Research and Practice of Passive Low Energy Residential Design in Rural Areas of Semi-Urbanized Regions in Hot-summer and Cold-winter Zone

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Abstract: The applicability of urban building energy-saving ideas and technologies to rural house deserves reflection. It requires to clarify the key points for rural house energy-saving in theory and practical exploration. Principles of Rural Passive Low Energy Residence should be: passive technology preferred and make full use of local conditions, cope with specific comfort standards and moderately enhance envelope performance, optimize energy supply structure and technical benefits should be obvious with reasonable costs. This paper takes the rural house case study design in Yongsheng Village as an example to carry out the research. Based on the principle of "passive priority and active optimization", the residential design makes full use of the potential of local microclimate, plane meets the living needs of winter and summer moderately improves the performance of envelope, takes wind tunnel as auxiliary temperature regulation system, and adopts distributed photovoltaic power generation system to provide domestic energy. The practice has achieved good operation results and obvious economic benefits. It provides an engineering example for the implementation of passive low energy technology in rural.

1. Introduction
The rural in Semi-Urbanized, also called rural-type semi-urban area, are urban-rural transitional areas based on China’s traditional urban-rural dual structural system which appear along with urban expansion, rural lands’ transformation development as well as the rising of peasants’ non-agricultural and part-time level [1],[2].

Due to the close geographic relation with cities, though registered as rural residents on the census register and still conducting relatively traditional rural production modes and living habits, the non-agricultural and economic income level of people in rural semi-urbanized regions is higher than that of people out in the countryside. Villagers’ life mode and their pursuit of life quality are closer to citizens , energy consumption in daily life increases day by day. But as villagers have good energy saving consciousness and accept to obtain longer-term energy saving benefits by increase appropriate investment. On the other hand, the rapid construction of new communities in rural areas further increases the energy consumption demands of residences in these areas. With the land utilization transformation and the intensive use of rural collective construction lands in these areas, a large number of new rural communities appear; but as there has no compulsory requirements of energy-saving in the design of these residences and also lacks of necessary energy-saving construction
measures, the phenomenon of energy losses is serious. In addition, in this area, there are spaces for further urbanization and as people’s life quality will further improve, the residence’s energy consumption will increase further.

The core of passive ultra-low energy consumption is ‘passive’, and the target is to realize ‘ultra-low energy consumption’. By fully tapping passive technical potentials has two meanings for rural buildings’ energy saving in the future. One is on the realistic level, i.e. as rural residences has a low energy consumption of a single building but large construction stock and increment. If it still uses the original energy utilization mode and energy structure which has a low efficiency, it will keep wasting a great number of energy in the future. Second is under the significant background of enhancing overall national building energy-saving requirements and standards, the applicability of urban building energy-saving ideas and technologies in rural area deserves reflections. So it requires to clarify the key points in the energy-saving development of rural residential theoretically and conduct practical explorations. But most of the research in theory and practice focused on urban buildings.

This paper focuses on the passive low energy consumption design target and technical system suitable for rural residential buildings in hot summer and cold winter areas.

⚫ First of all, it analyzes the reasons why the passive low energy consumption goals and principles derived from German passive housing are not suitable for Chinese rural housing in hot summer and cold winter areas, combined with the differences of rural residents’ living habits and thermal comfort standards. The future of rural residential energy conservation should be discussed on the basis of respecting the future energy demand of villagers.

⚫ Secondly, it puts forward the design goal and technical principles of rural residential in particular areas to achieve passive low energy consumption.

⚫ Based on the principles proposed in this paper, relying on the demonstration house in Yongsheng Village, Yibin, Sichuan Province, passive architectural design is carried out, and appropriate passive technologies are integrated and implemented.

⚫ The passive low-energy technology system of the demonstration building includes: respecting the site microclimate for building layout; using natural ventilation and shading to copy with the main contradiction of overheating in summer; moderately improve the thermal performance of building envelope. In addition, the auxiliary temperature regulation system of shallow ground heat source tunnel air is used to realize the auxiliary adjustment of indoor comfort; combined with the residential slope roof, the use of distributed solar photovoltaic power generation system to reduce energy consumption in building operation.

⚫ Through the demonstration project, the feasibility and acceptability of the principle and technology of passive low energy consumption of rural residential in the particular areas are tested. The experimental results show that the integrated technology system has achieved good environmental and economic benefits.

