Research on the Energy Utilization Structure of Rural Residence in Hunan Province, China

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Abstract
The purposes of this study are to look into the actuality of rural residential energy consumption in Hunan province, China, to improve energy utilization structure, and to protect the environment. An investigation on rural residential energy consumption was carried out in the villages of Xintian and Jiangwan from March to May 2005. Common energy is used in Xintian while marsh gas is popularized in Jiangwan. A questionnaire survey covered basic information of residences in the two villages, and energy consumption of each family was also tracked continuously. In this paper, the energy utilization structures of the two villages are contrasted. Sequentially, the economic and environmental benefits are assessed when marsh gas substitutes biomass energy. The conclusions are summarized as follows: a complicated energy structure is still dominant, where biomass energy accounts for a significant proportion and manifold energies exist simultaneously; and consumption of the energy is high. Nevertheless the usage of marsh gas makes a great contribution in optimizing energy consumption structure, which could reduce energy consumption and domestic costs, discharge less harmful gases and keep the ecosystem in balance. The comparison between common energy and ecotype energy provides instructions for the future development of rural residential energy consumption.

Keywords: rural residential energy consumption; marsh gas; ecotype energy; energy utilization structure; economic and environmental benefits

1. Introduction
Eight hundred million people are living in rural areas in China. To meet the great demand of rural residential energy consumption, 300 million tons of standard coal are utilized every year, which represents one fourth of the total energy consumption of the whole nation. Furthermore, biomass energy, such as firewood and straw has played an important role in rural residential energy consumption for a long time, and it has affected the environment and social economy seriously (Wang, 2003). With increasing attention to rural energy problems from "the sixth five-year plan" to "the ninth five-year plan", the energy utilization structure of rural residences has been adjusting gradually and the proportion of commercial energy has been increasing every year (Mua, 2004; Wang, 2001). The status of rural residential energy utilization and alteration to the energy structure that occurred in some representative countries in the last decade are analyzed by Feng (1996), Wang (2002), and Wang (2003), based on investigations by the agricultural ministry.

The great differences of natural resources, economic levels and local governmental policies from one province to another lead to the rural energy consumptions of different provinces having their own characteristics, which create new problems, as can be seen when going deep into rural energy constructions. The big agricultural province of Hunan, is affluent in biomass energy. The expansion of commercial energy use in recent years has aggravated the economic burden of farmers and also added more pressure on the supply of commercial energy (Gu, 1997). Besides that, the lack of energy service institutions has hindered the rapid generalization of energy-saving techniques and ecotype energy projects. Therefore, the investigations and analysis have been carried out on the actuality of rural residential energy consumption of Hunan province from March to May 2005, to achieve scientific energy utilization and to solve the problems of destroying the environment and the imbalance between energy supply and demand.

2. Investigation Method
Xintian village and Jiangwan village abut each other. The climate, geography and environment of the two villages are almost the same and the populations are
both around 1,000 residents. Considering the economic level and living standards, residences were chosen as samples from the two villages. Fig.1. shows the general sights of the two villages. Common energy is used in Xintian, while marsh gas is popularized in Jiangwan. Only when marsh gas is deficient, are other kinds of energy like firewood and coal used as complements. Fig.2. shows the establishment of marsh gas in a residence, which is the same as that of other residences in Jiangwan. The marsh gas pool in Fig.2. (a) is used to store gas which is fermented by biologic materials. The produced marsh gas is transported to marsh gas cookers by pipes and then burnt to provide heat for cooking. The marsh gas cooker has switches to control the ignition and firepower, as shown in Fig.2. (b).

Systematic sampling was adopted in the questionnaire survey and data collection regarding energy consumption. One sample was taken from every 10th residence, resulting in 36 samples in Xintian and 30 in Jiangwan. The questionnaire survey covered basic information of the residences, including residential characteristics, family income, utilization of household energy consuming equipment, and subjective estimation based on the local status of energy consumption. Residential energy consumption used in March, April and May of 2005 was tracked continuously. Electricity and marsh gas in each residence were measured by flow meters and the data were recorded every month. Coal, firewood and straw were all measured by weight when purchased or after being chopped. Liquefied petroleum gas was sold in cans of a uniform weight, for easy calculation of its consumption.

