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Will Cities Survive?

Comparison of the embodied energy of three architectural forms in rural areas of southwest China

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ABSTRACT: This With the launch of China's Poverty Reduction policy, rural construction has become an important issue in China's social development. The environmental and energy challenges associated with turning society in a more sustainable direction are tremendous and urgent. Building and infrastructure construction, in step with developments in industry and transportation, has become an important energy consumer in China. Now more and more rural buildings have been built in recent years which are according to the urban method and construction styles. To compare with the buildings which follow the traditional culture and respect the natural environment, these kinds of buildings may cause a certain waste of resources. This has increased in environmental stress. The research team has worked in rural China for more than 10 years and built rammed-earth buildings which followed the 3L principle "Local materials, local labor, and local technology". But a complete understanding of the resource consumption, embodied energy, and environmental emissions of rural projects in China is difficult due to the lack of comprehensive statistics. How to compare the energy consumption of different types of buildings in the countryside is a very important issue.
KEYWORDS: Embodied energy,Tthree architectural forms, rural areas, Southwest China

1. INTRODUCTION

With the launch of China's Poverty Reduction policy, rural construction has become an important issue in China's social development. The environmental and energy challenges associated with turning society in a more sustainable direction are tremendous and urgent. Building and infrastructure construction, in step with developments in industry and transportation, has become an important energy consumer in China. Now more and more rural buildings have been built in recent years which are according to the urban method and construction styles. To compare with the buildings which follow the traditional culture and respect the natural environment, these kinds of buildings may cause a certain waste of resources. This has increased in environmental stress. The research team has worked in rural China for more than 10 years and built rammed-earth buildings which followed the 3L principle "Local materials, local labor, and local technology". As the project officer and on-site architect of the team, I participate in the design, coordination and construction of these prototype projects. I was mainly responsible for refining design, procuring material, organising the construction, controlling construction progress and supervising construction quality. After the construction, I also collected the temperature data and conducted the Post Occupancy Evaluation. Analysis and evaluation using rural assessment systems indicate that building strategies can be made suitable for rural areas in Southwest China. But a complete understanding of the resource consumption, embodied energy, and environmental emissions of rural projects in China is difficult due to the lack of comprehensive statistics. How to compare the energy consumption of different types of buildings in the countryside is a very important issue.

2. Methodology

Life-cycle assessment (LCA) is a methodology for evaluating the environmental load and energy consumption of processes or products (goods and services) during their life cycle from cradle to grave (ISO, 2006). For the building and infrastructure life cycle, it can be defined as a practical management approach to achieve an optimum cost and benefit solution through the process of design, building material extraction, material processing, construction, building operation, and disposal management. The approach takes into account the economic and functional considerations, as well as the environmental and safety requirements.

In the last few years, there has been an increasing interest in the energy use of buildings in a lifetime perspective. The lifetime is mostly divided into production (including all processes from the extraction of raw materials up to the time the material is ready to leave the factory and feedstock), erection, operation, maintenance, and demolition. Numerous studies show that the operation accounts for the main part of the energy use in the general run of dwellings. The energy for production accounts for only about 10–15% in most cases.

To compare with different architectural forms in rural villages, the research team take brick-concrete building(A), rammed-earth building with wall bearing structure(B) and rammed-earth building with concrete frame structure(C) in the same village. All buildings are 150m^2 with 3m floor height and the life time is 50 years.

The life cycle of rural residential buildings (from construction to final demolition) can be broken down into five processes: 1. Building materials manufacture and preparation; 2. Construction; 3. Building operation and maintenance; 4. Building demolition. Each process has corresponding energy consumption and CO_2 emissions which the key points are different. The sum of CO_2 emissions in the four stages is the total emissions during the life cycle of the building P:

P=P1+P2+P3+P4

P1= CO_2 emissions during the manufacture phase

P2= CO_2 emissions during the construction phase

P3=CO_2 emissions during the operation and maintenance phase

P4= CO_2 emissions during the demolition phase

The calculation of the energy for transport to the building site was simplified in the following way. It was assumed that 75% of all materials, except crushed rock, were, on an average, transported 200 km with a large lorry, filled to 70%, and 50 km with a lorry of medium size, filled to 50%. Crushed rock was assumed to be transported 40 km with a lorry of medium size. CO_2 emissions for transport to the recycling plants was put at 2% of the gross savings (savings if transport was not included), based on the results in a previous study. The assumed distances in are presented in Table 1.