2. Passive Ultra-low Energy Consumption Technology Ideas Originated From Urban Buildings Is Not Suitable for Rural Areas

2.1. Emphasis on the ‘High Performance’ of Building Envelope Is Not Suitable for Realities in Rural Areas

The existing technology and related standards of passive ultra-low energy consumption or near-zero energy construction are developed based on the experience from Germany’s passive houses. Its main design principle and technical strategy emphasize the ‘high thermal insulation performance’ of building envelope, ‘high air tightness’ of building’s exterior door and window system and high-efficient heat recovery fresh air system. However, the emphasis of the building envelope’s high thermal insulation performance and air tightness is not suitable for hot-summer and cold-winter zone which will generate excessive heats in summer and greatly increase residential costs.

Besides, even the residential building has a good air tightness condition, it is also difficult to guarantee the actual air tightness effect due to rural residents’ living habits. The real rural life is
acquaintance society, villagers have frequent and close contacts, so the doors of houses (usually the entrance door) are kept open. In hot-summer and cold-winter regions, this circumstance exists no matter in summer or in winter. So significantly enhancing the air tightness is hard to play the due role.

2.2. Differences in Residents’ Thermal Comfort Identification Standards is Conducive to Reducing Energy Consumption

German’s ultra-low energy building pursue an indoor thermal comfortable environment ‘all the time and within the entire space’[6], which is not suitable for rural families. Even compared with urban residents in China, rural residents’ actual environmental endurance is also very strong[7]. Their comfort range is relatively wider and never pursue the thermal comfort ‘all the time and all the inner space’[8],[9]. In the ‘Standard for Energy Saving Design of Residential Buildings in Hot-Summer And Cold-Winter Regions’(JGJ 134-2010), main function rooms’ calculated temperatures through energy saving (the bedroom, living room, etc.) shall be 18℃ in winter and 26℃ in summer. But according to the indoor thermal environmental parameters calculated with energy saving of rural residence’s main function rooms in hot-summer and cold-winter areas in ‘Standards for Rural Residential Building Energy Saving Design’(GB/T 5824-2013), the calculated indoor temperature is 8℃ in winter and 30℃ in summer. The author found through the field investigations in many rural areas in Sichuan that when the temperature in winter is lower than 5℃, villagers still will have no heating. Such differences in thermal comfort identification standards shall not only be shown in differences in energy saving calculation basis but also be implemented in technical principles and measures.

2.3. Reduction of Energy Consumption Cannot Impact Villagers’ Objective Demands For Improving Comfort Level

Rural families’ energy consumption is relatively lower. If only taking the reduction of actual energy consumption as the standard, it is unfair to require rural residences to save energy. Rural residence’s low energy design shall face up to residents’ rising living quality demands and pay attention to improving the comfort level. Meanwhile, considering the relatively backward economic conditions of rural families, it is also important to reduce technical costs and enhance the sense of benefit gain.

3. Principles of Rural Passive Low Energy Residence

3.1. Passive Technology Preferred and Make Full Use of Local Conditions

Planning and building design shall make full use of local microclimate potentials. According to climate zones and local conditions, it shall adopt suitable passive design ‘combination’ strategies and focus on technical coupling and comprehensive effects.

3.2. Cope with Specific Comfort Standards and Moderately Enhance Building Envelope Performance

Passive ultra-low energy building requires to achieve 75% of energy saving. It is based on the requirement of higher comfort level ‘all the time and within the entire space’. In hot-summer and cold-winter regions, rural residents’ environmental tolerance is strong, especially in the winter; the thermal comfort issues brought by the high temperature in the hot summer is more prominent. So, one hand, it shall not force to significantly enhance building envelope performance and air tightness of building. On the other hand, the passive design should pay more attention to cope with the influence of the high temperature and high humidity in the summer and provide good natural ventilation.

3.3. Optimize Energy Supply Structure

Energy efficiency is the core of green building. Under the existing development condition, rural residents’ energy consumption is low in absolute value, while it is more urgent to solve the energy utilization structure. According to ‘Standard for reporting and verifying domestic energy consumption of rural dwellings’ (CECS 309:2012), rural residences’ energy consumption includes seven aspects
including ‘heating, cooling, cooking, lighting, household appliances, domestic hot water and others within the scope of house sites. Among them, energy losses in energy consumption of heating and cooling (by air conditioners) can be controlled by improving the building envelope structure’s performance and household energy consumption on the other five aspects can be controlled through energy supply by adjusting the energy structure of rural family and increasing the proportion of more efficient renewable energies.

