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Psychological Motivation Analysis of Farmers' Collective Energy-saving Behavior and Influence of Intervention Effect

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Abstract. The poor thermal performance of rural buildings in northern China and the serious pollution caused by loose coal combustion are practical problems that need to be solved urgently. In order to solve the two problems, this paper analyzed the current situation of the envelope structure of rural houses in the north of our country and the commonly used heating forms of farmers. It was found that the envelope structure of most rural houses did not take heat preservation measures and needed to be transformed to save energy. The commonly used heating systems for farmers are coal furnaces, hanging kang, earth heating, etc., and the wealthier rural areas use biogas or straw gasification for central heating, but there are still various problems to be improved in these systems. In order to improve the thermal performance of the farmers' building structure, the thermal performance measurement and energy-saving transformation of the enclosure structure of a typical farmer in Xiaoyi, Shanxi Province were carried out. Before the energy-saving transformation, Energy Plus software simulation analysis shows that the typical farmer can save 60% of the heating energy consumption after the energy-saving transformation. Before and after the energy-saving transformation, the actual measurement results show that the heat transfer coefficient of the wall, window and roof decreased by 72.7%, 61.59% and 64.99% respectively from 2.3 times, 1.43 times and 2.11 times the national requirement limit. The performance of the envelope structure after the energy-saving transformation can meet the national requirements. The actual statistics show that the biomass fuel consumption per unit temperature difference before and after the transformation is saved by 66.74%, which indicates that the energy-saving transformation has achieved good results, and shows the accuracy of the Energy Plus model. The psychological intervention of energy-saving transformation proposed in this study helps to improve people's awareness of energy-saving, reduces anxiety and fear, and has a very good effect on the psychological intervention effect.

Key words. Farmers' Energy-saving Behavior, Psychological Motivation Analysis, Intervention Strategy Effect, Sustainable Agricultural Development.

1. Introduction

The thermal performance of an envelope is an important index to evaluate whether a building is green or not, which directly affects the indoor thermal environment and building energy consumption. This paper discusses the research status of the comfort of rural houses from three aspects: envelope, thermal comfort and building energy consumption [1], [2]. Liang Yachao and others investigated and analyzed the farmhouses in North China, and found that the building envelope of the farmhouses was relatively weak, and even most farmhouses did not take heat preservation measures at all. The floor height was too high, the heating facilities were backward, and the thermal efficiency was low, resulting in great building energy consumption; People are not satisfied with the indoor air quality in winter, and the indoor temperature fluctuates greatly and the average temperature is low; This paper puts forward some suggestions for the current situation of building envelope, which provides theoretical data support for energy conservation for the construction of new countryside, but there is no measured data [3]. Lu Meijun et al. analyzed the thermal performance of the enclosure structure of rural houses in Tangyin County, Henan Province and optimized it. However, the energy consumption analysis here is based on a relatively simple design calculation, and there is still no actual data support. The actual situation of the enclosure structure of rural houses needs measured data to provide a reliable basis for future energy-saving renovation [4]–[6].

Compared with the standard requirements, the measured data of Hu Yanli et al. are quite different, indicating that the thermal comfort of farmers is very cold, and the indoor temperature of rural houses needs to be paid attention to and improved urgently [7], [8]. With the improvement of farmers' living standards, the indoor thermal environment of farmers should be improved accordingly. The 2013 edition of "Energy Efficiency Design Standard for Rural Residential Buildings" stipulates that the calculation temperature of heating design and calculation of main functional rooms of rural houses in severe cold and cold areas should be 14 °C. In 2013, Zhao Yunbing and others used Design Builder to simulate the thermal comfort of bedrooms and living rooms of typical houses in northern China. It is concluded that the average indoor temperature of existing farmhouses is only 7.4 ℃, and the corresponding PMV value is -3.0. The thermal feeling is relatively bad; Compared with the maximum room temperature of 7.5 ℃ measured by Hu Yanli et al. In 2009, the simulated indoor thermal environment was greatly improved, but it is still far below the limit required by the national standard, and the thermal comfort is still very poor [9]. On this basis, Zhao Yunbing and others optimized the typical farm house model and continued to simulate. The optimization results showed that the average indoor temperature rose to 13.9 ℃, which just met the relevant national standards, and the PMV rose to -1.2, which was in a cold state. In order to know whether the indoor temperature level of rural houses can reach the simulated state of 13.9 ℃ and whether it can reach the national limit, actual measurement must be carried out, and the measurement results can also provide the basis for solving the two major problems of rural heating [10], [11]. According to the large-scale survey data of rural energy consumption at Tsinghua University, the total energy consumption in rural areas of China has far exceeded 300 million tons of standard coal every year, and the heating energy consumption of northern farmers accounts for about 80% of the total energy consumption. The proportion of energy consumed by farmers in annual heating is increasing, but the huge heating energy consumption does not improve the indoor thermal environment accordingly [12], [13]. Yue Yanmin investigated and analyzed the total heating energy consumption of farmers The proportion of farmers whose annual coal consumption ranges from 1 t to 2.5 t is 63%, and the proportion of farmers whose annual coal consumption is greater than 2.5 t is 15%. Even some farmers consume more than 4t, while the proportion of farmers whose coal consumption is less than 1t is very small [14].

