

Analysis of Energy Balance for a Typical Energy Conservation Village in Northeast China

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Abstract: Through field survey and computer simulation, the estimation of the demand for energy is given and the energy supply is selected in village Huangbaiyu, Benxi, by which the energy balance analysis of ecology planning is made. The energy supply schemes and the optimisations are put forward through the advanced selection of clean and renewable energy supply system, which can indicate the sustainable development conception.

Keywords: energy conservation, straw-bale building, energy balance analysis, straw gasification, methane

1. INTRODUCTION

With the development of living standard in small towns of China, more and more villagers would like to make clean energy sources to take the place of direct firing biomaterial, which can produce a mass of straw or solid waste and then result in severe environmental pollution and renewable energy losses. Therefore, local biomass energy that can be transformed into superior quality energy should be made full use of, which will not only satisfy the living and production energy demands, but also significantly improve ecological environment in rural China.

2. SURVEY OF THE SOCIAL ECONOMY IN HUANGBAIYU

Take the Huangbaiyu village for example, which lies in Sishanling town in Benxi city and has 380 families and 1374 villagers. There are 2000 cattle in the slaughter plant and 150 swine bred by the villagers. Kang are used to supply building heating in winter by burning woods, straw or coal. The municipality supplies building electricity. The straw-bale building under contemplation (Fig.1) is 13 meters long, 7.6 meters wide and the 5 meters high, the total area of which is 99 square meters. Straw-bale buildings are built with compressive-stressed straw bale and are very popular for good heat-insulated effect, low energy consumption and nonnegative influence on environment.

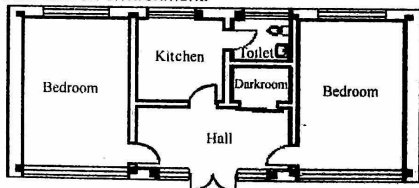


Fig.1: Straw-bale architectural plans

3. ESTIMATION OF THE ENERGY DEMANDS

To make rational use of rural biomass energy and study the optimisation of energy supply system, living energy consumption of the village should be provisional estimated at first, and then the advanced selection of clean and renewable energy supply system should be put forward.

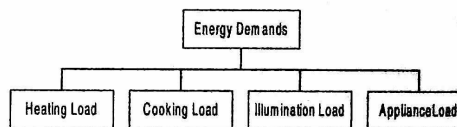


Fig.2: Categories of energy demand

3.1 Heating load

On the basis of establishing analysis model of energy consumption in a straw-bale building (SBB), the annual heating energy consumption of SBB in Benxi is simulated with energy consumption software DeST, from the model block of which, the meteorological condition of Benxi can be called out. Fig 3 presents the dynamic heating load curves during heating period, in which the dynamic heating load of SBB and BMB (Brick Masonry Building) with the same structure and different wall materials are simulated at the same design indoor temperature of 16°C.

The result indicates that SBB is more insulating compared with BMB. The former shows good energy-saving performance. The annual total heating load of BMB is 11401 kW·h, but SBB is 3620 kW·h. The heating energy can be saved by more than 60%, amount to standard coal over 2 tons, which means only 1 ton of coal should be consumed in the whole heating period. The biggest superiority of straw bale is taking full advantage of rural waste resources and

good energy conservation, so straw bale is regarded as an eco-friendly building material.

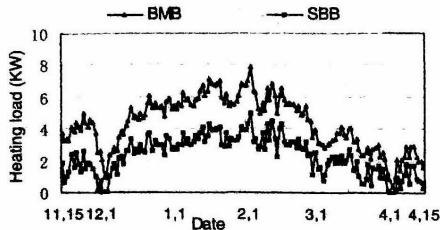


Fig.3: Dynamic heating load curves during heating period.

3.2 Cooking load

The cooking energy use level of the residents can be influenced by many factors, such as the climatic conditions, numerical strength of a family, living standard and the habit, on the basis of which, the average daily cooking energy consumption of one family (3-4 persons) ought to be 15MJ.

Considering the coefficient factor (0.142) of the whole village and the using efficiency (50%), the total daily energy supply should be 11400 MJ/d.

