POTENTIAL OF ENERGY CONSERVATION THROUGH RENOVATION OF EXISTING RESIDENTIAL BUILDINGS IN CHINA -THE CASE OF HANGZHOU CITY IN THE HOT SUMMER AND COLD WINTER REGION OF CHINA

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ABSTRACT: Existing buildings here are referred to the buildings designed and constructed before the energy conservation standard of China was executed. In this paper, the potential of energy conservation of urban existing residential buildings in the Hot Summer and Cold Winter Region of China were studied. Firstly, three types of residential buildings were selected as the study cases in Hangzhou, which are general urban buildings, historic residential buildings and rural housings. Secondly, the present envelop conditions of these existing buildings were surveyed and analyzed. Then, suitable renovation plans of thermal performance were made according to the considerations of less retrofit, simple technology, short construction period and clear effect. Consequently, the effects of energy conservation were simulated according to the renovation plan. Great potential of energy conservation could be found in the simulation analysis, which could be helpful to the decision and policy making in the practice of renovation of urban existing buildings.
KEYWORDS: existing building, energy conservation, renovation, simulation

1 INTRODUCTION

With the rapid economic development in China, more and more energy is consumed for the improvement of people's living conditions. Most of the existing housings, however, were built with poor thermal qualities, and the energy efficiency of these buildings is very low.

Existing buildings in this paper are referred to the buildings designed and constructed before the energy conservation standard of China was executed. There was almost no consideration of energy conservation in these existing buildings; therefore, the thermal performance of the existing buildings is very bad, and the indoor thermal environment quality is quite poor. The energy consumption of existing buildings is about twice than the requirement of the energy conservation standard; and three times than the standard of developed countries with the similar climate conditions. There are large quantities of existing buildings in China with high energy consumption and low thermal comfort. Therefore, it is of great emergency to carry out research and practice on the renovation for them.

A number of studies [1-5] in some European countries have proven that energy-efficient retrofitting of existing residential buildings with poor thermal quality would benefit much to energy security and environmental protection in reducing energy consumption in the city.

In this paper, the potential of energy conservation of urban existing residential buildings in the Hot Summer and Cold Winter Region of China were studied. Firstly, three types of residential buildings were selected as the study cases in Hangzhou City, which are general urban housings, historic residential buildings and rural buildings. Secondly, the present envelop conditions of these existing buildings were surveyed and analyzed. Then, the suitable renovation plans of thermal performance were made according to the considerations of less retrofit, simple technology, short construction period and clear effect. Consequently, the effect of energy conservation was simulated under the renovation plan.

The China has 5 climatic regions according to the Thermal Design code for Civil Buildings [6], which are Severe Cold Region, Cold Region, Hot Summer and Cold Winter region, Hot Summer and Warm Winter Region, and Temperate Region, see Fig.1. Residential buildings in Hot Summer and Cold Winter region must include both heat insulation (in summer) and heat preservation (in winter) in thermal designs. This region accounts for more than 40% of the Chinese population and nearly 50% of the country's economy.

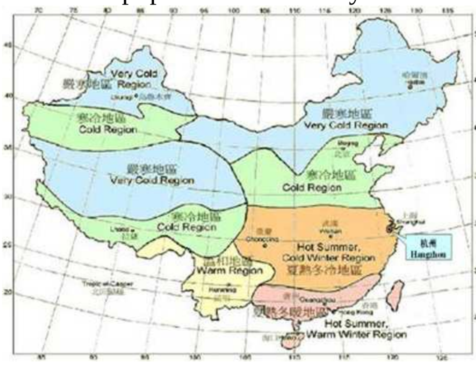

Figure 1 Climatic Regions of China and the location of Hangzhou City

Hangzhou City, the capital of Zhejiang Province, is a typical Hot Summer and Cold Winter city in the region (Fig.1). It is located in the South Wing of the Yangtze River Delta, which is the most economically developed region in China. The per capita GDP of the city grew three times than that of China average during 1996 to 2005. The energy shortage of the province has also restricted the economic development and normal residential life seriously. The Hangzhou Statistical Yearbook [7] reported that urban residential electricity consumption increased from 986 kWh million in 2000 to 2,798 million kWh in 2005.

The Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter zone [8] was executed from 2001 in Hangzhou City. According to the Hangzhou Statistical Yearbook [7], more than 250 million m^2 of residential buildings were built in the city before 2001. There was almost no consideration of energy conservation in these residential buildings. Therefore, the thermal performance of these buildings is very bad, and the thermal environment quality is poor. In this paper, three types of residential buildings were selected as the study cases in Hangzhou, which are general urban buildings, historic residential buildings and rural buildings.

2 SURVEYS OF THERMAL CONDITION OF THE EXISTING BUILDING IN HANGZHOU

2.1 General urban building

A seven-floor typical urban residential building built in 1995 was selected as one of the research objects (See Fig.2). It is located in the Zijin Neighborhood of Hangzhou. There are 28 households in the building without vacancies. Most of the residential storied-buildings before 2001 were built with the same structure and materials as this building. Therefore, it holds typical value for the research of energy efficient renovation of general urban residential buildings.

Thermal performance: The object building's thermal variables were made clear through the surveys of the blueprints of the building, as well as some on-site surveys. The exterior windows are made of aluminum frame and 5mm flat glass, with the heat transfer coefficient (*K*) and shadow coefficient (*SC*) of 6.25 $W/(m^2 \cdot k)$ and 0.80. The exterior walls are made of clay brick and the roof is made of cement board. The *K* value of the roof and exterior walls are 3.969 $W/(m^2 \cdot k)$ and 2.355 $W/(m^2 \cdot k)$ respectively.

Figure 2 Photos of the general urban case residential building

Energy Consumption Simulation**:** The response coefficient method was a proven dynamic whole-building simulation method and can accurately calculate the hourly building heating and cooling loads of one year. The only simulation program recommended in the standard [8], Doe-2, was eligible and would be applied to calculate the energy consumption for heating and cooling loads of the object buildings in the paper. Through simulation, we can find that the current annual energy consumption for space heating and cooling is 90.79 kWh/(m^2·yr).

2.2 Historic urban buildings

Wooden building has a history of nearly 3,500 years in China. In the area of Zhejiang Province and Jiangsu Province, the main frame structures of traditional dwellings are wooden, such as beam, column, stairs and floor slab. The envelop is often made of brick and the inner surface is made of thin wooden sheet. Windows and doors are also wooden. Although almost all of the residential buildings in Hangzhou are built with the concrete structure now, there are also some old wooden buildings in the city, which are of high historic values. These residential buildings should be protected and renovated instead of demolition.

The residential building of Zhu Yangxin, is one of the case buildings of this research. It is one of the Designated Historic Conservation Buildings of Hangzhou City. It is located in Dajing Lane, which is the famous historic district of Hangzhou. The building is constructed in the Late Qing Dynasity of China, with the typical wood and brick structure.

General architectural conditions of Zhu Yangxin Historic Building: We made investigations on the basic status of the building. We found that the envelop of the building is made of brick and rammed soil, and the frame structure and inner surface of the wall are wooden.

Although the whole structure of the existing building is kept relatively completed, some parts are damaged seriously. The roof has several leaks, and the air tightness of windows and doors is rather poor. Some parts of the envelop were damaged and were repaired with materials of poor thermal insulation properties, such as iron sheet. The outer and inner plastering surface of the rammed-soil envelop split off in many places(Fig. 3).

Investigation on the thermal environment condition: There are two kinds of external walls in the building: Type 1 is made of 600 mm rammed soil and Type 2 is made of 40 mm wooden sheets. The pitched roof is also made of wooden boards.

For the safety reason, we could not conduct measurement of thermal environment on the building. Therefore we conducted investigations on a similar building nearby, which is preserved in relatively good condition. The investigation was conducted on 25-27, Feb., 2009.

Figure 3 Photos of the case historic residential building

The investigation was divided into two steps. In Step1 of the condition of no-heating, the temperature, humidity and thermal comfort level were investigated. In Step2 of the condition of heating, heat transfer coefficient of the envelop and external windows were investigated, as well as the factors of temperature, humidity and thermal comfort level.

