Research Paper

Strategies for energy efficiency renovation and evaluation system of existing residential building in hot summer and cold winter zone

M.Y. Lu [1], J. Ge [2], T.T. Shen [3] and X.Y. Luo [4]

ARTICLE INFORMATION

ABSTRACT

According to the climate characteristics in Hot Summer and Cold Winter (HSCW) zone, this study summarizes the special strategies for retrofitting the Existing Residential Buildings (ERB) in four aspects: envelop reformation, external environment improvement, energy saving behavior and renewable energy utilization. Then this study constructs the evaluation system frame of energy saving effect through 3 factors which are architecture design, construction and economic investment to comprehensively assess the practical effect of transforming. This research chooses a classical residential building in Huzhou as a case study and adopts the technologies to rebuild and uses the above evaluation system to figure out the most suitable reforming project. We hope our study about the reconstruction technologies and evaluation system can give some reference to renovation of existing residential buildings in other regions in China.

1. Background

1.1 Building energy consumption in China

Currently, energy crisis and environmental issues have been paid more and more attention by all mankind, and sustainable development has become a global strategy and consensus of the long-term development of human society. With the gradual advancement of China's urbanization level and the continuous improvement of people's living level, people have increasingly higher demand for thermal comfort about interior environment, and the energy consumption of buildings would also increase rapidly (Ma, 2009; Bai, 2011). By 2011, the total energy consumption of buildings had raised to 687 million tons of standard coal (Mtce), which accounted for 20 % of national energy consumption (Fig. 1) (National Bureau of Statistics of the People's Republic of China, 2012;

THUBERC, 2013). Hence, building energy saving is an important measure which concerns directly with the implementation of state resources strategy and sustainable development strategy.

Building energy saving includes the energy saving design of new buildings and the energy efficiency renovation of existing buildings. Compared with new buildings, existing buildings account for the majority and are widely distributed. Moreover, in the process of design and construction, there was no awareness of energy saving and restriction of corresponding energy saving laws, which resulted in the big energy consumption. By 2012, the total floor area of existing buildings had reached 50 billion square meters. Among them, only 0.15 % (nearly 75.8 million square meters) can reach building energy saving standard (China Society for Urban Studies, 2013).

[1] Department of Architecture, Zhejiang University, Hangzhou, CHINA, 709953403@qq.com
[2] Professor &IALT member,Department of Architecture, Zhejiang University, Hangzhou, CHINA, gejian1@zju.edu.cn
[3] Zhejiang TransfarCo.Ltd, Hangzhou, CHINA, 173828633@qq.com
[4] Department of Architecture, Zhejiang University, Hangzhou, CHINA, teacher_xiaoyu@126.com
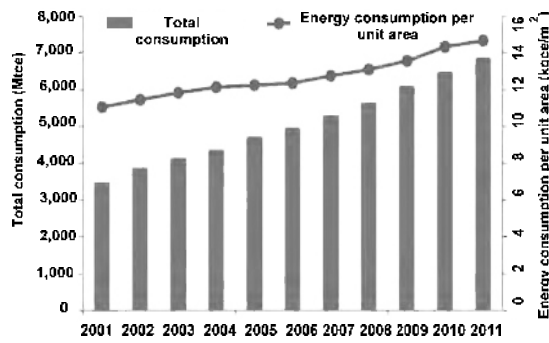*Note:* Discussion on this paper is open until December 2015
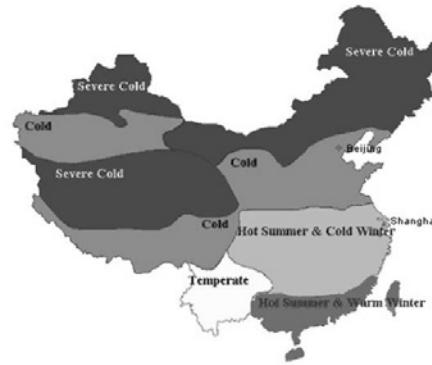
Fig. 1. Total energy consumption of buildings.