3.4. Technical Benefits should be Obvious with Reasonable Costs.
Energy saving design and technology often refer to the utilization of materials and equipment with better performances. Economical efficiency of them is the focus of rural families not only the low absolute costs. The reasonable technical costs shall be that the incremental costs of technical investment are affordable. The rural family’s economic condition in the semi-urbanized areas are relatively good. With the active urban-rural interaction, residents’ energy saving consciousness is advanced, they can afford and also are willing to afford certain investment in energy saving technologies. While compared with the costs, they focus more on the expected benefits brought by the technologies. It is conducive for the true realization and promotion of energy saving technologies in the rural areas only by making rural residents truly feel the enhanced indoor comfort level and obvious reduction in costs of heating and cooling and make them actually obtain the benefits brought by low energy technologies.

4. Practice of Passive Low-energy Rural Residences in Yongsheng Village, Yibin, Sichuan
In this part, it will takes the demonstration rural house(Shown Fig.1) in Yongsheng Village, Yibin, Sichuan as an example to explain the application and reflections of the concept of rural passive-centered low energy consumption residences in engineering practices as stated in the above. The project is conducted mainly from the following aspects:

![Real view of the house being built](image)

\(\text{Fig.1} \) Real view of the house being built

- Passive building design priority. provide good shading and ventilation, residential layout utilize the local climate featuring river-land wind and organize internal natural ventilation in an effective way.
- Refer to the standard of urban residential buildings’ 50% of energy saving and enhance the thermal insulation performance of building envelope;
- Use the shallow ground source and tunnel wind system to facilitate regulation of the indoor thermal environment;
- Introduce the photovoltaic power generation system to solve household energy consumption.

4.1. Basic Conditions of Residences’ External Environment

4.1.1. Location
The case study house located in Yongsheng Villager’s settlement (with a total of 52 residences) in Lizhuang Town, Yibin. The settlement is close to Binjiang Road-Yanli Road, and about 3 miles away from the entrance of Lizhuang (Historic Towns of China), and about 30-minute ride away from Cuiping District (the core district) in Yibin (Shown in Fig.2). The house is an independent two-floor building with a sloping roof. The total area is 239.24M².

4.1.2. Climate Characteristics
The settlement locates by Yangtze River on a higher ground (shown in Fig3.). The land is flat and influenced by the river-land wind. The temperature at night declines rapidly, so the temperature difference between day and night is obvious. The site has a high air humidity with an annual average humidity remaining above 80%. Seen from the continuous field measurements of outdoor temperature and humidity in winter (the testing period lasts from January 18, 2016 to January 27, 2016), its lowest temperature in winter is no lower than 0℃.

4.1.3. Villagers’ Demands
Villagers here will either go out for non-framing works or provide home-stay-tourist service relying on Lizhuang all of whom enjoy good family economic conditions. Air conditioners, heating equipment and solar water heaters are popular. They are more sensitive to the hot environment in summer than that in winter. In the early investigation, it can be found that villagers who feel ‘hotter’ or ‘very hot’ in summer account for more than 50%, but they usually response with ‘not cold’ or ‘ok’ in winter.

Due to the summer is both hot and humid, the key point in improving residences’ comfort is to enhance natural ventilation for comfortable physical feeling in summer, and improve building envelopes’ thermal insulation performance so as to cope with the thermal insulation demand in winter.

4.2. Residential Building Layout Cope with Microclimate
Passive building design is an optimal combination process under complex constraints. It shall first focus on the local climate condition and utilize natural resource to the utmost extent through reasonable designs and adoption to the climate characteristic[10][11][12]. Then also take social and cultural background into consideration.

As the constructable range of the settlement is in a long strip, the overall building layout shall be considered comprehensively based on orientation, land saving, microclimate characteristics, construction scale, etc. The residences face Lizhuang (at 55° north by east) so as to respond to the local cultural demands(Fig.3). But as this orientation is not good for the main rooms to receive sunshine in winter. So, it requires to pay attention to the orientation of main living rooms in plane design and also prevent the sunshine from the western exposure in summer. The building layout is basically vertical to the river bank line and natural river-land wind ‘channel’ can be formed between rows of buildings so as to guarantee each household to obtain well outdoor natural ventilation.

If the building is generally facing the river (about 39° north by west), it will bring better landscape. But it can not satisfy local culture; on the other hand, this orientation is neither a suitable orientation range according to microclimate. As the space between rows of buildings is not spacious, it is easy to generate a large scope of wind shadow which is not conducive to obtaining a good outdoor air environment (Fig 4. and Fig.5).