To sum up, the proportion of corresponding thermal insulation measures for walls, windows and roofs is almost 0. In terms of thermal comfort, from the measured data of the highest indoor average temperature of 7.5 ℃ in 2009 to the simulated data of 7.4 ℃ in winter in 2013, the indoor thermal environment has been greatly improved, but it still falls far short of the standard requirements. However, the energy consumption of coal has been increasing, and the total domestic energy consumption in rural areas of Northeast China alone reached 65.87 million tons in 2014. In order to respond to the national policy and provide a reliable basis for the promotion of clean heating policy, we need measured data. Biomass solid briquette furnace is suitable for promotion in all northern rural areas. This paper provides corresponding reference data for energy-saving transformation and clean heating transformation of northern farmers by using biomass and solar energy combination and heating systems.

2. Analysis of Energy Consumption of Existing Typical Farmers

A. General Situation of Architecture

According to the analysis literature, most of the rural houses in Shanxi are single-storey buildings, and 82% of the roofs are wooden houses with tile roofs; 67% of the wall materials are brick walls; 59% of the windows are single-layer wooden windows; 72% of the external doors are single-layer wooden doors. At present, the average indoor temperature of farmers in winter may be as low as 10 ℃, which is related to the fact that the envelope has hardly taken heat preservation measures [15], [16]. In order to make the data more convincing and make the previous statistical data more profound, we will select a typical household to carry out a numerical simulation analysis of energy consumption and actually measure the heat transfer coefficient of its envelope.

A typical farmer in Shunguang Village, Xiaoyi City, Luliang District, Shanxi Province was selected as the research object. The farm house was built in 2006, facing south. The roof was prefabricated reinforced concrete roof, the exterior wall was made of 370 mm ordinary fired solid brick, and the windows and doors were made of wood. The building is divided into two small households with exactly the same pattern from east to west. Each small household has two rooms from south to north. Because there is plenty of sunshine in the south during the day, and the indoor temperature and lighting are good, the south rooms with and without external doors are set as living rooms and master bedrooms, with a length and width of 4.8 m and 3.85 m respectively; The room connected with the living room in the north is the kitchen, and the room not connected with the living room is the second bedroom, with a length and width of 4.2 m and 3.85 m respectively. These thermal parameters all meet the national energy saving standards.

B. Principle of Energy Consumption Analysis

The preliminary understanding of rural houses can not intuitively reflect the defects of existing rural houses and the existing problems of rural heating [17]. In order to grasp the energy consumption of residential buildings and determine the key points of an energy saving, energy consumption analysis must be carried out. The existing energy consumption analysis data can be analyzed and calculated with the help of the China Statistical Yearbook or the establishment of the numerical model. China Statistical Yearbook is mainly aimed at urban housing based on macro-adjustment calculation results, so rural housing energy consumption analysis can only be based on survey data to establish a model for simulation analysis. There are many commonly used energy consumption simulation software, and their simulation results will be quite different for the same problem. The characteristics of simulation software, the user's proficiency and accuracy, and the cognitive concept of input parameters can all affect the simulation results, among which the influence caused by the different calculation principles of each simulation software is the most critical. Nowadays, the commonly used energy consumption analysis software mainly includes Energy plus, DeST, DOE-2 and so on. DeST and Energy plus are more accurate than DOE-2 in calculating heat transfer, because the latter does not strictly consider heat transfer. Energy plus is different from DOE-2 and DeST in that the latter two can only deal with linear time-invariant systems, while the former can deal with convection and heat conduction by CTF or finite difference calculation methods, which makes the calculation more in line with the actual situation. Therefore, when the energy consumption analysis is simulated by Energy plus energy consumption analysis software, CSWD format meteorological documents are generally used, which comes from "Special Meteorological Database for Building Thermal Environment Analysis in China" compiled by Tsinghua University according to the measured data of 270 meteorological stations in China. Rural building energy consumption includes heating, cooking, lighting, household appliances, etc. This topic mainly aims at the heating problem of rural houses, so the energy consumption here only considers building heating energy consumption.