From Fig.4, we can see that the mean outer temperature is 7□ with the maximum temperature 9.6□ and minimum temperature 6□, and there is no abrupt change in temperature, which shows the typical condition in winter in Hangzhou. In the case of no-heating, the mean indoor temperature is 11.2□, 4-5□ higher than the outer temperature, with the maximum indoor temperature 13.55□and the minimum indoor temperature 9.5□. There is also no abrupt change in indoor temperature.

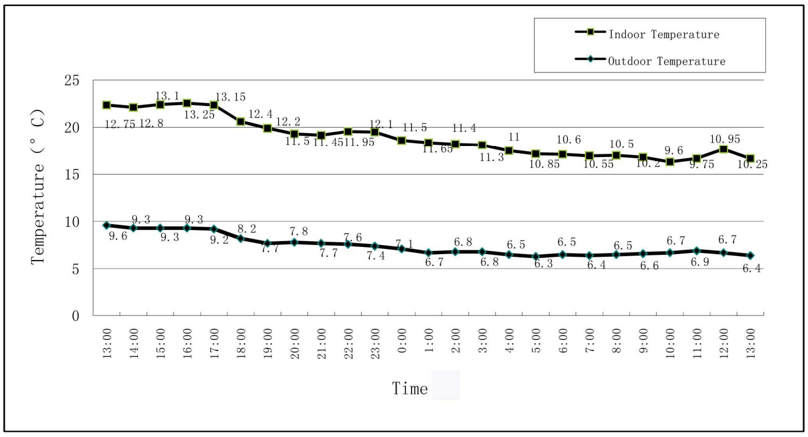

Figure 4 Indoor and outdoor temperature in condition of no-heating

It is indicated in the Fig.5 that in the condition of no-heating, the mean PMV is -1.07, and the minimum PMV is -1.39, which both are beyond the standard of China, -0.75~0.75[9]. People indoor feel cold living in such conditions. During 24 hours in a day, PMV of daytime is slightly higher than that of nighttime and in the early morning the PMV is minimum. PPD shows that there are at most 45% and at least 14.4% of the people, who are not satisfied with the indoor thermal environment. Anyway, in the condition of no-heating in winter, thermal comfort level in such building is generally low.

From Fig.6, we can see that the mean outer temperature is 6.7℃ with the maximum temperature 7.4℃ and minimum temperature 6.1℃. In the condition of room heating, the indoor temperature range from 20-25℃, and when heating to stable condition the indoor temperature keeps at 25℃. The temperature difference between indoor and outdoor is 16-18℃.

When heating, the maximum indoor PMV is 0.56, and the minimum PMV is -0.615 (Fig.7). There are at most 12.9% and at least 5% of the people, who are not satisfied with the indoor thermal environment. Although there exist some fluctuations, the PMV are still in the range of the standard of China, -0.75~0.75. It is concluded that after heating the thermal comfort level has been improved significantly and can meet the thermal comfort request of most people indoor.