Tab.1: Cooking energy demand

Families	Total Demand (MJ/d)	Using Efficiency (%)	Theoretical Supply (MJ/M)
380	5700	50	342000

3.3 Electrical load

The electrical load of a family concludes illumination and appliance. In accordance to field survey of the living and electric resource conditions, the category and amount of power utilization is given in Fig.4.

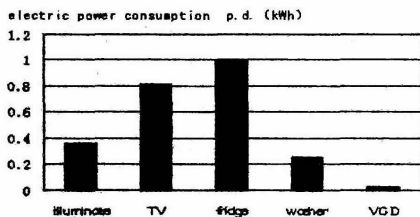


Fig.4: Electrical energy consumption of one family

The daily electric power consumption of each family is 2.44 kW·h and considering the coefficient factor, the monthly consumption is 67.35 kW·h. Each family is supposed to be the same electro-mode, so

the total electric power consumption of the village should be 25593 kW·h/m.

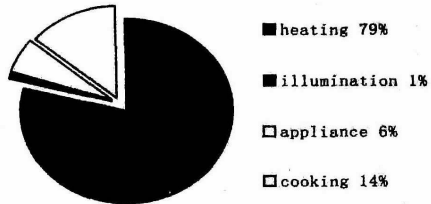


Fig.5: Energy consumption of one family per month

We can see from fig 5 that heating energy consumption of Huangbaiyu village in cold area accounts for the most, which should be nearly 80%.

4. ENERGY RESOURCES AVAILABLE

The rural natural resources available are: straw, feces, wind energy, and solar energy, and geothermals, as fig 6 presents. It is the multiplicate energy selection that makes optimisation of the supply system.

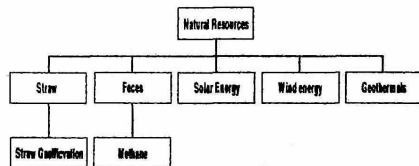


Fig.6: Rural natural resources

4.1 Straw gasification

Biomaterial gasification technology is a course of energy transformation that combustion and reducing reaction of biomaterial would happen under the anoxic condition. It can change the solid biomaterial into fuel gas handy and clean, which concludes charcoal and escaping gas CO, H₂, CH₄. Straw gasification is a new technology, which can not only make the best of useless straw, but also enhance heating availability factor when taking straw as fuel and decrease the environmental pollution. But this kind of technology is not so mature and perfect, and it is still in process of studying.

Today, with the yield increase of foodstuff, the increasing straw can be the big pollution source of rural China. Burning straw would be the most social effects of pollution. So to actualize straw gasification engineering can replace the consumption of firewood in use for cooking and heating of the villagers or generating electricity.

The efficiency of straw gasification is 70-75%, and the service efficiency of straw biogas burner is 50-

60%, so the total efficiency is 35–45%, while straw direct firing efficiency is only 12–15%.^[1]

Through soft ware simulation, the heating energy consumption of each family is confirmed to be 3620kW h in the whole heating period (152d). When straw biogas is serving for heating and the heating efficiency is considered 35%, the straw biogas consumption in winter should be 7004m³ each family. Supposing each straw-bale building consume winter heating energy equally, the straw biogas consumption of the whole village should be 525314m³/M, and the straw consumption should be 262.7t/M.

Straw gasification and central gas supply technology is a village level system of biomass energy transformation with its radius less than 1000 meters, which consists of straw gasification unit, gas transmission and distribution system, and indoor system. Given that lower calorific value of straw biogas is 5.316MJ/m³, the cooking demand of straw biogas is shown in table 2. If 1kg straw can produce 2m³ straw biogas, the total capacity of straw yield just for cooking should be 32.2t/M of the village.