C. Energy Consumption Analysis

Taking the first small household of this typical household as the research object, the heating energy consumption simulation is carried out by using Energy plus building dynamic energy consumption simulation software. Because the 270 weather stations in Tsinghua University do not include the data of Xiaoyi City, the dynamic climate data of Jiexiu City, which is close to Xiaoyi City in geographical location and climate, is selected as the simulation condition [18]. The indoor design temperature is 14 ℃, the heating end is a radiator, the water supply temperature is 75 ℃, and the return water temperature is 50 ℃. The simulated operation time is set as a heating season, from November of the first year to March of the second year. The enclosure structure is set according to the actual situation: the outer wall is 370mm solid brick wall and 10mm limestone mortar from outside to inside; The roof is 120mm solid brick, 200mm light clay and 120mm reinforced concrete, and the windows are 3mm single-layer wooden windows. The energy consumption results of Energy plus show that the total energy consumption of the first small household in the heating season is 31.38 GJ, and the heat load index is 95.30 W/m^2. The heat index of residential buildings in the Practical Heating and Air Conditioning Design Manual is 45–70W/m^2, and the energy consumption index of this farmer is 1.36–2 times of the prescribed limit. In recent years, China has advocated housing energy saving, and reduced the heat index to 30–45 W/m^2, which is twice or even three times the required value of energy-saving buildings. This shows that there is a lot of energy-saving space for rural houses in Shanxi, and the energy-saving renovation of rural houses must start by improving farmers' awareness of energy conservation. First, farmers must understand the energy consumption of their rural houses and encourage them to actively participate in energy-saving renovation.

3. Energy-saving Transformation

A. Determination of Thermal Parameters of Existing Typical Farmer Envelope

In order to understand the root cause of the problem that the total heating energy consumption of this typical farm house seriously exceeds the standard, it is necessary to understand the present situation of the enclosure structure of the farm house through actual tests. The thermal performance of the building envelope includes the physical characteristics that affect indoor and outdoor heat transfer, such as building shape coefficient, window-wall ratio with different orientations, and heat transfer coefficient of each envelope [19]. Other thermal parameters except for heat transfer coefficient have been proposed above, including the south window-wall ratio of 0.45 and the north window-wall ratio of 0.3, which meet the energy-saving design limits of rural residential buildings in cold areas [20].

The measurement of the heat transfer coefficient of each envelope is complicated, so the commonly used detection methods are introduced. Hot box method is to set cold and hot boxes on both sides of the envelope, artificially set the temperature of the box, measure the temperature and heat transfer by temperature sensor and heat flow meter, and calculate the heat transfer coefficient by heat transfer formula. Because the cold and hot boxes are large and inconvenient to install and carry, they are generally used in laboratories. The infrared thermal imager method uses the principles of optical imaging and infrared detection to obtain the thermal field distribution of the envelope. The instruments and equipment of the infrared thermal imager method are convenient to carry and operate, but the technology is not mature enough and can only be used for qualitative analysis. The heat flux meter method is similar to the hot box method, and the heat transfer coefficient is calculated by measuring temperature and heat. The difference is that the measured temperature in this way is not artificially manufactured but ambient temperature, so the heat flux meter method is greatly affected by seasons and can only be used in heating seasons with large temperature differences between indoors and outdoors. It is generally accepted that the heat flow meter method [21].