Figure 5 PMV in condition of no-heating

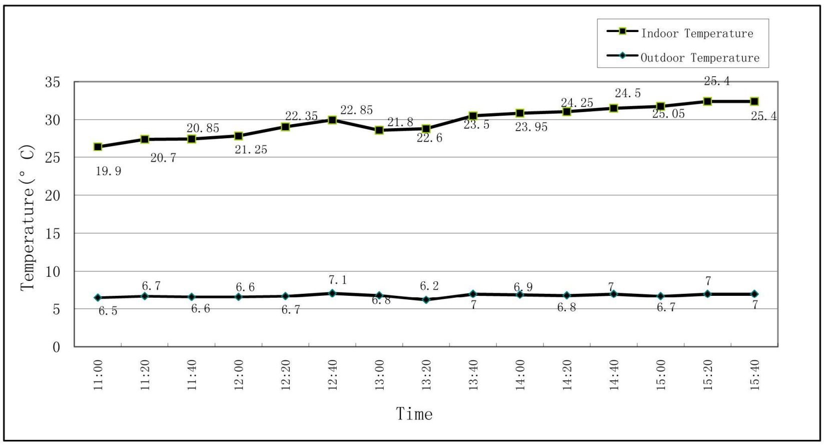

Figure 6 Indoor and outdoor temperature in condition of heating

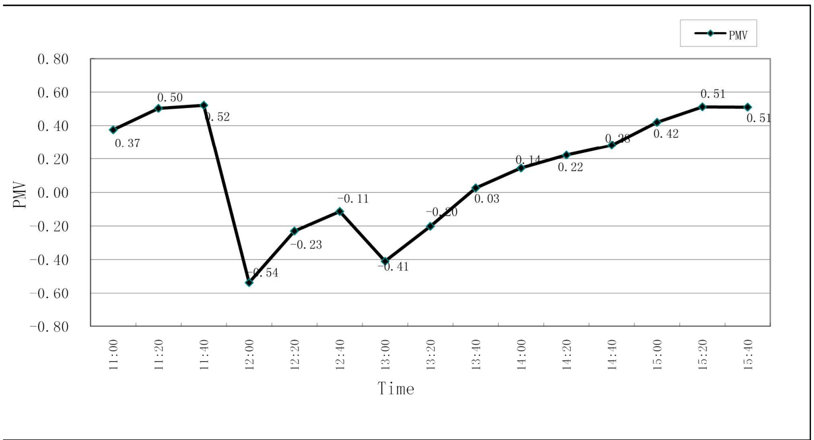

Figure 7 PMV in condition of heating

As indicated in the Fig.8, before 13:00 siginificant change amplitude can be noted due to unstable indoor temperature and frequent people move in and out. After 13:00, the indoor temperature tends to be stable and the heat flux could be adopted to calculate the thermal resistance of the envelop.

It is also sown in the Fig.8 that the heat flux of Wall 1 and Wall 2 are close, and heat loss of Window 2 is more than that of Window 1 due to poor air tightness of Window 1. In general, the heat loss of inner wall is relatively small, with the average of 24.7W/m^2. Then comes the wooden external wall, with the average of 31.6 W/m^2. The heat loss of the window is the biggest, with the average of 51.2 W/m^2.

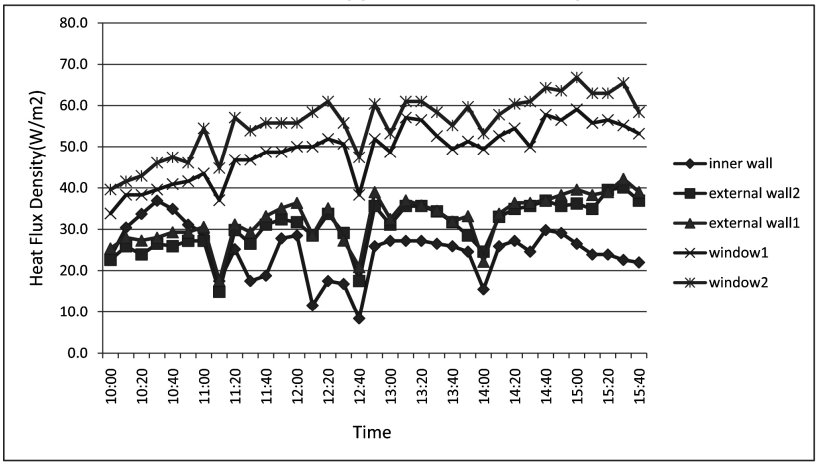

Figure 8 Heat flux

Accordingly, the heat transfer coefficients of these parts of the envelop are calculated, see Table 1, in which the heat transfer coefficients requested by the design standard are also listed.

Table 1 Heat transfer coefficients

	External wall	window
Heat transfer coefficient by measurement (W/m^2·K)	3.378	5.618
Heat transfer coefficient requested by the standard (W/m^2·K)	1.5	2.5

The thermal comfort level was improved after using the heating appliance; however, the heat transfer coefficient of the envelope was very big, which means the heat loss of the envelope was very high. From Table 1 we can find that the heat transfer coefficients of the external walls and windows are about twice than that of the requirements of the design standard. Therefore, the energy conservation potential is very high for this kind of existing historical residential buildings.