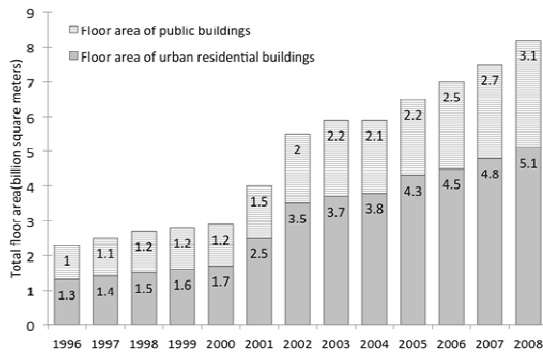Fig. 2. Architectural climatic zoning map of China.

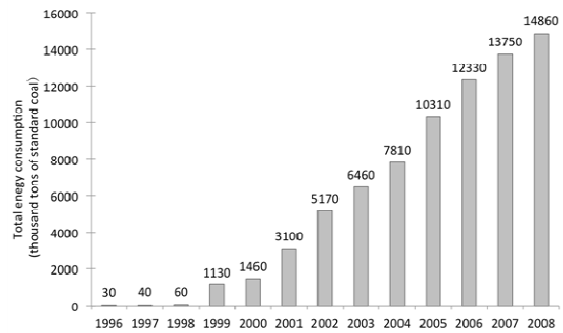Fig. 3. Total floor area in HSCW zone.

Fig. 4. Total energy consumption in HSCW zone.

1.2 Characteristics of building energy consumption in HSCW zone

Major cities in Yangtze River Delta belong to Hot Summer and Cold Winter (HSCW) zone (Fig. 2). Although this area is less than 1/5 of the area of national territory, 40 % of population lives here, which is most densely populated, and its GDP also accounts approximately for 48 % of the whole country. Summer is hot while average temperature in the hottest month is 25°C -30°C, and the highest temperature can reach above 40°C On the contrary, the weather is gloomy and cold in winter. The average temperature is 4°C in the coldest month and the coldest temperature is below -10°C (Zhang, 2014). However, this area belongs to non-heating areas, which is intolerably gloomy and cold.

Moreover, in previous architectural design, building envelope had low thermal performance, which did not consider summer heat insulation design and winter heat preservation design. With the improvement of living level, cooling in summer and heating in winter with air-conditioners have become the main method of acquiring indoor comfort for residents, which resulted in the sharp increase of building energy consumption in such areas (Lu, 2014). The total floor area in this region has raised from 2.3 billion square meters in 1996 to 8.2 billion square meters in 2008, of which, 60 % were residential

buildings. The heating energy consumption has risen from less than 100 million kWh to 46 billion kWh, and the heating energy consumption per unit area had been 5.6 kWh/m^2 in 2008, as shown in Figs. 3 and 4. (THUBERC, 2011).

Hence, energy efficiency renovation of Existing Residential Buildings (ERBs) in HSCW zone can not only decrease the waste of energy resource and improve the environment, but also improve the thermal comfort degree and exert enormous social and economic benefits, which is an urgent measure at present.

1.3 Related research

Various countries in the world, especially the developed countries have attached full attention to energy saving technologies of residential buildings.

Not only the buildings under construction fully abide by energy saving standard (Dong, 2007), but also the renovation of ERBs have achieved decisive results. Of which, the target of renovation in German is: comfort, energy saving and environmental protection. The popular technologies are (Lu, 2005): adopting three layers of Low-E glass sealed windows, which are filled with inert gases; manufacturing paraffin into scattered granules and mixing into thermal insulation material, then coating on the inner side of the external wall to regulate room temperature; integration of external thermal insulation

and decoration. Through the efforts of various sides, the carbon dioxide emissions of ERBs had decreased 40 kg/ (m^2·year) (Fan, 2007).

The technologies in Britain (Gu, 2002) were to fill highly efficient thermal insulation material in air space within wall and add transparent glass window to use air layer for thermal insulation. It substantially decreased the proportion of fuel and power charge in family expenditure, thus obtained remarkable economic and social benefit (Tu, 1997).

The Japanese attach great importance to the innovative ideas on the energy efficiency renovation of existing buildings, and take the building energy efficiency and reducing carbon emissions as a key content (Ji, 2012). When analyzing energy consumption in housing, three main factors (including surrounding environment, resident's action and technology matters) are taken into consideration. Surrounding environment focus on achieving a suitable thermal environment by using local resources, e.g. use of locally available building materials, implementation of heating and cooling passive strategies, hence reducing the energy input needs. Resident's action corresponds to occupants' interaction with housing. The technical features correspond to the characteristics of the housing materials and of the equipment installed (Lopes et al., 2005).