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In the local customs, it hopes that the main entrance of each residence will face Lizhuang Ancient Town as it is said that this will bring lucks in making money.
4.3. Natural Ventilation and Sunshade

Compared with winter, the contradiction between the heat and humidity in summer is more prominent as it has a greater influence on people’s life and will consume more energy to cooling. There are more cloudy days in winter in Sichuan so direct sunshine is scarce, so the internal design should consider how to obtain more direct sunshine for main rooms to improve the indoor thermal environment in winter. Therefore, the plane design attaches importance to indoor natural ventilation and receipt of direct sunshine in the frequently used rooms.

As shown in Fig.6, the layout of door and windows aims to form cross ventilation for summer. On the first floor, there will be cross ventilation channels between the entrance door and the opened windows in the dining room which is conducive to forming large-space air flow. On the second floor, there will be a through air flow channel between the open windows in the living room and stairs. In order to get the direct sunshine in winter, the main rooms shall face the southwest by 55° south by west, which is opposite to the entrance. In this way, the drawing room, the dining room, the living room and three of the four bedrooms (in total of 7 main rooms) can obtain sufficient sunshine.
It can be determined through Ecotect’s Weather Tool that the residence’s best orientation over the whole year is 17°30′ south by east. But combined with the settlement’s overall layout, it can be found that main rooms’ orientation shall be 55° south by west (Fig. 7). Though it can obtain more direct sunshine in winter, there are western exposure in summer. To cope with thermal insulation and sunshine from the western exposure, a combined shading system is designed for external windows. Considering the coordination with the facade molding, the exterior windows are designed as bay windows. Vertical sunshade is mainly used to shade western exposure. The level and vertical sunshades formed a combined sunshade unit. The bay windows’ baseplates can also provide utility functions.

4.4. Moderately Enhance Building Envelope Performance According to the Standards of Energy Saving By 50%

Residences’ building envelope is 200mm-thick autoclaved aerated mixed clay block by adopting XPS plate as the external insulation material (see Fig.8). Light material is conducive to thermal insulation in summer, easy to be constructed with relatively low process requirements and could have relatively good completion under the existing technological conditions in rural. External windows adopt double hollow glass windows made of bridge-cutoff aluminum alloy (6mm+12 mm+6mm) and the reinforced concrete roof panels adopt 50mm-thick XPS as the insulation layer. Main insulation (components) materials’ heat transfer coefficients refer to Chart 1. In order to strengthen the overall external insulation, insulation materials are also used to fill the gaps on walls between windows and sun shields so as to weak cold bridges.
Chart 1 Heat Transfer Coefficient of Insulation Materials And Each Component Used in Residences’ Building Envelope

| Building Part | Main Insulation Materials | Thickness (mm) | Material’s Heat Transfer Coefficient (W/(m²·K)) | Average Heat Transfer Coefficient (W/(m²·K)) | Standard Value (W/(m²·K)) |
|---------------|---------------------------|----------------|-----------------------------------------------|-------------------------------------------|---------------------------|
| External Wall | XPS                       | 35             | 0.030                                         | 0.63                                      | 1.0 (S≥0.43 D>2.5)       |
| External Window | Double Hollow Glass Windows Made of Bridge-cutoff Aluminum Alloy | 6+12+6         | 2.9 (Glass Part)                              | 3.2 (Including Window Frame)             |                           |
| Bay Windows’ Top Tray, Bottom Plate And Side Plate | XPS                  | 100            | 0.93                                          | 0.93                                      | 2.0                       |
| Roof          | XPS                       | 50             | 0.030                                         | 0.6                                       | 0.6                       |

According to ‘Standards For Sichuan Province’s Residential Building Energy Saving Design’ DB51/5027-2012, Dest-H is adopted to conduct residential energy saving performance simulation. The result shows that the annual total energy consumption is 13944.64 kWh and the reference building’s total energy consumption is 16245.68 kWh with a building energy saving rate arriving at 57.08% (see Chart 2).

