle; Carbon emission.

1. Research Background

The greenhouse effect poses a serious threat to global climate change and human survival and development, with data showing that atmospheric carbon concentrations have risen dramatically over the past 100 years, with global temperatures rising by an average of 0.9 degrees Celsius between 1910 and 2005, and by 60% of the total after 1970. In the Third National Assessment Report on Climate Change published in China, it is mentioned that the rate of warming in the China is higher than the world average, in addition to the fact that in the more than 30 years since 1980, the coastal sea level rise in the country was 2.9mm/year, again higher than the global average. The warming has brought about an increasing number of extreme weather events such as heavy rainfall and flooding, in addition to the abnormally high summer temperatures that have become commonplace in recent years. This poses a major threat to the health, lives and property of our people.

As a responsible power, our country is highly concerned about the climate issue. In recent years, China has made a series of measures to solve the climate problem, such as vigorous development of new energy sources and afforestation. On 22 September 2020, President Xi Jinping solemnly announced at the 75th session of the United Nations General Assembly that "China's carbon dioxide emissions will strive to reach a peak by 2030 and work towards achieving carbon neutrality by 2060". In terms of time course, it is currently 40 years until the strategic goal of carbon neutrality is achieved.

The growth in carbon emissions from buildings has been one of the main sources of carbon emissions growth in China. During the period 2000-2015, China's building energy consumption increased from 264 million tons of standard coal to 868 million standard coal, an annual increase of about 7.39%.

According to the 2018 China Building Energy Consumption Report. It is shown that 46.5% of China's carbon emissions are generated throughout the life cycle of buildings. Among them, urban buildings are the most important source of carbon emissions. Urban buildings account for 45% of the country's building area and 42% of the country's carbon emissions; public buildings account for 19% of the country's building area and 37% of the country's carbon emissions; rural residential buildings account for 36% of the country's building area, but their carbon emissions are only 21% of the country's carbon emissions.

This shows that rural buildings have a much smaller carbon footprint than urban buildings and public buildings in terms of the ratio of carbon emissions to floor space. Therefore, we can start with rural buildings and seek ways and strategies to reduce energy consumption in comparison to urban buildings.

In the construction of rural residences, the ability of the rural settlement to adapt to the climate determines the energy use needs of the locals, and thus whether the entire rural settlement is low carbon. Villages that are climate-resilient can make effective use of their local environment to create a healthy and comfortable microclimate through passive energy efficiency, thus making the whole village appear low carbon.

According to the American architect Amos Rapoport, elements such as climatic technological materials in traditional settlements have an important influence on spatial form; in the UK Ronald Brun skill argues that vernacular buildings and settlements are often designed and built by lay people, using predominantly local materials and incorporating local environmental features and customs. As a result, rural traditional villages are generally more resilient to climate and tend to exhibit low-carbon characteristics as well. Yang Weitong studied the whole life cycle of rural houses in Luonan and proposed low-carbon optimization strategies for rural houses. A study by Liu Jianhao et al. found that traditional settlement landscapes in the southwest are characterised by low-carbon nature. .

To sum up, this paper will analyse the energy consumption of traditional buildings in southwest Hubei throughout their life cycle, and compare it with modern cities, using tradition as a mirror to explore the possibilities of future building energy efficiency.

2. Introduction to the Traditional Wooden Architecture of the Tujia Family in southwest Hubei

Enshi Tujia Autonomous Prefecture is located in the southwest of E, at the intersection of E, Xiang and Chongqing provinces. The living environment of Tujia is relatively diverse. The typical dwelling rings of the Tujia range in height from 400 to 1700 metres, with Tujia living at different altitudes, and the topography of these places is very rich, resulting in a very rich dwelling culture.

The Hanging foot buildings is a common form of traditional Tujia architecture. It is also a living space built by the Tujia people in an environment adapted to natural conditions. It has also gradually become a cultural symbol.

Hanging foot buildings are dry-pen buildings, divided into upper and lower floors, with the upper floor housing people and the lower floor keeping livestock. Among the surviving forms of hanging foot buildings in the Tujia family, the three most common are the one-shaped house, the key-head and the Sanhe water. In front of the building there is a field dam, a space similar to a traditional courtyard, but which is not enclosed by stone walls.

In the Tujia family, there are three main forms of typical hanging houses, and in any village, these three house types, when combined slightly and varied according to the topography, become a very richly staggered façade, and then turn again with the topography to create an even richer village landscape, with architectural sequences staggered throughout the façade, full of the interest of the mountainous countryside.

3. Research Methodology

The method of this study is the life cycle evaluation method. This method considers multiple factors based on the full life cycle of a product. Due to the complexity of its environmental impact mechanisms, this method cannot provide an absolutely accurate assessment. However, its results can be used as a reference for later work.