In addition, other countries (such as America, France, Canada, Denmark and Sweden) (Danny Harvey, 2009) (Akbari et al., 2008) also take a lot of effective measures, which can be divided into several categories. First of all, improving the thermal performance of the envelopes, and the heat transfer coefficient K value has been regulated between 0.2 W/ (m^2·k) and 0.35 W/ (m^2·k) in some developed countries (Wang, 2011).

In terms of energy-saving design of the windows, some glasses with good heat insulation performance (such as double-pane glass, heat-absorbing glass and heat-reflecting glass) are often used. Second, some passive strategies, e.g. natural ventilation, the use of sun-shading system, are extensively paid attention. Otherwise, the use of new energy (such as solar energy and wind energy) has been very mature.

China's building energy saving work had been carried out in 1986, the promulgated Design Standard for Energy Efficiency of Residential Buildings in Northern Zone (JGJ26-1986) had set the energy saving target as 30 %. Current standard has already been spread to each climate zones and public building design field, and the target has also increased to 50-65 %. In the energy efficiency renovation of existing buildings, the Ministry of Construction had promulgated Technical Specification for Energy Conservation Renovation of Existing Heating Residential Building in October 2000 (JGJ129-2000),

which provided legal basis for building renovation. While Ninth Five-Year Plan on Building Energy Construction and 2010 Plan had formulated the procedure and target of building energy saving work of existing buildings in heating zone, the existing building shall achieve energy efficiency renovation in most part of China until 2020 (Tu, 2002).

As compared with that of cold areas, the research on the energy saving renovation of existing buildings in HSCW zone started relatively late, which began in 2001 (JGJ134-2001). Since then, the energy saving work has achieved tremendous effect in our country. However, compared with the developed countries, the gap is still large. Heat transfer coefficient K value regulated by energy efficiency design standards in the first stage was obviously higher than those countries with similar climate conditions (Yu, 2004). And the heating consumption in per floor area was 2-3 times higher than those in similar latitude (Liang, 2007).

Therefore, the improvement of thermal performance of building envelope is critical to energy efficiency renovation. And exterior wall external insulation technology is the most effective measure for improving the thermal performance of envelope. Other relatively mature technologies, such as roof thermal insulation technology and doors and windows energy saving technology, can be used in energy efficiency renovation of existing buildings.

Otherwise, the renovation cannot just rely on the administrative power of the government. Stakeholders including owners, construction enterprises, developers and investors can benefit in building energy reconstruction project through market means (Wang, 2011). However, China is still not perfect in this aspect at present (Sina.net, 2008).

2. Research content and method

On the basis of research about the existing buildings' renovation measures at home and abroad, the technologies of energy efficiency renovation of ERBs in HSCW region are summarized in menu type. Then this study constructs the evaluation system frame of energy saving effect through 3 factors to comprehensively assess the practical effect of transforming. This research chooses a classical residential building in Huzhou as a case study and adopts the technologies to rebuild and uses the above evaluation system to figure out the most suitable reforming project. We hope our study can give some reference to renovation of ERBs in other regions in China.

Table 1. Strategies of energy-saving renovation of ERBs in HSCW zone.

Content	Element	Details	Practice
Energy saving design of envelops	Walls	Exterior insulation	EIFS of powder polystyrene particles insulation mortar
			EIFS of polyurethane
			EIFS of EPS
		Vertical greening	Climbing plants in building vertical plane
	Roofs	Adding insulation layer	Trimming the waterproof layer and adding the TIL
		Changing into Sloping roof	Build-in TIL
		Changing into ventilation roof	Setting ventilation layer above the TIL
		Green roof	Soilless cultivation and planting soil
	External windows	Changing original windows	Install energy-saving windows such as double-decked glass with break heat aluminum
		Keeping original windows	Switching to energy saving glass with another window frame
			Forming a double window after adding another one
			Coating glass with good thermal insulation performance
		Setting effective shading device	Adopting movable external sun-shading in south and west sides
	Stairwell	Closing stairwell	Adding security doors and windows
Environmental Improvement	Exterior surface	Material's color	Adopting exterior ornament materials with light color
	Outdoor greening	Vegetation	Multilayer plantation structure with alternating trees, shrubs and lawns
		Water	Increasing the water area
		Pavage	Increasing the permeable ground
Users' behaviors		Regulating electric use	Using energy-efficient appliance
			Closing appliance in time
			Cleaning and maintaining appliances regularly
		Indoor greening	Preferring small and medium-sized plants
Utilization of renewable energy		Solar water heater	