3. Sample Information Analysis

The investigation shows that the number of persons in each residence is from 2 to 6. The percentage of families with 2 and 3 members in Xintian and Jiangwan reaches 63.7% and 73.3% respectively, while families with 4 to 6 members are relatively few. The average number of persons to a residence is 3.2 in both villages. The reason why the per-household population is decreasing in recent years is that the young workforce leaves to work in the cities for the entire year. As for the residential characteristics of the two villages, it was found that 75% and 88.9% of the buildings were built in the 1990s or after 2000 in Xintian and Jiangwan respectively, while the rest were built during the 1970s and 1980s. The Brick-concrete structure plays an
important role in building enclosures, which represents 94% and 96.7% of the buildings respectively; while the rest are adobe masonry structures. Correspondingly, 81.8% and 96.7% of the buildings are two storied respectively; while the rest are old bungalows. Fig.3. shows a typical residential building, while Fig.4. illustrates the floor areas of the tenements. Per-household floor area in the two villages ranges from 78 m² to 414 m², and is usually between 150 m² and 250 m², while per-capita floor area is as large as 72 m²/person and 64 m²/person respectively. Fig.5. shows the annual income of the families, which is distributed similarly in the two villages, mostly concentrating on 10–20 thousand RMB per year. Table 1. lists the number of household energy consuming equipment owned in the villages. It shows that necessary electrical equipment, such as color TV sets, washing machines, and electrical cookers is widely used, while equipment, such as refrigerators and amplifiers, is relatively rarely used. The actual possession of household equipment indicates that the current living standards of rural families just meet the basic requirements for living. To sum up, the residential background information, per-household members, residential characteristics and economic status of the two villages are generally at the same level.

4. Analysis of Rural Residential Energy Consumption

4.1 Analysis of rural residential energy utilization structure

Table 2. lists the corresponding percentage of residences using different energy. As the electricity network reconstruction has been completed, its popularization rate has reached 100%. In Xintian, 81.8% of residences use firewood and 87.9% of them use coal; the families using marsh gas and liquefied petroleum gas are relatively few; straw is rarely used by the residents because its calorific capability is too low. Thus it is found that firewood and coal are the main source of residential energy. In Jiangwan, all the residents use marsh gas. Only when marsh gas is deficient, do half of the residences use coal and other firewood.

Table 1. The Number of Household Energy Consuming Equipment Owned in Xintian and Jiangwan

| Categories of Equipment | Electric Light | Black and White TV Set | Color TV Set | Washing Machine | Electrical Cooker | Video Compact Disc |
|-------------------------|---------------|------------------------|--------------|-----------------|------------------|-------------------|
| Numbers in Every 100    |               |                        |              |                 |                  |                   |
| Families in Xintian Village | 1097      | 23                     | 83           | 83              | 63               | 57                |
| Families in Jiangwan Village | 836        | 18                     | 88           | 67              | 61               | 36                |
| Numbers in Every 100    |               |                        |              |                 |                  |                   |
| Families in Xintian Village |           |                        |              |                 |                  |                   |
| Numbers in Every 100    |               |                        |              |                 |                  |                   |
| Families in Jiangwan Village |           |                        |              |                 |                  |                   |
| Numbers in Every 100    |               |                        |              |                 |                  |                   |
| Families in Xintian Village |           |                        |              |                 |                  |                   |

Table 3. shows the calorific values of different energy units. All the consumed energies are transformed into primary energy. According to these values, Figs.6. and
7. reflect the residential energy utilization structures of the two villages. Regarding total energy consumption during the investigation period in Xintian village, the ratio of biomass energy use reached 79.21%, while commercial energy contributed a small proportion with 19.04% and ecotype energy only 1.75%. The results indicate that residential energy utilization in Xintian village is of a complicated energy structure, where biomass energy contributes a significant proportion and manifold energies exist simultaneously. Regarding total energy consumption in Jiangwan village, because marsh gas is the main energy source, the ratio of firewood use is only 46% and is relatively smaller compared with that of Xintian, while the consumption ratios of commercial energy and ecotype energy increase to 28% and 26% respectively. By comparing the two figures, the ratios of commercial energy and ecotype energy used in Jiangwan are relatively higher than those in Xintian, while the ratio of biomass energy is smaller. Thus, the energy structure of Jiangwan is definitely better than that in Xintian.