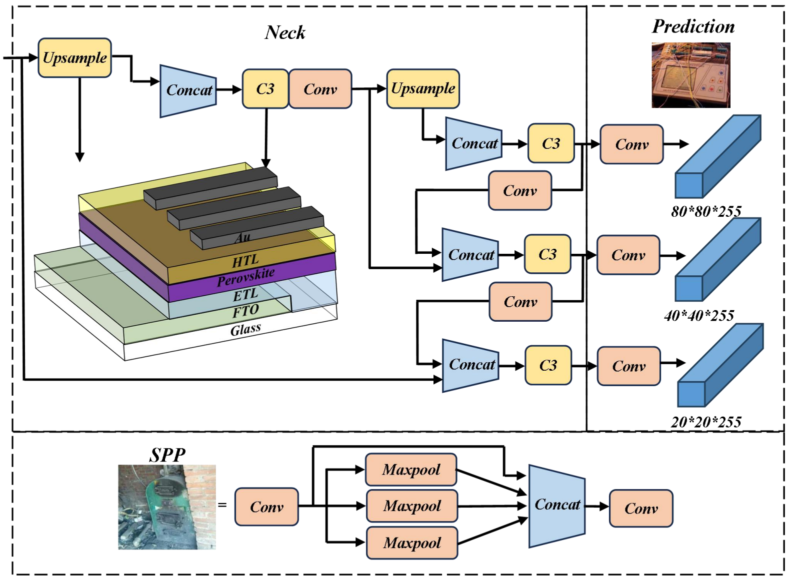

Figure 1. Heat Flow Measurement

Figure 1 shows the flow meter measurement method. In this paper, the heat flow meter method is used to measure the heat transfer coefficient of the typical farmer envelope. The equipment used is a BES-GP intelligent multi-channel temperature and heat flow detector developed by the Institute of Building Energy Saving Technology of Harbin Institute of Technology. The constant C of the heat flux meter used in the collector is 11.63 W/ (m^2 mV). The formulas for calculating the heat transfer coefficient are shown in Equations (1), (2) and (3).

$$R = \frac{\theta n - \theta w}{q} \tag{1}$$

$$Ro = Ri + R + Re \tag{2}$$

$$K = 1 / R0 \tag{3}$$

The formula for calculating the annual value of heating scheme cost is shown in Equation (4):

$$f = z\frac{i(1+i)^m}{(1+i)^m - 1} + F \tag{4}$$

B. Energy Consumption Analysis After Energy-saving Transformation

Compared with the last time, this energy consumption analysis changed the materials of the envelope structure, mainly adding polystyrene boards with different thicknesses to exterior walls and roofs, and adding a layer of aluminium alloy windows to windows [21]. This energy consumption analysis does not change except for the changes in envelope materials, including building structure, meteorological conditions, simulated indoor design temperature setting value, heating mode and supply and return water temperature. The thickness of the additional polystyrene board is 30 mm, 50 mm, 75 mm and 100 mm.

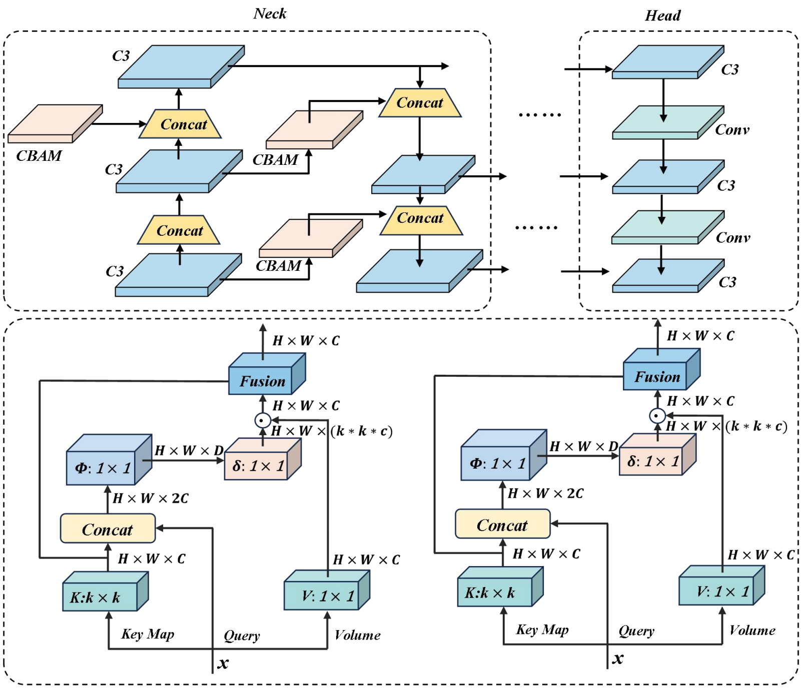

Figure 2. Feature Extraction of Energy Consumption Simulation

Figure 2 is the flow chart of feature extraction of energy consumption simulation, and the comparison table of energy consumption analysis results of energy consumption simulation software Energy Plus for the above schemes of selecting polystyrene boards with different thicknesses. In the renovation scheme of adding single-layer aluminium alloy windows outside log windows and polystyrene board insulation layers with different thicknesses to exterior walls and roofs.