Chart 2 Energy Saving Effect Simulation Calculation Result

| Indicator Item        | Reference Building | Demonstration Building | Remark            |
|-----------------------|--------------------|------------------------|-------------------|
| Thermal Load (kWh)    | 11722.28           | 9848.51                | Dest Software Calculation |
| Cooling Load (kWh)    | 4523.4             | 4096.13                | Dest Software Calculation |
| Total Energy Consumption (kWh) | 16245.68        | 13944.64               |                   |
| Energy Saving Rate ηe | 57.08%             |                        |                   |

4.5. Low Power Indoor Comfort Adjustment: Shallow Ground Source Tunnel Air Auxiliary Temperature Regulation System

The auxiliary temperature regulation system consists of air through tunnel, ventilation shaft and air supply pipeline system (see Fig. 9) which makes use of natural sources of heat and cold located on the shallow ground. It takes air as the media to improve indoor thermal comfort[13].

Air tunnel adopts finished concrete pipes with a diameter of 1.1m and the total length is 50.2m (See Fig. 10). Its buried depth is 2.0m (the distance between center point of pipe section and indoor grade level. See Fig. 11). The underground coiling arrangement is connected to the ventilation shaft and the air inlet is located on a side of the house. The indoor air supply shaft consists of two square concrete shafts with cross-section in parallel. The net size of each shaft’s inner wall is 0.4m*0.4m which supplies air independently for each floor. Air outlet is located on ceiling of the dining room on the first floor. On the second floor, the air supply shaft combines with ventilation ceiling to supply air to each room through axial fans (The air supply system for each floor can be controlled independently).
It is reflected from the temperature and temperature differences of tunnel air inlet and outlet (testing point sees Picture 13) that the temperature during the hottest periods in summer will drop by an average of 5℃ and that in winter will drop by an average of 6.9 ℃ (See Chart 3). Under the condition of an average temperature of -0.5 ℃ at the air inlet in winter (Testing period is from January 23, 2017 to January 24, 2017), the average temperature of all air outlets was 6.9 ℃ with the maximum rising was by 7.5 ℃. The average temperature of air outlets in bedrooms facing northwest on the second floor could arrive at 5.9 ℃ (See Chart 4). In summer, the test was conducted during the period of maximum sunshine from the western exposure in the afternoon of the typical hottest day (the testing period is from 15:00-16:00 on August 23, 2016.). When the average temperature at the air inlet was 35.9 ℃, the temperatures of all air outlets were stable (See Fig 12); the maximum decreasing temperature could arrive at 5.4 ℃ and the minimum was 4.6 ℃, with an average decreasing temperature of 5 ℃. The temperature at the air outlets in the dining room on the first floor dropped in a most prominent way, by 7.1 ℃(See Chart 3). The temperature of indoor air outlet in the living room on the first floor was basically kept between 28 ℃ and 29 ℃.
| Test Position          | Effective Testing Period | Temperature (°C) | Decreasing Temperature (°C) |
|-----------------------|--------------------------|------------------|----------------------------|
|                       |                          | Maximum Value    | Minimum Value              | Average Value | Maximum Value | Minimum Value | Average Value |
| Tunnel Air Inlet      | 2016.8.23 15:00-16:00    | 36.4             | 35.2                      | 35.9          | /             | /             | /             |
| 1F Dinning room       |                          | 29.2             | 28.5                      | 28.8          | 7.5           | 6.7           | 7.1           |
| 2F Living Room        |                          | 31.8             | 28.5                      | 31.6          | 4.7           | 3.9           | 4.4           |
| 2F Master Bedroom     |                          | 32.2             | 31.8                      | 32.1          | 4.2           | 3.5           | 3.9           |
| 2F Bedroom Facing North |                        | 31.5             | 20.9                      | 31.2          | 5.2           | 4.3           | 4.8           |
| Average Value of All Outlets |                | 31.1             | 30.6                      | 30.9          | 5.4           | 4.6           | 5.0           |

**Chart 4 Tunnel Heat Transfer Performance in Winter**

| Test Position          | Effective Testing Period | Temperature (°C) | Decreasing Temperature (°C) |
|-----------------------|--------------------------|------------------|----------------------------|
|                       |                          | Maximum Value    | Minimum Value              | Average Value | Maximum Value | Minimum Value | Average Value |
| Tunnel Air Inlet      | 2017.1.23 19:00          | 0.1              | -0.9                      | -0.5          | /             | /             | /             |
| 1F Dinning room       | 2017.1.24 09:00          | 7.8              | 5.8                       | 7.0           | 8.2           | 6.0           | 7.5           |
| 2F Living Room        |                          | 6.8              | 5.8                       | 6.4           | 7.5           | 6.2           | 6.9           |
| 2F Master Bedroom     |                          | 6.8              | 5.4                       | 6.1           | 7.2           | 5.6           | 6.6           |
| 2F Bedroom Facing North |                        | 6.6              | 5.5                       | 5.9           | 7.3           | 5.8           | 6.4           |
| Average Value of All Outlets |                | 7.6              | 5.6                       | 6.5           | 7.9           | 5.8           | 7.0           |
| Tunnel Air Inlet      |                          | 6.9              | 5.7                       | 6.4           | 7.6           | 5.9           | 6.9           |