4.2 Analysis of the rural residential energy consumption quantities

Fig.8. shows per-capita energy consumptions of the two villages during the period of the investigation. The figure shows that per-capita energy consumption

| Categories of the Energy | Electricity | Liquefied Petroleum Gas | Coal | Firewood | Straw | Marsh Gas |
|-------------------------|-------------|-------------------------|------|----------|-------|-----------|
| Percentage of the Residences in Xintian Village (% ) | 100 | 21.2 | 87.9 | 81.8 | 3 | 27.3 |
| Percentage of the Residences in Jiangwan Village (% ) | 100 | 10 | 50 | 50 | 0 | 100 |

Table 2. Percentage of Residences Using Different Energy Sources

| Categories of the Energy | Electricity | Liquefied Petroleum Gas | Coal | Firewood | Straw | Marsh Gas |
|-------------------------|-------------|-------------------------|------|----------|-------|-----------|
| Calorific Values of Units | 10.91MJ/kwh | 41.9MJ/kg | 21MJ/kg | 20.2 MJ/kg | 13.97 MJ/kg | 19.9MJ/M³ |

Calorific values of units of coal, firewood, straw, and liquefied petroleum gas are adapted from Nu (1997), Xiang (2000), and Xi (1995);
of Xintian village is 326.785kgce/person, while that of Jiangwan village is only 107.85kgce/person, much lower than that of Xintian village (1kgce=29.31MJ). Analysis of energy consumption discrepancies between the two villages shows on the one hand, that firewood is wasted a lot during use in Xintian, while on the other hand it shows that marsh gas is dominant and firewood is used only to meet emergencies in Jiangwan, while firewood is the main energy in Xintian. Relative tests show that the thermal efficiency of marsh gas cookers is 58% while the value range of firewood hearths is between 8% and 15% only; therefore, to meet a certain efficiency energy requirement, the total consumption of marsh gas is much lower than that of firewood. The above causes ultimately result in per-capita energy consumption in Jiangwan village being just one third of that in Xintian village.

Although firewood is consumed more than marsh gas in terms of per-capita energy consumption in Jiangwan village, its efficiently utilized energy is much lower, and that is why marsh gas is still the main source of residential energy there.

Fig.9. gives the distribution of per-capita energy consumption for each family in the two villages. It illustrates that 71.4% of the families have a per-capita energy consumption below 100kgce/person in Jiangwan village, while in Xintian village it is between 56.94~1588.47kgce/person, while for 34.4% of the families it is between 300 and 1000 kgce/person.

4.3 Reasons of energy consumption actuality

Many factors affect the residential energy consumption of the two villages such as rural natural environment, domestic economic status, combustion equipment, and conceptions and living habits of farmers. In Xintian, natural resources of firewood and straw are abundant; meanwhile, farmers chop trees directly from the mountains nearby to collect firewood, so the cost of the biomass energy is extremely low; furthermore, the purchasing ability of farmers is also at low levels. All the above reasons result in biomass energy of firewood and straw having been largely used by the farmers in Xintian during the past years. Further analysis shows that, since the biomass energy is "no-cost" energy, its excessive usage reduces the expenditure of rural residential energy consumption. Investigations show that 74% of residences in our survey spend less than 5% of their domestic income for energy expenditure annually and the majority is satisfied with the cost. The intense satisfaction of residences with the expenditure status leads to a concurrence between manifold energy styles and the dominant status of biomass energy.

With the process of rural energy construction in China, the government usually appropriates a large sum of money to a small part of the country selectively, in order to encourage the development of energy demonstration projects. In Jiangwan village, a marsh gas demonstration village in Hunan province, the government appropriated 2,300 RMB to each family as a subsidy for high-grade marsh gas pools and 700 RMB for common marsh gas pools besides a part of the construction cost which is paid by farmers themselves. The popularization of marsh gas has not only optimized the energy utilization structure of Jiangwan village but also decreased per-capita energy consumption. Meanwhile energy expenditure is also reduced. In terms of farmers' attitude to energy utilization, all the families are willing to use marsh gas. When marsh gas is insufficient, 50% of the families are content to use coal and 10% prefer to use liquefied petroleum gas as the accessorial energy. Thus it is clarified that the governmental energy policy and consumption conceptions of farmers are the important factors affecting the energy utilization structure.

5. Contrastive Analysis of Economic and Environmental Benefits of the Residential Energy Utilization in the Two Villages

Relative to the biomass energy, marsh gas is a clean, economical and highly efficient source of energy. The use of marsh gas improves drastically the sanitation of lavatories and corrals. Meanwhile, marsh gas, by replacing firewood as a main living energy source, has lightened housework and improved living quality. More important is that the use of marsh gas has produced distinct economic and environmental benefits.
RMB/household, while the corresponding expenditure in Jiangwan village is only 93 RMB/household as the use of marsh gas has reduced the consumption of commercial energy. In addition, analysis of the total amount of energy consumption from Fig.8. shows that per-capita consumption of firewood, straw and coal in Jiangwan are less by 186.36 kgce/person, 21.71 kgce/person and 26.81 kgce/person respectively than that in Xintian. In other words, firewood, straw and standard coal burnt in Jiangwan village are less by 270 kg/person, 46.6 kg/person and 26.81 kg/person respectively. Assuming that there are 1,000 inhabitants in every village, 270 tons of firewood, 46.6 tons of straw, and 26.81 tons less of standard coal were burnt in Jiangwan village than in Xintian village during the three months of the investigation. Accordingly, by simple calculation, it is found that the energy saving in one year is considerable.