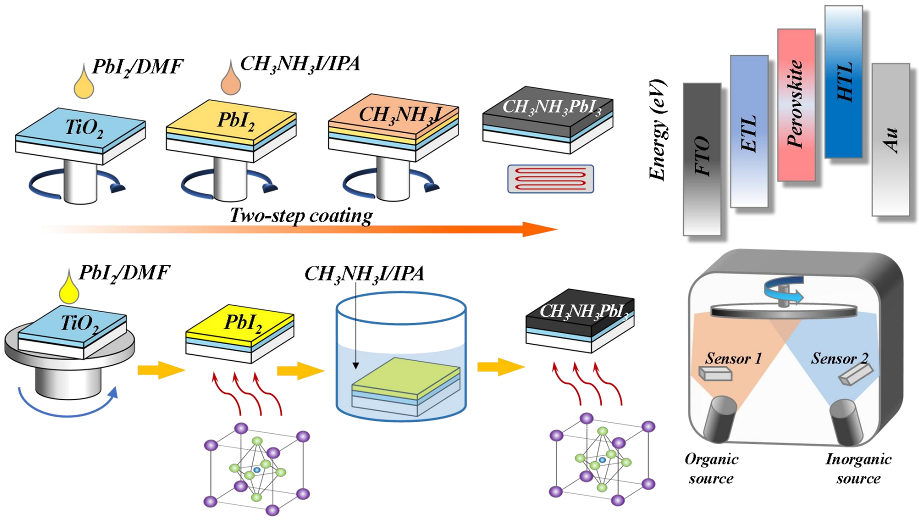

Figure 3. Design Steps of Polystyrene Board Insulation Layer

Figure 3 shows the design steps of the polystyrene board insulation layer. The increase of polystyrene board insulation layer thickness brings about a decrease in total energy consumption in the heating season, but its change slope is getting smaller and smaller, that is, the increasing trend of energy saving rate gradually slows down. In the process of energy-saving transformation, we can't simply think that the thicker the added insulation layer, the higher the cost performance of energy-saving transformation. This is not economic and scientific, which may lead to an increase in energy-saving benefits far lower than investment costs. In energy-saving transformation, it is best to carry out numerical simulations and compare schemes when conditions permit. Combined with the simulation results and the market price, the 50 mm thickness polystyrene board insulation layer is the most cost-effective.

C. Effect of Energy-saving Transformation and Psychological Intervention

Psychological intervention of energy-saving transformation helps to improve people's awareness of energy conservation, reduce anxiety and fear, cultivate energy-saving habits, enhance social support, and stimulate innovation and sustainable lifestyles, thus helping individuals to better cope with environmental challenges, reduce energy consumption, reduce environmental impact, and contribute to protecting earth resources and coping with climate change [22], [23]. After simulating and determining the energy-saving renovation plan, the team carried out an energy-saving renovation on the typical farmer in December 2016. A 50 mm polystyrene board insulation layer was added outside the roof, and color steel tiles were laid on the insulation layer; A 15 cm ceiling is made inside [24].

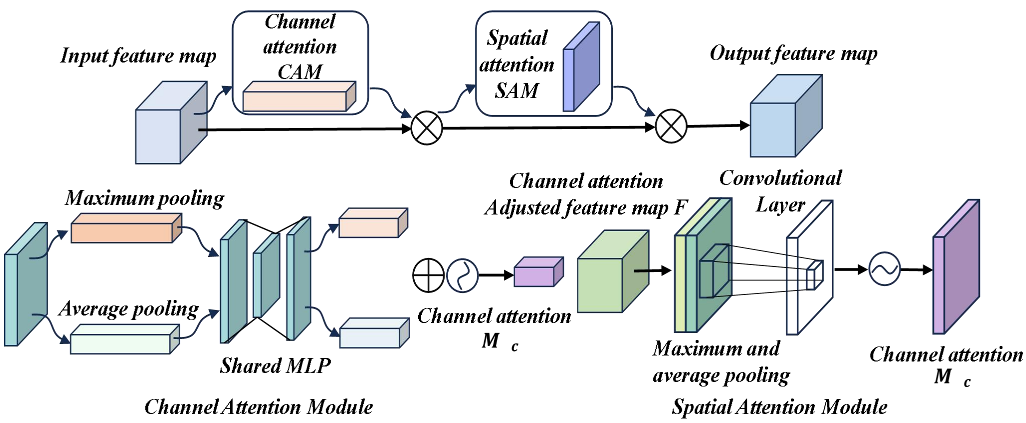

Figure 4. Feature Extraction Analysis Architecture

Figure 4 shows the analysis framework of feature extraction. Before and after the transformation, the radiator is used as the end and the biomass solid briquette furnace is used [25]. Its temperature and humidity error ranges are

0.2 ℃ and 1.5% respectively. Despite the fact that outdoor temperatures have noticeably decreased post-renovation compared to pre-renovation levels, indoor temperatures have not correspondingly dropped; instead, they have increased. Based on Formulas (5), (6), and (7), in the external environment where the temperature difference between indoor and outdoor was 11.21 ℃ before the renovation and 17.37 ℃ after the renovation.