*EIFS represents External Insulation Finish System;   *TIL means Thermal Insulation Layer.

3.   The Strategies of energy efficiency renovation

The energy efficiency renovation of ERBs is different to that of newly built buildings, and also different to that of existing public buildings. It should be carried out under the conditions of not damaging original structure to the greatest extent and not changing original residing function. Meanwhile, it should make the construction method as simple as possible, and cause less damage to original indoor decoration. Furthermore, the influence to the daily activities of residents should also be less, so as to facilitate the operation.

The majorities of ERBs are built early, and the thermal performance of exterior walls, roofs and windows have not reached the requirements of design standard for energy efficiency, which have great influence on energy consumption and indoor thermal environment. Therefore, it mainly take the renovation of building envelops as the priority. Secondly, as the main equipment in this zone, air-conditioning is appointed to improve the indoor environmental quality, which is controlled by each household. Therefore, the guidance to residents' energy saving behavior should be taken into consideration. Besides, the use of renewable energy can decrease building energy consumption and save daily living expenses. So the strategies are divided into four parts, including energy saving design of envelops, improvement of external environment, users' energy saving behaviors and utilization of renewable energy (see Table 1 for details)

4.   Evaluation system of reconstruction plan

4.1   The necessity of evaluation system

At present, the assessment of reconstruction plans are almost confined to energy simulation in our country, while the plan with the highest energy reduction would be chosen eventually. However, under the ideal parameters (such as meteorological condition, indoor temperature, population density, etc.), the results simulated cannot reflect the actual energy consumption. In the meantime, using the default values to replace some data, which
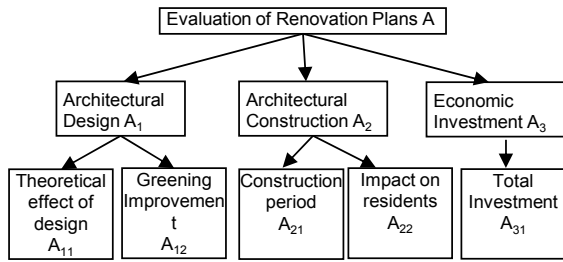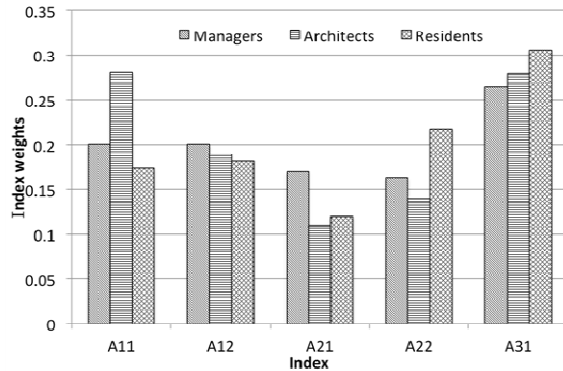
Fig. 5. The framework of evaluation system.

Fig. 6. The calculation results of index weights.

Table 2. The calculation results of index weights.

	A11	A12	A21	A22	A31
Managers	0.201	0.201	0.170	0.163	0.265
Architects	0.281	0.189	0.110	0.140	0.280
Residents	0.174	0.182	0.120	0.218	0.306

cannot be measured in the process of simulation, may have larger deviations.

Otherwise, some unquantifiable factors (including households' behaviors during the reconstruction and use stage, the utilization of equipment, etc.) also had a big impact on energy consumption. Therefore, social, cultural and economic factors should be comprehensively considered while evaluating the rebuilt programs, as well as the simulation result.