Tab.2: Straw biogas for cooking demand

Lower calorific value (MJ/ m ³)	Theoretical Supply (MJ/M)	Straw Gas (m ³ /M)
5.316	342000	64334

4.2 Methane

Methane is a type of transformation of biomass energy. It is a kind of combustible gas that is found in swamp initially. Methane is a sort of gaseous mixture which comprises CH₄, CO₂, O₂, N₂, and H₂S. Methane's proportion is 55–70%, and carbon dioxide's is 30–45%. Methane is high grade fuel. With its high calorific value, steady thermal efficiency, and convenient employment, methane's technicality and economical efficiency is only second to liquefied petroleum gas (LPG). Calorific value of all manner of methane is different because of the diversified fermentation, and it is usually between 18841–25122kJ/m³. Methane will break up into CO₂ and H₂O if burnt, which will be absorbed by vegetation, and then organic substance will be made by photosynthesis. So methane is always known as a kind of renewable energy source and clean energy free from contamination.

Tab.3: Production capacity of biomaterial^[5]

Biomaterial	Defecation capacity (kg/d)	Emission capacity (kg/d)
Cattle (50kg)	5	15
Swine (500kg)	34	34

Tab.4: Rate of methane production

Biomaterial	Solid content (%)	Theoretical rate (m ³ /kg)	Estimated rate (m ³ /kg)
Cattle manure	4	0.40	0.30
Swine waste	18-20	0.45	0.35

There are 2000 cattle and 150 swine in Huangbaiyu. If the water content of stale is 98%, the solid portion of cattle defection is calculated like this:
 $2000 \times \{ [34 \times (1-0.98)] + (34 \times 0.14) \} = 10880 \text{ kg/d}$

The theoretical rate of methane production is:

$$10880 \times 0.4 = 4352 \text{ m}^3/\text{d}$$

The estimated rate of methane production is:

$$10880 \times 0.3 = 3264 \text{ m}^3/\text{d}$$

In the same way, the methane production of swine can be worked out, such as table 5 shows.

Tab.5: Total quantity of methane production

Biomaterial	Theoretical rate (m ³ /kg)	Estimated rate (m ³ /kg)
Cattle manure	4352	3264
Swine waste	84.4	65.6
Total quantity	4436.4	3329.6

Productivity of methane will be different as the different anaerobic digestion technics is adopted.

Methane productivity of thermophilic fermentation will be above what of mesophilic digestion. Actually in large project of anaerobic fermentation methane productivity of high COD organic wastewater can approach to the theoretical rate. Consequently, the total quantity of methane supply should be confirmed between 3329.6–4436.4m³/d.

With the development of comprehensive application of methane, a kind of generation technology based on combustion of methane came to light. This device has an integrated power generation system, with methane used for the engine so that electric energy and thermal energy can come into being. Domestic researches of generator mainly focus on internal-combustion engine series. If generating efficiency is considered 1.7kW · h/m³, the daily generating capacity will be 5660–7542kW · h, then the monthly capacity should be more than 169810kW · h. Given that the electrical energy consumption of whole village is 25593kW · h per month, methane demand should be 15055 m³/m.

Central methane supply system is a system based upon the minitype power generation and supply system within village scale which usually cleanse and dehumidify the gas first and then distribute it to every door for cooking fuel. Given that lower calorific value of methane is 21.223MJ/m³, the quantity of the gas will be 537m³/d or 16110m³/m.

4.3 Solar energy

The annual radiant index of Liaoning province is 5016-5852MJ/m², and the annual solar radiation time is 2200-3000h, so the radiant index in unit time should be 1.95-2.28 MJ/m² h, heat quantity of which can be equivalent to what of 170-200kg standard coal. Anyway it belongs to the medium resources belt.

Solar electric power generation is a kind of clean energy system, which can apply to almost anywhere, for instance, large constructions, manufactories or residential buildings. Solar electric power generation system consists of solar energy storage battery, control unit, and accumulator cell. If out-put supply is alternating current of 220V or 110V, there should be a inverter collocated.

According to the radiant index in Benxi, if the solar photovoltaic system is fixed, 98.8-137W electric energy can be achieved per hour in each meter roof area. Photoelectric conversion efficiency of single crystal silicon solar energy has been improved, the maximum of that is 15-20%. It is the highest efficiency among all that of solar battery, but the cost is comparatively great. Supposed that the daily equivalent irradiation time is 6.3 hours, the annual quantity of solar power generation should be 1000-1200 MJ/m².