$$A_c = \frac{Qf}{J_t \eta_{cd} \left(1 - \eta_L\right)} \tag{5}$$

$$Q_d = C \times M \times \left(T_{chilled\_in} - T_{chilled\_out}\right) \tag{6}$$

$$Q_i = f\left(PLR, COP, P_{chiller}\right) \tag{7}$$

The change in the heat transfer coefficient of each envelope, shows that the energy-saving transformation has achieved good results. In order to make energy-saving transformation recognized by farmers and popularized in rural areas, the cost of energy-saving transformation must be acceptable to farmers [26], [27]. It can be obtained through the formulas of Formula (8), Formula (9) and Formula (10). The renovation price is according to the local market price: a new layer of renovation for doors and windows: 200 yuan; Wall renovation: 120 yuan; Roof renovation: 120 yuan; A total of 30,000 yuan, within the economic level that farmers can afford.

$$Q_f = f\left(Q_d, Q_i, t_h, t_m, T_d, T_w\right) \tag{8}$$

$$Q_i = P_{chiller} \times COP \tag{9}$$

$$\Delta Q_{d,j} = Q_{d,j} - Q_{d,j-1} \tag{10}$$

4. Experimental Results and Analysis

The building structure of the selected typical farmers in Guihua Village in Luliang area is basically the same as that of Xiaoyi typical farmers, so the energy-saving renovation houses are still taken as an example in the design, facing south, with a single flat roof, a building area of 69.3 square meters, a window-wall ratio of 0.37 in the south, a window-wall ratio of 0.18 in the north and a shape coefficient of 0.26 [28]. The heat transfer coefficients of exterior wall, window, roof and door are 0.406 W/(m^2·k), 1.535 W/(m^2·k), 0.370 W/(m^2·k) and 3.124 W/(m^2·k) respectively. The design parameters are determined according to the energy-saving design standards of residential buildings in Shanxi Province, but the indoor design temperature is set to 16 ℃, which is higher in thermal comfort. Low temperature floor radiant heating system with supply and return water temperatures of 45 ℃ and 35 ℃ is selected at the end of the heating system. Because of the high resistance along the heating system, the mechanical circulation mode is selected.

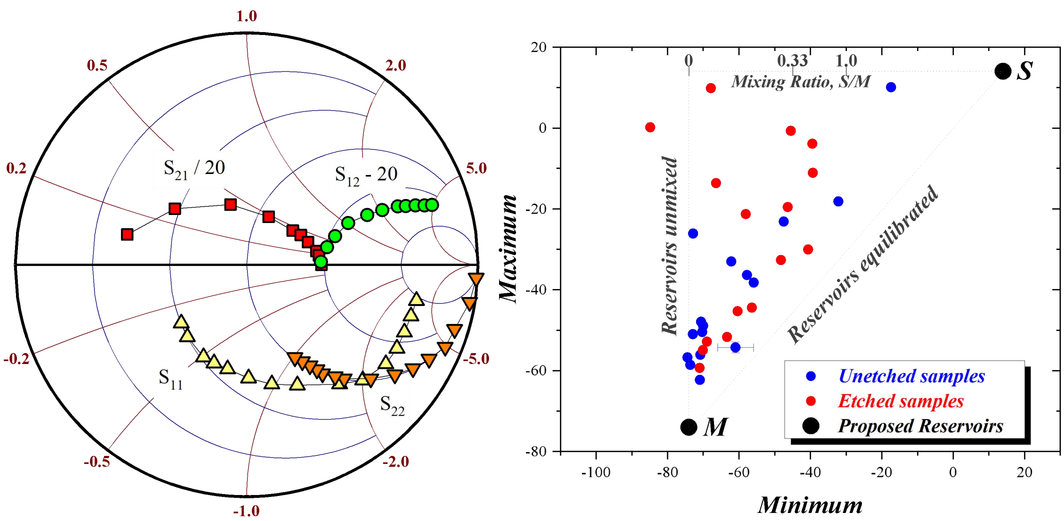

Figure 5. Heating Load Analysis

Figure 5 shows the analysis results of the heating heat load. For farmers, the heating heat load includes the heat consumption of envelope structure and the heat consumption of cold air infiltration. The heat transfer of the envelope is an unstable heat transfer process, but it is simplified to a stable heat transfer calculation method because of the complexity of the calculation. The heat consumption is calculated according to Formula (11), and the following four factors should be considered for additional heat consumption: the sunlight rate of the building in the due south and due north direction is 75%, so the correction coefficients in each direction are 10% in the north direction, -5% in the east and west directions and -25% in the south direction respectively; The building is located in the rural buildings, with a floor height of 4 meters, without considering the influence of wind and height; Its outer door is single-layer without door bucket, and the additional rate is calculated by 65%. The infiltration heat consumption of cold air is calculated according to Formula (12) of the infiltration heat consumption of cold air in the gap of doors and windows. After calculation, the heating load of this typical farmer in winter is 4032 W.