Fig. 13 Test location for heat transfer performance of tunnel air system
4.6. Clean Renewable Energy: Household Distributed Photovoltaic Power Generation System

Photovoltaic power generation system was used to supply electricity for household equipment. At the same time, through the grid-connected to create additional benefits. Compared with cities, houses in rural have a low residential volume with smaller shading but high air cleanliness. Though Sichuan is a region lacking of solar energy in China, its major issue is the uneven distribution of sunshine over the whole year and its amount of solar radiation during the concentration period in summer is larger than the average national amount which has the feasibility of using[14][15].

Grid-connected photovoltaic power system used by the case residence consists of 8 photoelectric boards in a total size of 12.76M². It is located on the sloping roof at 35°south by east (See Fig 19 and Fig 20) and the sloping roof’s slope gradient is 30°. The system’s designed maximum generating power is 2KWP with an annual generating capacity of 2088KWh. It was officially put into used in January, 2015 and in June, 2015, it realized the grid connection with the State Grid.

After the system was put into service for one year, it is found by checking the household electricity consumption record in the State Grid. It is showed that from the day in June 2015, when the system was successfully grid-connected to the State Grid to April 15 2016 (in total of 319 days), the system generated in total of 1364 KWh of electricity and its daily average generating capacity was 4.27KWh. During the same period, its theoretical generating capacity was 319d / 365d * 2088 KWh =1825 KWh, and its actual generating efficiency was 1364 KWh / 1825 KW =74.7%. Also during the same period, the resident’s actual electricity consumption was 752 KWh, accounting for 55.1% of the actual generating capacity. The system saved a cost of ¥376 in electricity consumption for the resident (calculated according to ¥0.5 yuan/Wha) and obtained an economic profit from electricity sale of ¥306. The photovoltaic system has a designed service life of 25 years and without considering equipment aging, decline in generation efficiency, it can generate electricity of 4.27*365*25=38964 KWh cumulatively and save ¥10,755 in household electricity consumption and the revenue from sales of the overflowed part can be ¥8,753 with an accumulated revenue of ¥19,508. For regions lacking of solar energy resources, this system can not only satisfy household demands but also realize good economic benefits.

5. Conclusion

This project was completed at the beginning of 2015.

Test of typical indoor temperatures in summer (testing period lasts from 17:30 on August 22, 2015 to 17:30 on August 23, 2015) shows that under the same service conditions, compared with the
neighboring contrast residence without heat insulation provided by external building envelope, and the condition when the tunnel air system works, the period when the temperature within the test room was below 30°C extended from 16.5hs (from 19:30 on August 22, 2015 to 12:30 on August 23, 2015) of the contrast residence to 21.5hs (17:30 on August 22, 2015 to 15:30 on August 23, 2015). Indoor comfort period lengthened by 5hs which was extended by 30% (See Picture 16). The average temperature within the test room of the case building was lowered by 1.5°C than that of the contrast building.

The case studying does not emphasize the ‘high performance’ of building envelope and ‘strong’ air tightness, or complex heat energy recovery equipment. But it tries to fully tap into the passive technical potentials and adjusts energy supply structure based on the standard of 50% energy saving by introducing clean energy. According to the above, it explores a localization route suitable for hot-summer and cold-winter rural areas that is different from urban residential passive ultra-low energy consumption technical route.

After being put into service, the residence’s indoor thermal comfort time range in summer was extended obviously in which the use of tunnel air played a role of regulating the indoor thermal environment. Its regulation effect in summer was much better than that in winter. The photovoltaic power generation system provided all electricity for household appliances and also brought obvious economic benefits by grid-connection. The implementation of the design provides an engineering demonstration for the landing and promotion of passive low energy consumption technologies in rural areas.

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There is no body living in the test room nor the contrast room during the testing period so there is no influence by human activities or household appliances, etc. In the test room, there is a tunnel air system to supply air

Rural population’s thermal comfort temperature range is 10-30°C.
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