Meanwhile, according to the standard provided by Zeng (2004), 270 tons of firewood are equal to an annual output of 47.5-hm² of firewood forests (1 hm² = 10,000m²). The saved firewood has protected local forest resources and produced obvious environmental benefit. While in Xintian village, local residents chop pines for firewood directly from the mountains nearby, which has produced a negative influence on the local environment.

In addition, analysis of the environmental benefit is made from the angle of atmospheric pollution caused by burning coal and firewood. The calculated values of harmful gases discharged by the burning of unit-mass coal and firewood under the condition of using home hearths are listed in Table 4., according to the related data provided by Calverc (1987) and Chen (1985). Based on Table 4. and combined with the data in Fig.8., Fig.10. calculates the total amount of harmful gases released when coal and firewood are burnt respectively during the three months of the investigation in the two villages. The figure demonstrates that as 26.81 tons of coal and 270 tons less of firewood are burnt in Jiangwan village, 472.6 kg of SO₂, 1,407 kg of NO₃, 3.696 tons of CO, 7.05 tons of granule and 558.658 tons less of CO₂ are released. While marsh gas, a high-quality energy source, releases only CO₂ and water when burnt. Moreover little CO₂ is released by marsh gas, compared with coal and firewood. Thus it is seen that the use of marsh gas has produced enormous environmental benefit for Jiangwan village.

6. Conclusion
In this study, residential energy use in Xintian village mainly depends on the available amount of local biomass energy due to the inferior living standards. Therefore the complicated energy structure is still dominant, where biomass energy represents a significant proportion and manifold energies exit simultaneously. Energy consumption is also at a high level due to the poor thermal efficiency of firewood hearths and waste during use.

Together with the process of rural energy construction in China, the commercial energy market has been standardized and ecotype energy projects have been gradually generalized. Thus, commercial energy and ecotype energy will replace biomass energy. Jiangwan village is just a representative example. The use of marsh gas not only has optimized the energy utilization structure, but also has yielded remarkable economic and environmental benefits. The generalization of ecotype energy will have a profound impact on rural energy utilization in China, the
supply system of commercial energy, and the natural environment.

References
1) Calverc, S. and Englund, H.M. (1987). Handbook of air pollution technology. Beijing: Ocean Press.
2) Chen, S.Y. and Zhang, L.L. (1985). Fuel burning and burning equipment. Beijing: Metallurgy Industry Press.
3) Feng, Z.M. and Wang, X.H. (1996). Analysis on the rural household living energy consumption in China. Rural Energy, 3, pp.3-5.
4) Gu, S.H. and Liu, W.Q. (1997). Research on the rural household energy consumption under the system of market economy. Rural Energy, 1, pp.3-6.
5) Mua, H. Kondou, Y. Sato, Y. Zhou, W. Ning, Y. Sakamoto, K. (2004). Grey relative analysis and future prediction on rural household biofuels consumption in China. Fuel Processing Technology, 85, pp.1231-1248.
6) Nu, N. (1997). Conspectus of new energy. Beijing: China Agriculture Press.
7) Wang, X.H., Dai, X.Q., Zhou, Y.D. (2002). Domestic energy Consumption in rural China: A study on Sheyang County of Jiangsu Province. Biomass and Bioenergy, 22, pp.251-256.
8) Wang, X.H., Feng, Z.M. (2001). Rural household energy consumption with the economic development in China: stages and characteristic indices. Energy Policy, 29, pp.1391-1397.
9) Wang, X.H., Feng, Z.M. (2003). Common factors and major characteristics of household energy consumption in comparatively well-off rural China Renewable and Sustainable Energy Reviews, 7, pp.545-552.
10) Xi, S.G., Wu, W.L., Jiang, J.Y . (1995). Boiler and equipment in boiler house. 3rd ed. Beijing: Chinese Architecture and Building Press.
11) Xiang, Y.Q. (2000). The handbook of common data in the gas thermodynamic project. Beijing: Chinese Architecture and Building Press.
12) Zeng, J. and Wang, H.J. (2004). Evaluation on the environment and technique economy of integrative utilization of marsh gas in the countryside. Chinese Agricultural Mechanization, 4, pp.26-28.