$$Q = AK\left(t_n - t_W\right)a \tag{11}$$

$$Q_i = 0.278 L p_\alpha c_p \left(t_n - t_m\right) \tag{12}$$

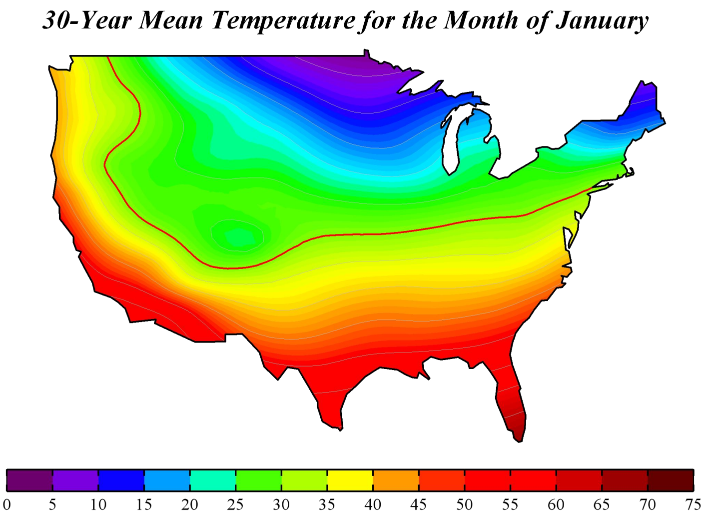

Figure 6. 30-year Average Temperature

Figure 6 shows the average temperature in 30 years. For this typical farmer, transforming the heating system of the first small household from the traditional small coal-fired boiler to the heating system of a biomass solid briquette fuel furnace only changed the boiler body, and the rest remained unchanged. Other initial investment costs will be used no matter which heating method is adopted, so the initial investment in calculating the annual cost only considers the boiler and its installation and commissioning costs, which is 2,500 yuan for small coal-fired boilers and 2,000 yuan more expensive for biomass boilers. The operating expenses of this single farmer are only considered as electricity and fuel costs. Fuel is a necessary condition to maintain the normal operation of the heating system, and it is the main component of operating cost. Biomass solid briquette furnace heating system boilers have a chain to transport fuel and to promote the secondary combustion of the exhaust fan, conveyor belt and induced draft fan, which are driven by electricity, electricity is also essential for biomass boilers. At present, the area where the farmer is located does not pay the water fee temporarily, and the water loss of the small heating system is less and can be ignored; Farmers manage and maintain the heating system by themselves, so the rest of the operating expenses can be ignored in the heating system of the farmers. According to the investigation and analysis, the prices of biomass solid briquette fuel and loose coal in the market are all 600 yuan/t, and the electricity charges are charged in steps, but the electricity consumption does not exceed the first step during operation, so the first step electricity price is 0.47 yuan/kWh.