Process	Transport distance (km)
Landfill, places for filling masses	20
Incineration plant	45
Reuse/recycling plant (stone, sand, macadam)	20
Reuse/recycling plant (other materials)	30
Mineral wool, material recycling	200
Gypsum card board, material recycling	150

Table 1 Assumed transport distances to landfills and recycling plants

2.1 CO_2 emissions during the manufacture phase

CO_2 emissions during the manufacture and preparation phase of building materials are the sum of the CO_2 emissions to the environment from the energy consumed to produce the various building materials. This is directly related to the type and amount of building materials used. The main building materials currently used in rural housing and traceable to the relevant energy consumption indicators are steel, clay bricks, cement, sand and gravel, wood, glass, stone, aluminium and paint, while other building materials are used in smaller quantities and are not included in the calculations. The relevant data are as follows.

Material	A-CO_2 emissions/t	B	C
steel	6.95	0.42	0.45
earth	0	0.2	0.2
sand	7.87	0.56	0.56
cement	34.69	3.08	3.22
wood	1.9	0.12	0.26
brick	18.59	0	0
glass	0.84	0.05	0.05
aluminum	2.05	0.26	0.26
stone	2.77	0.17	0.17
paint	4.27	0.32	0.32

Table 2 Building materials manufacture phase of CO_2 emissions

2.2 CO_2 emissions during the construction phase

CO_2 emissions during the construction phase include the amount of CO_2 emitted by the means of transport during the transportation of building materials and the amount of CO_2 generated during the construction process, while CO_2 emissions from the transportation process of building materials are related to the quality of the building materials, the means of transport chosen and the specific transport distance, as mentioned in Table 1 above. CO_2 emissions from building construction are mainly determined by the construction energy consumption, which is closely related to the construction process, and the data from Professor Shi's research is referred to in this paper as a reference.

Material	CO_2 emissions/t
steel	0.05
sand	2.62
cement	0.52
wood	0.15
brick	1.3
glass	0.01
aluminum	0
stone	0.55
paint	0.03

Table 3 Building materials during transport phase of CO_2 emissions

construction	CO_2 emissions/t
Site clean	0.13
Material storage	0.05

Site layout	0.72
foundation excavation	0.35
earthwork excavation	0.12

Table 4 Construction process of CO_2 emissions

2.3 CO_2 emissions during the operation and maintenance phase

The energy consumption in the operation and maintenance phase of the building mainly includes cooking energy consumption, household appliances and air conditioning energy consumption. The energy consumption of cooking and home appliances is mainly known from the survey of rural residents around the area, and the cooking energy consumption is mainly liquefied gas, biogas, coal, fuel wood, straw and electricity. The air conditioning load is calculated using dynamic and dynamic methods, taking into account the floor area of the rammed earth dwelling, the thermal parameters of the envelope, the local air conditioning usage habits, the heating period and meteorological data.

According to Prof. Shi's data, the annual coal consumption of a brick building is 3.99t and the monthly electricity consumption is 160 kwh, resulting in a total emission of 814.6t CO_2 over a 50-year lifetime, while the total emission of a rammed-earth building with wall bearing structure and rammed-earth building with concrete frame structure are 123.23 t over 50 years.