2.3 General rural buildings

There are about 800 million people living in the countryside in China now. By the end of 2005, there are 22 billion m^2 rural residential buildings in the country, and the annual construction area of new building is about 800 million m^2, in which residential building area is about 600 million m^2. However, in the new constructions, only basic living conditions such as safety, sanitary, space arrangement etc are considered, while the thermal comfort and energy conservation of the building are seldom taken into consideration. Although the design standard of energy conservation has been taken into effect in the Hot Summer and Cold Winter Region since 2001, the construction of rural housings are not compulsorily required to obey the standard yet. Furthermore, large quantities of exiting rural housings are of severely poor condition of thermal performance. With the rapid economic development of the countryside in China nowadays, the energy consumption of heating, cooling, lighting and so on increase faster and faster year by year. Therefore, the potential of the energy conservation through renovation are very huge in the countryside.

<u>On site survey and measurement:</u> In February 2009, we conducted an on-site survey and questionnaire survey in Anji County. We found that most of the existing rural residential housings are constructed during the end of last century and the beginning of this century. Most of the housings are of 2-3 floors, with the area of 150~250 m^2 per building.

In this research, a typical building was selected as our research subject, see Fig.9. This building of 2 floors and total area 220m^2 was constructed in the May of 2008. The external wall was constructed with clay brick of 240mm thickness, whose average heat transfer coefficient is 1.62 (W/m^2.K). The pitched roof was made of wood frame with asbestos cement board, whose average heat transfer coefficient is 1.59(W/m^2.K).

The windows are push-pull type, single glazed windows of aluminum frame, whose average heat transfer coefficient is 6.4(W/m^2.K). According to the design standard of energy conservation of residential buildings in Zhejiang Province, the heat transfer coefficient of the wall, roof and window cannot meet the requirement.

Figure 9 Photo of the case rural building in Anji County of Zhejiang Province

The measurement of thermal comfort of the housing was performed on 13th, February, 2009. The climate that day is quite typical in the winter. The indoor and outdoor temperature is illustrated in Fig. 10, without space heating. The thermal comfort level of the indoor environment is shown in Fig.11.

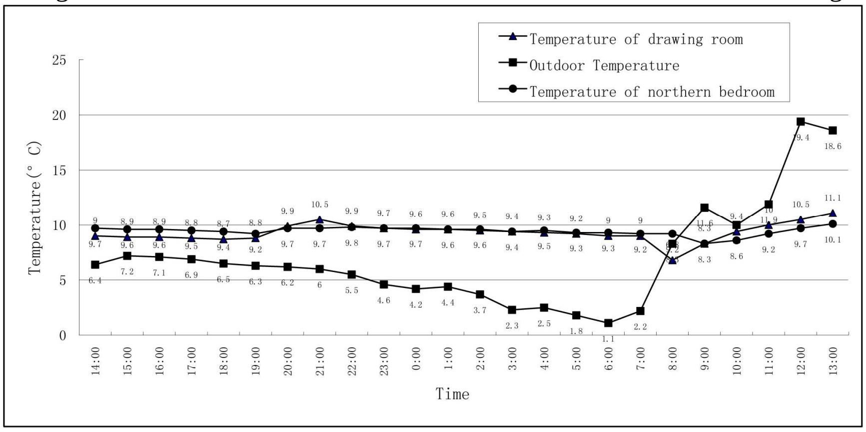

Figure 10 Indoor and outdoor temperature in Anji rural building

From Fig. 11, it can be seen that the thermal comfort of the room is dissatisfied. The PMV values were all below -1.0, which means that the thermal environment was evaluated to be cold. Few people use heating equipment in the winter in the countryside like Anji County, and the thermal environment condition of the housing is poor.