4.2 The framework of index system

Learning from UK BREEAM (2000), the evaluation system was divided into building performance (architectural design), design and build (construction) and operation management (economic investment). As can be seen in Fig. 5, it included one general objective, three factors and five detailed indexes. The general objective is to get the Energy Saving Effect Index (ESEI) to find the most optimal solution.

In the evaluation system, each index exerts different impacts on retrofit effects so different evaluation indexes should be endowed with various weights, which reflects the relative importance between evaluation indexes. As a result, it is of great importance for improving the evaluating precision and sensitivity to give the reasonable weights of evaluation indexes. After study on the common weighting methods including regression analysis method, Delphi method, sorting method and AHP method, AHP method was used to determine the weights of factors eventually in order to avoid the randomness of weight coefficient of each index and guarantee the evaluation's comprehensiveness.

The AHP method (the Analytic Hierarchy Process), proposed by American scholar T.L.Saaty in 1970s, refers to the multi-objective assessment method. It decomposes the complex problem into few levels, of which each consists of several factors. And then taking the factors in the upper level as a guideline, the AHP method make paired comparison between factors in the next level and then by judgment and calculation, the weight of each factor can be obtained.

A total of 30 questionnaires were issued by this investigation and all were taken back, while the recovery rate was 100 %. Of the people being investigated, one third were from relevant government departments, one third were designers engaged in building design and energy efficiency renovation, and the left were local residents. To certain extent, it comprehensively reflected the recognition of the relevant persons towards the effect of renovation scheme. Because of different cultural background, professional career and economic interests, different objects such as government managers, designers, builders and housekeepers hold different views on the importance of each index. So the weights differed from each other (Table 2 and Fig. 6).

As shown in Fig. 6, all of them pay more attention to the investment of renovation plans. However, architects or designers care more about the energy consumption than other two groups and take less attention on the construction period. The managers may consider all factors equally important except the cost.

4.3 The evaluation results

The results of evaluation system were based on the energy consumption simulation and yield investigation results. Each indicator was divided into 5 levels, including 1,3,5,7 and 9 scores, which would get an independent score from government manager, architect and user relatively. For example, if the energy consumption reduces more than 50 %, between 40 % and 50 %, between 30% and 40%, between 20% and 30%, and under 20% after renovation, the score of the theoretical effect of design A11 would be 9,7,5,3 and 1seperately. Besides, as for impact on residents A22, if it doesn't

influence the daily life, it may get the highest score. On the contrary, the score may be only 1 if the residents need to move out during the reconstruction stage. Besides, different persons may have different scores towards the impact. Then according to the different proportions of different objects, the renovation plan would get 3 results from those three groups. As the weights of these three groups are equally important, so the average score of total scores would be the final result.

$$ESEI=(ESEIa+ESEIb+ESEIc)/3=(0.201xA11a+0.201xA12a+0.170xA21a+0.163xA22a+0.265xA31a)/3+(0.201xA11b+0.201xA12b+0.170xA21b+0.163xA22b+0.265xA31b)/3+(0.201xA11c+0.201xA12c+0.170xA21c+0.163xA22c+0.265xA31c)/3 \qquad [1]$$

*Among them, a represents the scores from government managers, b represents the scores from architects and c is on behalf of the scores from households.

As you can see, ESEI is a relative value. The higher the ESEI is, the better the final effect of the energy-saving renovation plan is. The plan with the highest score will be recommended.

5. Case study and evaluation

5.1 Basic information

As the energy efficiency design standards has been carried out in 2001 in HSCW zone, the residential buildings built between 1981 and 2001, which cannot reach the standards (JGJ134-2001), should be the main parts of those need to be reconstructed (China Society for Urban Studies, 2013).The selected building, located in Huzhou, is a 6-storey normal brick-concrete structural residence which is completed in 1998. It is a typical residential building need to be rebuilt in this area. Exterior wall is 240 millimeters solid clay brick, the inside and outside are coated with mixed cement mortar, and external facade is white painting, which have no thermal insulation treatment. Roof is general plane roof, which has no insulation layer. The open balcony has been closed with aluminum alloy single layer glass windows at the time of decoration. Now 24 households have all installed split-type air-conditioner, and each household has 1.6 sets in average. The Fig. 7 below shows the current appearance of the renovated building. The Fig. 8 shows the building's standard floor plan.