Production scale of solar energy water heater is continually enlarged, the price of which is consequently reducing. At present, price of ordinary hot water system is always 15RMB/m², while solar energy hot water system is 30RMB/m², so the initial investment of the latter is greater. When the user number is more than 100, the electricity generation system of solar energy can be accepted as a supplement system. It can be combined with methane power generation system.

On all accounts, owing to the limited condition of Huangbaiyu, the energy sources available are mainly straw biogas and methane. Solar energy is considered a supplementary energy source.

There are many other energy supply modes, like solar gas range, wind electric power generations, small hydropower stations, or geothermal heat pump system, and so on. But with the restriction of the local resources supplies, there would be no analysis of these schemes here.

5. THE FEASIBLE SCHEMES

The possible energy supply schemes are: straw biogas supplies heating, methane supplies electricity, methane supplies cooking, straw biogas supplies cooking, methane supplies electricity, or solar energy supplies electricity, just as fig 7 shows.

Pay attention to that straw resource is supposed to be adequate in any case and when the five plans above are adopted, we can get three different energy supply schemes (Fig8-10). The unit kW · h/M is taken for the etalon. Scheme 1 shows that solar energy is not enough for electric power generation, but it can be solved by bring the redundant part of methane for cooking to this energy gap, which can meet through computation. Scheme 2 tells us that the total quantity of methane demand for power and cooking of whole village is 31165m³/M and the monthly generating capacity of methane is not less than 99888m³, so it

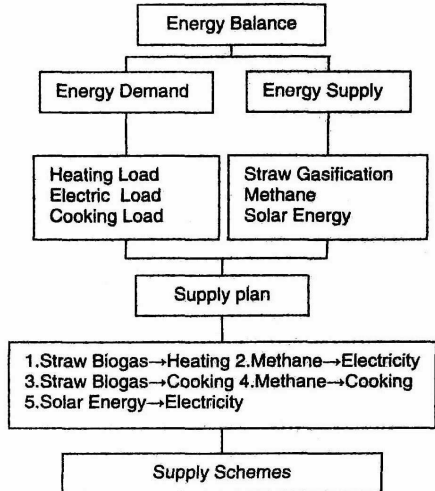


Fig.7: The energy balance frame

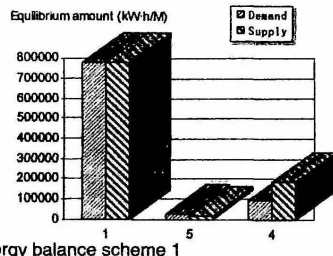


Fig.8: Energy balance scheme 1

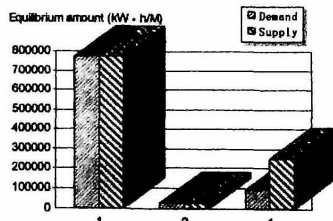


Fig.9: Energy balance scheme 2

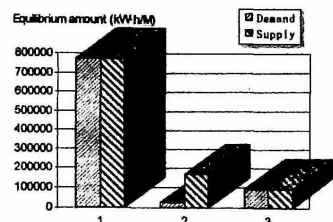


Fig.10: Energy balance scheme 3

can completely meet the demand for power and cooking in theory. Scheme 3 is obviously display that straw biogas and methane is totally adequate for all kinds of living energy demands in this village.

6. CONCLUSION

On the one hand, through the diagram we can see that when straw biogas is confirmed to serve heating demand, the gas consumption will be the highest, because in winter of Northeast China, heating is the biggest part of energy consumption. So we can consider a catenation energy use system, for example, the excess heat of cooking energy can be delivered to Kang via smoke flue, which can partly satisfy the heating energy demand, so that energy conservation can finally be achieved. On the other hand however, considering the lower methane productivity in winter, corresponding measure should be taken to enhance the productivity in winter. Or we can take a synergistic energy system which one form of energy should be combined with another form of energy.

From the energy balance analysis the conclusion can be drawn that energy supply of Huangbaiyu can completely satisfy the natural demand of the villagers' lives. And we simultaneously make it a point to the

sustainable development, which is greatly important to environmental protection.

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