The whole life cycle of a building can be divided into 5 parts, namely 1. material production 2. material transportation 3. building construction 4. building operation and maintenance 5. demolition and waste disposal.

4. Whole life cycle energy characteristics of traditional buildings - comparison with modern buildings

4.1. Material production

Among the traditional residential buildings in southwest Hubei, wooden structures are the most common type of structure. According to a study released by the China Association of Building Energy Conservation in 2018, the total energy consumption of the whole building process in the country was 2.147 billion tce, accounting for 46.5% of the total national energy consumption. The energy consumption of the production phase of building materials was 1.1 billion tce, consuming 51.3% of the building's total life-cycle energy consumption, again a proportion of 23.8% of the total national energy consumption. The three building materials with the highest carbon emissions are steel, aluminium and cement.

In terms of energy saving and emission reduction, wood has a unique advantage. Yan Pengfei's research shows that the carbon emissions of processing 1m^3 of wood is 73.9kg CO_2. However, wood is a renewable resource. During the growth of wood, it will absorb CO_2 through photosynthesis, synthesize cellulose and lignin and fix CO_2 in the trunk of the tree. Therefore, zero carbon or even carbon sequestration can be achieved by scientific planning to achieve a balance between felling and planting to ensure that trees have enough growth time to solidify a certain amount of CO_2. Modern timber and its products used in construction can have a lifespan of 35 years or more, which is sufficient for the breeding of trees. Therefore, wood can be considered as an environmentally contributing material. On this basis it can be deduced that 1m^3 of wood with a density of 0.5g/cm3 can store 250kg/m3 of carbon and fix 916.7kg/m3 of CO_2 in the air, thus emitting negative 842.8kg of CO_2 per cubic metre of dimensioned timber. 352kg, which is a far cry from the negative 842.8kg of wood. Wood is therefore the perfect building material when it comes to reducing carbon emissions.

4.2. Material transport

In the traditional architecture of the Enshu Tujia, materials are generally sourced locally and do not have to be transported over long distances. Modern buildings, on the other hand, are divided within cities and between cities, resulting in building materials generally needing to be transported long distances to the construction site. During this process of transportation, significant carbon emissions are generated. The Ministry of Transport of the People's Republic of China published a statistical bulletin on the development of the transport industry in 2021, in which there are five main modes of transport in China, namely railway transport, road transport, water transport and civil aviation. The annual CO_2 emissions from rail transport are estimated to be 3.32 million tons of CO_2 and road transport is estimated to be 72 million tons of CO_2.

The advantages of traditional timber framing in relation to high transport costs and large carbon emissions are demonstrated by the fact that the materials are sourced locally. In traditional buildings, the materials are often wood from nearby hills. This reduces a great deal of the large carbon emissions that arise from transportation. Therefore, the traditional houses in southwest Hubei can reduce a large amount of carbon emissions during the stage of material transportation.

4.3. Building construction

The traditional dwellings in southwest Hubei are often located in the middle of mountainous terrain, and uneven and elevated sites are a frequent problem for Tujia villagers in building.

When faced with the problem of height differences, modern thinking is more about levelling them, which is the first step in construction. The operation of construction machinery during the levelling stage will generate significant carbon emissions.

The Tujia in southwest Hubei have long lived in a mountainous environment and have a respect for nature. Therefore, when faced with the complex and changing mountainous terrain, the way to build is often to build on the hills and use timber for the hanging foot building. This is the way to deal with the complexity of the mountainous terrain and the differences in height. This is a more energy-efficient and low-carbon approach than the modern way of levelling height differences.

In terms of building construction, the traditional wooden structures of the Tujia are often constructed using human labor. This act has gradually become a culture in itself. For example, when building the main beams of a house, there is a series of customs such as singing a song about the beams.

Traditional manual construction methods are less efficient and more limited than mechanized construction. However, the accumulation of thousands of years of building can also be mentioned for its exquisite skills. Particularly in the fine details of the building, such as the column bases, stone cliffs and thresholds, there will be exquisite carvings. Moreover, the entire material is carefully designed in terms of its proportional relationship and the richness of its craftsmanship. This was something that would not have been imagined in the days of mechanization. In modern architecture, bespoke components are sometimes much more expensive and resource intensive than modelled builds.

4.4. Building Operations and Maintenance

4.4.1. Ventilation and energy saving in summer

After the house has been built, it enters the operation and maintenance phase of the house. During the O&M phase, the house accounts for 46.6% of the total carbon emissions. It is also the phase with the highest carbon emissions apart from the production of materials.

During the operation and maintenance phase, the carbon emissions of the house are mainly in the form of daily production and living. In today's modern world, there is not much difference between traditional timber frame houses and town houses. However, the unique spatial layout of traditional timber frame buildings gives them a unique advantage in terms of reducing carbon emissions.