2.4 CO_2 emissions during the demolition phase

The demolition of buildings is essentially a manual operation with essentially no energy consumption. If no new houses are built on the same site and some building materials are removed for reuse, some transport energy is consumed, while other building materials are left in situ with essentially no other consumption. Therefore, the energy consumption in this phase is mainly the transport energy used to recycle building materials, which are still transported by tractor. Sand and gravel, clay and wood chips are considered for disposal close to the site, while steel, cement, linoleum, asphalt shingles, glass and timber are to be recycled for the vast majority, except for a small amount of waste. According to Prof. Shi's data, the demolition phase of CO_2 emission of a brick building is 6.9t, while the CO_2 emission of a rammed-earth building with wall bearing structure is 0.19t and rammed-earth building with concrete frame structure is 0.2t.

So the building full life cycle phase CO_2 emission is as follow(CO_2 emissions/t):

phase	A	B	C
manufacture	80.99	5.18	5.49
construction	5.41	1.36	1.45
Operation/ maintenance	814.6	123.23	123.23
demolition	6.9	0.19	0.2
Total	907.9	129.96	130.37

3. RESULT

According to the result of calculating we can find that the rammed-earth building with wall bearing structure has the least embodied energy, rammed-earth building with concrete frame structure has the 2nd embodied energy and brick-concrete building has the most embodied energy in life cycle. The calculations show that the whole-life CO_2 emissions of rammed earth buildings are much lower than those of brick-concrete buildings, indicating that rammed earth buildings are good at low carbon dimension. Whereas rammed-earth building with wall bearing structure and rammed-earth building with concrete frame structure have different types of structures, the difference in whole-life emissions is not significant. Secondly, the energy consumption of appliances and cooking in the operation phase of rammed earth buildings is mainly related to the residents' energy use habits and consumption levels, and the size of this part of energy consumption is basically the same as that of other types of residential buildings, while the proportion of CO_2 emissions from this part of energy consumption is as high as 73.6% of the total life-cycle emissions, indicating that the rammed earth buildings' This means that the CO_2 emissions of rammed earth buildings are much lower than those of ordinary houses in other phases and in the use of air conditioning. Thirdly, in terms of the distribution of CO_2 emissions in each phase of the life cycle of rammed earth buildings, the largest proportion is in the operational phase of the building, indicating that rammed earth buildings have good low carbon performance in terms of choice of building materials, construction methods and demolition methods, and that they are less expensive than ordinary brick houses, proving to be a suitable form of building for local construction.

4. CONCLUSION

Different economic developments and peasant income levels determine differences in construction and development strategies. They are prerequisites and constraints for any rural building development research that must be defined in advance. National architecture-related policies are the basic background for analysing rural building development. They also provide an important guarantee for the research results to be promoted. The concept of ecological sustainable development is the overall guideline that all research related to rural construction development should follow. The three aforementioned points provide an important theoretical basis for rural construction development research and practice.

Sustainable development is a major trend in global development. Sustainable development has three dimensions that are suitable for building environmental assessment: environmental, economic and social dimensions. To achieve the three dimensions of sustainable development, the passive design and active system of a building environment are significant. However, several problems exist in rural construction. Many rammed-earth buildings in Southwest China exhibit poor performance, and local governments want to rebuild villages rapidly. However, villagers need inexpensive, safe, comfortable and culture-sensitive buildings. The analysis found that rammed-earth buildings exhibit considerable advantages that satisfy the needs of rural areas in Southwest China. Improving the anti-seismic performance and durability of rammed-earth buildings has become an important issue. The mitigation of seismic risk is possible only when the villagers themselves adopt improved rammed-earth construction systems as an essential part of their own culture. The adoption of rammed-earth construction systems is important in earthquake-prone and other areas.

For some developed countries, the cost-efficiency aspect remains of paramount importance. Several authors said "earth construction is economically beneficial", nevertheless one cannot take this as a guaranteed truth because the economics of earth construction depends on several aspects such as: construction technique, labor costs, stabilization process, durability, repair needs. These authors state that production and construction costs represent the most important part because earth construction is labor intensive. However, this is not the case in less developed countries in which labor is available for a very low cost. According to our research in rural areas of China, this provides a saving CO_2 way in rural construction, at the same time it also provides a very important way to create job creation, especially for the rural construction under "Local material, local labor and local technology" strategies.

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