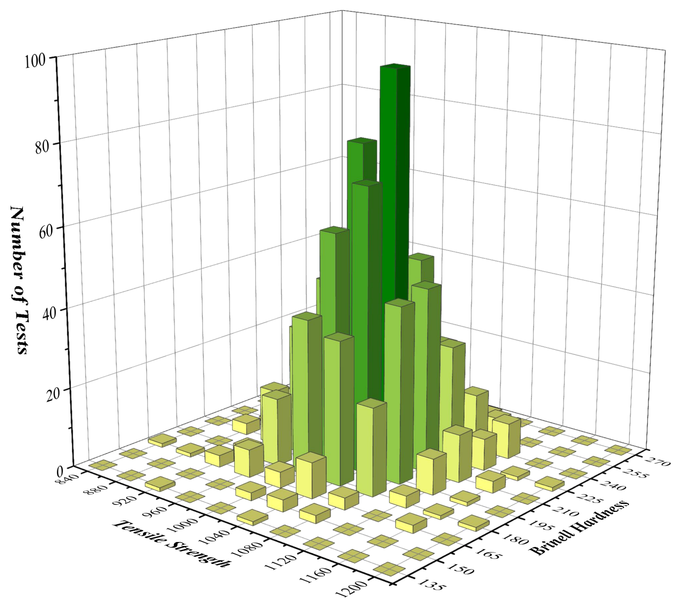

Figure 7. Running Statistics

Figure 7 shows the operation statistics. According to the operation statistics, in January and February 2017, the total consumption of biomass solid briquette fuel was 1.4 t, the electricity consumption was 145 kWh, and the loose coal was 2.2 t. The calorific value of biomass fuel is lower than that of standard coal, and the room temperature of the first household is obviously higher than that of the second household by thermal comfort analysis, but the actual consumption of biomass solid briquette fuel is lower than that of bulk coal, which shows that the use efficiency of small bulk coal combustion boiler is far less than that of biomass solid briquette fuel furnace. According to the proportion of fuel consumed in January and February of each year to the fuel consumption in the whole heating season, the first small household in the whole heating season needs 2.39 t of biomass solid briquette fuel, 247 degrees of electricity and 1550.47 yuan of operating cost; The second small household needs 3.75 t of coal, and its operating cost is 2250 yuan. The initial investment and operation cost of two heating systems are brought into the calculation formula of annual cost value, and the annual cost value of each heating system is obtained. The annual heating cost of the first small household and the second small household is 2079.39 yuan and 2543.80 yuan respectively, that is, the annual cost of replacing the traditional loose coal combustion furnace with a biomass solid briquette fuel furnace can be reduced by 464.31 yuan, and the heating cost per unit area can be saved by 6.70 yuan per square meter every year, with obvious advantages. However, in many areas, especially in remote areas, low-income farmers often buy inferior coal at a low price from lawless elements, about 200–300 yuan/t. The burning value of inferior coal is not high, so farmers can only increase coal consumption blindly in order to improve indoor temperature, and use at least 5t in heating season. The use of inferior coal by farmers not only pollutes the environment, but also increases the investment of farmers' manpower and physical strength, but the annual cost is 1293.65–2293.64 yuan. If the country wants to promote energy-saving and environment-friendly biomass boilers, it must control the illegal trade of inferior coal, pay attention to and improve farmers' income in remote areas, and give certain policy support in special areas.

In the photos of gas and ash produced by the operation of the two boilers, no flue gas emission can be seen by the naked eye after the ignition of the biomass furnace is stable, while black smoke is always emitted during the operation of the loose coal combustion boiler. Searching for literature; The concentrations of soot, SO_2 and NO_X emitted by loose coal combustion are 328.86~3634 mg/m, 69~1443 mg/m and 159~374 mg/m respectively. Biomass solid fuel combustion basically does not emit, and its mass concentration is 1/10~1/2 of that of coal-fired boilers. On November 17, 2017, the 3012H automatic smoke tester was used to monitor the biomass boiler running in the first small household of this typical farmer. The average emission concentrations of sulfur dioxide and nitrogen oxides were 20.05 mg/m, 0.00001 mg/m and 307 mg/m, respectively. These data show that the smoke emission of biomass boilers is far lower than that of loose coal combustion, and the emission can be considered as 0, but the emission is similar to that of bulk coal combustion. The ash contrast diagram between the two is also quite clear. The ash burned by biomass solid briquette furnaces is powdery, also called plant ash, which can be used for fertilization. However, the ash particles produced by loose coal combustion are large, even mixed with black coal particles, which obviously do not fully burn. In the former, the combustion of the furnace body is full with an induced draft fan, and the ash amount is less, which is 1/7~1/5 of the ash amount of the coal-fired boiler. To sum up, from the perspective of environmental protection, biomass boilers still have more advantages than loose coal combustion furnaces.

5. Conclusion

This study reveals the complex psychological motivation behind farmers' collective energy-saving behavior, among which environmental awareness, cost-benefit cognition, social norms and personal responsibility are proved to be the key factors. Targeted interventions, such as energy-saving knowledge training, incentive mechanism and community participation activities, have shown significant effects in improving farmers' energy-saving behavior. These findings underscore the critical importance of comprehending and addressing the psychological motivations that influence farmers' energy-saving behaviors. Individual variances, such as age, level of education, and economic status, exert a substantial influence on the efficacy of intervention measures. Consequently, these distinctions should be taken into account when devising energy-saving strategies, necessitating a more tailored and goal-driven approach. The study posits that policymakers and practitioners should prioritize community-level engagement and collective action in forthcoming energy-saving initiatives to enhance policy effectiveness and long-term viability. The research reveals that the annual heating costs for the first and second small households are 2079.39 yuan and 2543.80 yuan, respectively. In other words, replacing the traditional loose coal combustion furnace with a biomass solid briquette fuel furnace can yield a cost reduction of 464.31 yuan annually, leading to savings of 6.70 yuan per square meter in heating expenses each year—an evident advantage. The average emission concentrations of sulfur dioxide and nitrogen oxides stand at 20.05 mg/m and 0.00001 mg/m, respectively, while the figure for carbon emissions reaches 307 mg/m. These data unequivocally demonstrate that biomass boilers emit significantly lower levels of smoke compared to loose coal combustion, with emissions that can be practically regarded as negligible. Biomass boiler has more advantages than loose coal combustion furnaces.

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