In a related wind simulation study, it was verified that the traditional wooden structure of the Tujia family is scientific in terms of ventilation and cooling from the settlement layout to the building layout. Such a spatial layout can be effective in reducing the indoor temperature in summer and the grey space is also pleasant to the eye. [11-12]

Tujia settlements are generally built on hills, with buildings arranged along contours and in a staggered pattern. This arrangement is not only elegant, but also brings effective energy exchange. In this arrangement, the ridge of the front row of buildings is generally close to the height of the eaves of the back row. In this case, the rear building is not in the wind shadow of the front building. On the contrary, when the height of the front and rear ridge is similar, the rear building within 3.75 times the height of the front building will be in the wind shadow area of the front building of the building, not subject to direct incoming wind and poor ventilation.

In terms of building plan, traditional wooden buildings of the Tujia often give way to field dams through the typical handful of openings in order to resist the humidity of the mountain climate. And in the traditional wooden buildings of the Tujia, whether it is Sanhe water or a key head, the sign is usually not directly connected to the dwelling and an alleyway is left empty. The field dam and the alleyway are not only places for the Tujia to dry their crops and rest and relax. They are also a key factor in influencing the indoor environment. The role of the field dam in ventilation is to organize the ventilation so that the wind from outside flows along the walls, creating a swirling zone of minimum wind speed in the center of the field dam, while the grey space under the eaves and the alleyway will have a better initial wind speed. In another case, the venturi effect is created when the wind blows from the open area into the alleyway and causes air to be constantly sucked out of the field dam by the alleyway as well. In its simulation, the alleyway space between the main house and the thousand sons has a constant incoming phoenix of 1.17 to 1.26m/s. Wind also flows along the walls in the field dam. Therefore, the gable space of the hammock is relatively comfortable in summer.

In contrast, the huge electricity consumption brought by summer cooling. Take Hubei as an example, according to the data, on the day of July 29, 2019, the electricity load in Hubei province was 36.703 million kilowatts, of which the air-conditioning cooling load reached 15 million kilowatts, accounting for more than 42% of the whole grid load. This shows that the arrangement of traditional wooden buildings of the Tujia family has great advantages in cooling and creating comfortable spaces in summer that other buildings cannot compare.

4.4.2. Front field and back yard, work and live together

The production factor is an important consideration in the layout of traditional Tujia timber buildings. For this reason, the traditional wooden buildings of the Tujia family are often spatially located in front of fields and behind courtyards. The close proximity of the fields to the houses allows the inhabitants to engage in productive work in a convenient manner.

Figure 1. The front field and back yard of the Hanging Foot House （Photo source: Li Xiao）

However, in modern urban life, an intensive and productive lifestyle inevitably generates commuting times. To make matters worse, commuting distances increase due to a number of factors such as housing prices, and with this comes an inevitable increase in the carbon emissions generated by commuting. In a study by Tong Anti-Resistance and Mark Ming, the length of commuting distance has a significant impact on personal transport carbon emissions, with a 21% reduction in commuting distance leading to a 28% reduction in annual transport carbon emissions, and a 56% reduction in commuting distance leading to a 53% reduction in annual transport carbon emissions

The spatial integration of production and living can therefore be effective in reducing carbon emissions from personal transport. In urban living, there are more constraints. Traditional settlements do not have many constraints and can choose the optimal way to arrange the settlement space.

4.4.3. Backward energy structure

As most of the traditional wooden buildings of the Tujia are located in mountainous areas, they are often affected by humidity and mosquitoes. And in winter, when the climate is cold, corresponding heating measures are also required.

In traditional Tujia timber-framed buildings, the tang huts will have high storeys in order to allow more sunlight in as a way of removing damp and heating the interior. Another method is by means of fire pits and fire houses. Fire pits are also called fire pits. The fire pit is a unique and functional local space, located on the side of the hall, usually a small room with a fire pit in the centre, while wealthy families make it into a bunk, which becomes a fire shop. It is generally used for heating and to remove dampness. On top of it simmered soup and smoked meat, and the smoke would smother the house with a layer of oil, thus acting as a moth-proof barrier.

However, this means that a large amount of fuel needs to be used. In traditional Tujia settlements, firewood is generally used to obtain energy. This is relatively inefficient and emits large amounts of carbon.

To address this problem, the state has vigorously promoted biogas projects. According to the research results of Xu Wanying, Zhou Chuanbin, Chen Yonggen and Wang Rusong , biogas digesters have been vigorously promoted in Enshi since 2000 and have brought immediate emission reduction results. Between 2000 and 2010, the total carbon emission reduction benefit in Enshi was 5,192,600 tons CO_2. As the biogas project progressed, the emission reduction benefits increased year on year. Among them, in 2010, the emission reduction benefit of Enshu was 709,300 tons CO_2/a. The biogas project has not only effectively treated the manure produced in agriculture, but also reduced the amount of firewood burned, saving a total of 525hm2 of forest.