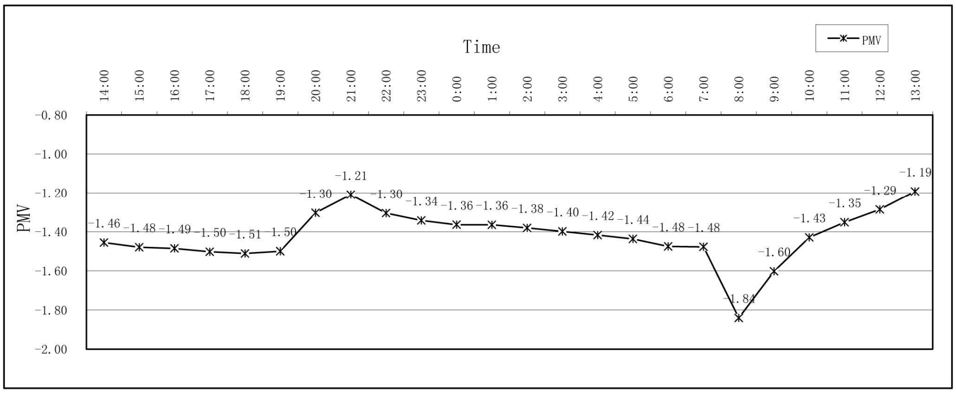

Figure 11 PMV in Anji rural building

Simulation of the energy consumption of space heating and cooling: Most of the people do not adopt space heating and cooling in Anji nowadays. However, with the development of the economy and quality of life, it is predicted that more and more people will use the electrical appliance to improve their thermal comfort condition of the buildings, and the energy consumption of the rural buildings will increase quickly. Therefore, we simulated the annual energy consumption of the housing in the condition of using air conditioning equipment by means of the software recommended by the design standard. As a result, the simulated annual energy consumption for space heating and cooling will be 104.861 kWh/ m^2, which will exceed the required value of the design standard greatly (68.184 kWh/ m^2). Because there is not any measure for the energy conservation in the design, the waste of the energy will be very serious in the near future.

3 SUITABLE RENOVATION PLANS OF THE EXISTING BUILDINGS AND THE ENERGY CONSERVATION EFFECTS

3.1 General urban building

Suitable renovation methods: Six rational renovation methods are suggested according to the considerations of less retrofit, simple technology, short construction period and clear effect.

Method 1: Installing two doors at the two entrances of the building respectively and installing windows for the entire staircase to separate the staircase from the outside air.

Method 2: Substituting plastic double glazed windows for old ones. The *K* and *SC* of the exterior windows change to 2.85 W/(m^2·k) and 0.70.

Method 3: Applying curtains and/or aluminum blinds to reduce the *SC* of the exterior windows to 0.30 in summer.

Method 4: Adding insulation material (40mm XPS) to the roof to change the roof's *K* and *D* to 0.672 W/(m^2·k) and 2.376.

Method 5: Adding insulation material (10mm XPS) to the exterior walls to change the *K* and *D* to 1.296 W/(m^2·k) and 3.236.

Method 6: Applying light colored paint to the surface of the exterior walls and roof to change the absorption coefficient of the outside surface to 0.4.

Analysis of energy saving effect of the renovation methods: After completing the simulation calculation, the total energy use for heating and cooling loads of the suitable plan was 48.77 kWh/(m^2·yr). While the current value is 90.79 kWh/(m^2·yr), the overall energy-saving effect of the suitable plan was very encouraging, with about 46.28% reduction of the annual energy use for heating and cooling loads in simulation calculation.

3.2 Historic urban residential building

Suitable renovation methods: The suitable renovation methods were proposed to the historical urban residential buildings with consideration of their special wooden structure and historical value, as following:

External walls: For the rammed soil walls, the external insulation of insulating mortar consisting of gelatinous power and expanded polystyrene pellets of 40mm thickness was applied. For the wooden wall, the internal insulation of rock wool of 20mm thickness was sandwiched inside the two layers of wooden sheets.

Internal walls: two layers of the wooden sheet were used for the internal walls.
Windows: double glazed window was applied.
Roof: 60mm XPS board was used in the roof for the heat insulation.

Analysis of energy saving effect of the renovation methods: Through calculation by using the software recommended by the energy conservation standard for residential buildings in the Hot Summer and Cold Winter Region (2001), the energy consumption of the building for space heating and cooling after renovation will be 63.2 (kWh/m^2). Before renovation, the energy consumption of the building for space heating and cooling was 155.9 (kWh/m2). Therefore, the energy conservation efficiency of the renovation plan will be 59.45%.

3.3 General rural residential buildings

Suitable renovation methods: According to the respectively low economic level, the energy conservation renovation of rural buildings should consider more about the economic condition of countryside, such as the rural material and resource.

External wall: Through our survey, most of the external walls in Anji County are made of clay brick with the thickness of 240mm, whose thermal performance is poor. In this case, the external insulation of insulating mortar consisting of gelatinous power and expanded polystyrene pellets of 40mm thickness was applied.