4.5. Dismantling and waste disposal

Traditional wooden buildings can last for hundreds of years in normal conditions. Among the traditional villages in Enshi are many hanging foot buildings from the Qing Dynasty. The greatest advantage of traditional wooden buildings over modern concrete buildings is that they can be replaced when they break down and can be disassembled and assembled off-site.

For demolished traditional timber-frame buildings, the wood can be further processed. Even if they cannot be used, they can be degraded in landfills. The disposal of wood is much less energy intensive and carbon-intensive than with other materials.

5. Conclusion

In the whole life cycle of the building, the low-carbon strategies of traditional wood frame buildings of the Tujia compared with modern buildings include: 1. choosing carbon-fixing wood as the building structure in the material selection stage; 2. taking local materials in the transportation stage to reduce the transportation distance; 3. conforming to the topography and reducing earthwork in the construction stage; 4. maximizing the use of natural conditions through reasonable design in the operation and maintenance stage to meet the building's 5. reduce the spatial distance between production and life, and reduce unnecessary transportation carbon emissions. 6. emphasize the reuse and harmless treatment of construction waste in the demolition stage.

In the current environment, technology is developing at a rapid pace, but the problems that arise from this development cannot be solved in a mature and appropriate way, such as carbon emissions. Large amounts of carbon emissions are not only accelerating the global greenhouse effect, but are also a trigger for extreme weather. China and the world have made great efforts to control carbon emissions, such as new energy projects, China's Three Northern Protected Forests and other projects. We believe that in the near future, people will completely solve the problem of carbon emissions at the source, through changes in the energy mix. But until then, we need to find ways to deal with the problems that arise today. These strategies are valuable lessons that we can learn from our future building design and construction, and are also the precious legacy of our ancestors.

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References

[1] Webster M D, Meryman H, Kestner D M. Carbon emissions and building structure: what the structural engineer needs to know about carbon in the 21st century[C]//Structures Congress 2011. 2011: 472-482.

[2] He J, Yue Q, Li Y, et al. Driving force analysis of carbon emissions in China’s building industry: 2000–2015[J]. Sustainable Cities and Society, 2020, 60: 102268.

[3] China Building Energy Consumption Research Report 2020[J]. Building Energy Efficiency (Chinese and English), 2021, 49 (02) : 1-6.

[4] [USA] (1969) Rapputt, Amos. The Shape and Culture of the House. Beijing: China Architecture Industry Press, 2007:45-48.

[5] Brunskill, R. W. (1978). Illustrated handbook of vernacular architecture.

[6] Yang Weitong. Research on Low Carbon Design of rural Residential buildings in Luonan Based on the Whole Life Cycle [D]. Xi 'an University of Architecture and Technology, 2020.DOI:10.27393/d.cnki.gxazu.2020.001281.

[7] Liu Jian-hao, YU Yi-fang. Low-carbon landscape in traditional rural settlements in Southwest China [J]. Chinese garden, 2010,26(10):84-86.

[8] Wang Changbo, Zhang Xiaoxiao, Pang Mingyue. A Review of the Research on Life Cycle Evaluation Methods -- and the development and application of hybrid life cycle evaluation [J]. Journal of Natural Resources, 2015,30(07):1232-1242.

[9] Yan P F, Yang Jun. An improved method of environmental impact assessment and its application [J]. Environment and sustainable development.,2007(05): 10-12.DOI:10.19758 / j.cnki.issn1673-288x.2007.05.004.

[10] Yang Qianmiao. Quantitative evaluation of the environmental impact of construction products in their whole life cycle [D]. Tianjin University, 2009.

[11] Sun Y, Li X W. Simulation of summer monsoon environment and summer thermal environment of stilted houses in typical Tujia settlements in southeast Chongqing [J]. Journal of Western Human Settlement Environment, 2016,31(02):96-101.DOI:10.13791/j.cnki.hsfwest.20160218.

[12] Dong R J. Study on inheritance of natural ventilation of traditional villages and stilted buildings in western Hunan based on wind environment simulation [D]. Hunan University, 2020.DOI:10.27135/d.cnki.ghudu.2020.001480.

[13] Boy resistance, Makemin. Effects of resident-employment distance on transportation carbon emissions [J]. Acta Ecologica Sinica, 2012,32(10):2975-2984.

[14] Xu Wan-ying, ZHOU Chuanbin, Chen Yong-gen, WANG Rusong. Carbon emission reduction benefit calculation of rural household biogas project: A case study of Enshi Prefecture, Hubei Province [J]. Journal of Ecology and Rural Environment, 2013,29(04):449-453.