Roof: Through the surveys we can find that most of the newly constructed rural buildings are of pitched roof, while existing housings are of flat roof. However, none of the roofs was designed with the thermal insulation measures. Here, we adopted insulating mortar consisting of gelatinous power and expanded polystyrene pellets of 40mm thickness, and the average heat transfer coefficient of the roof will be 0.94(W/m^2.K).

Windows: The single glazed windows with steel or aluminum frame are widely used in Anji County right now. The heat transfer coefficient of this kind of windows is far bigger than the requirement of the design standard nowadays. According to the economic condition of the countryside, the simple energy saving windows of low price should be selected for the suitable renovation, such as glass membrane, plastic-steel window frame and so on. Here, windows were changed to plastic-steel double glazed window with the heat transfer coefficient of 4.2(W/m^2.K).

Sunlight shading: The indoor soft curtains are used popularly in Anji County as the sunlight shading. However, due to the strong radiation from the south and west direction, the indoor curtains are not enough. Therefore, the following methods for sunlight shading are recommended: (1) fixed shading; (2) movable and adjustable shadings. Anji is famous for the bamboo, which is called the County of Bamboo. Therefore, this local material should be made full use as the sunlight shadings; (3) greening shading. It is a suitable method for low-rise buildings like rural building. With the trees planted in front of the windows and the bines on the western wall, not only the direct sunlight through the window, but also the heat transfer through the wall will be reduced. Furthermore, the cost is low and the construction is easy. We adopted simple shading in the renovation plan.

Analysis of energy saving effect of the renovation methods: The energy consumptions of the sample building were simulated in the two cases of before and after renovation of the envelope. After simulation of the annual energy consumption by using the software recommended by the Chinese standard, the energy consumption for space heating and cooling will be 79.55kWh/ m^2 per year. While for the current condition, the energy consumption for space heating and cooling is 104.86 Wh/ m^2. The energy saving effect of the renovation will be 24.13%.

4 CONCLUSIONS

In this paper, the potential of energy conservation of existing residential buildings was studied in the Hot Summer and Cold Winter Region of China. The present envelop thermal performance of three residential case buildings: a general urban building, a historic residential building and a rural building, were investigated, which illustrated that all these three residential buildings are poor in thermal performance and comfort no matter when they were built. Then, the suitable envelop renovation plans of the case buildings were formulated considering less retrofit, simple technology, short construction period and clear effect. The effects of energy conservation were simulated under the renovation plan. Simulation results shows that the general urban case building could achieve 46.28% reduction of the annual energy consumption, historic case building 59.45%, and the rural building 24.13% respectively. This result illustrates that for China the existing residential buildings have huge potential of energy conservation, and the renovation plans formulated in this paper could be effective and suitable.

ACKNOWLEDGEMENT

This research is supported partially by the Funding for Agriculture Development of Hangzhou City, 2008.

REFERENCES

[1] Verbeeck G, Hens H. Energy savings in retrofitted dwellings: economically viable. Energy and Buildings 2005,37(7): 747-754.
[2] Tommerup H, Svendsen S. Energy savings in Danish residential building stock. Energy and Buildings 2006, 38(6): 618-626.
[3] Arslan O, Kose R. Thermoeconomic optimization of insulation thickness considering condensed vapor in buildings. Energy and Buildings 2006, 38(12): 1400-1408.
[4] Lollini, Barozzi, Fasano, Meroni, Zinzi. Optimisation of opaque components of the building envelope: Energy, economic and environmental issues. Building and Environment 2006, 41(8): 1001-1013.
[5] Poel B, Cruchten GV, Balaras CA. Energy performance assessment of existing dwellings. Energy and Buildings 2007, 39(4): 393-403.
[6] Thermal design code for civil building, GB50176-93
[7] Hangzhou Statistics Bureau. Hangzhou Statistical Yearbook. China Statistical Press, 2007. (in Chinese) http://www.hzstats.gov.cn/webapp/more01.aspx?id=0_1_69_
[8] Design Standard for energy efficiency of residential buildings in hot summer and cold winter zone, JGJ134-2001.
[9] Moderate thermal environments-Determination of the PMV and PPD indices and specification of the conditions for the thermal comfort, GB/T18049-2000