In terms of the energy consumption, the monthly average power consumption of the whole building was 3490 kWh (Fig. 9). Results showed that the energy consumption peaked in summer, followed by that in winter, and lowest in spring and autumn. Besides, after the dynamic calculation of energy efficiency software PKPM (Wang, 2009), energy consumption per unit area

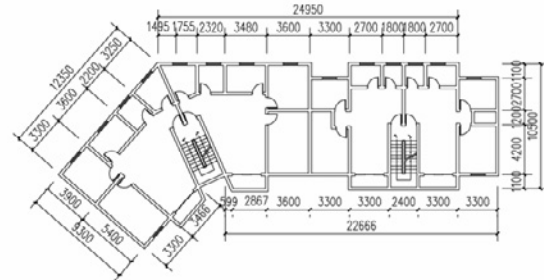Fig. 7. Current appearance of case building.
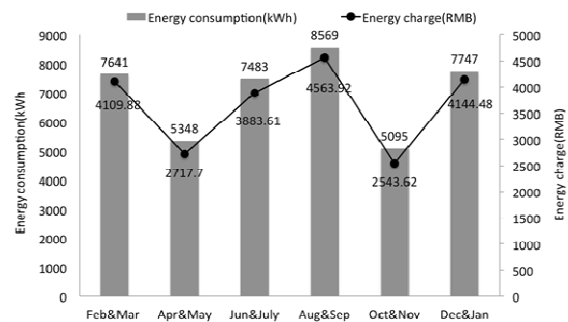

Fig. 8. Standard floor plan.

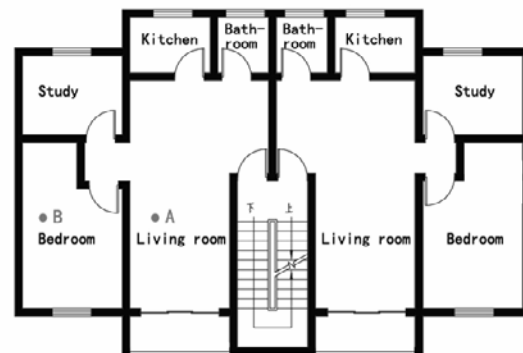Fig. 9. The statistics of the case buildings' energy consumption from February 2008 to January 2009.

Fig. 10. The arrangement of measuring points.

of this building under standard working condition was 77.24 KWh/m^2, which was far higher than the limit 54.60 kWh/m^2 regulated by energy efficiency design standard.

One household on the third floor, unit 1, within the building was selected by this paper to measure the indoor thermal environment (such as temperature, humidity and PMV) in summer and winter respectively. In

the process of measurement, the residents kept normal living status. The measuring points are shown in Fig. 10. The testing time in summer of 2009 was from 19:00, October 29 to 19:00, October 30. During the period, the highest outdoor temperature was 34°C and the lowest was 28°C. The curves of temperature and relative humidity showed in the parlor (Fig. 11) the temperature was generally about 30°C changing at a modest rate and the mean relative humidity was 65.7 %; the mean temperature in the bedroom was 28.4°C between the highest 29.9°C and lowest 26.6°C, and the mean relative humidity was 57.6 %. The temperature stayed at 27°C with air conditioning at night.

The testing time in winter of 2010 was from 13:00, January 1 to 13:00, January 2. During the period, the highest outdoor temperature was 9°C and the lowest was 0°C, which was the coldest time in the year. The mean temperature in the parlor was 8.7°C between the highest 12.1°C and lowest 7.2°C. The indoor temperature changed with that of outdoor, which were very close to each other. The relative humidity indoor changed in the range of 45-85 % (Fig. 12).

PMV and PPD are important indexes to evaluate indoor thermal environment. The average PMV value in living room was 1.68 in summer and -1.54 in winter, while that in bedroom was 0.85 in summer and -1.66 in winter, which exceeded national standard requirement of -0.75∼0.75 (Figs. 13 and 14). Under the conditions of no utilization of refrigeration or heating equipment, people would feel hot in summer and cold in winter. So it was essential to implement energy efficiency renovation.

5.2 Plans of energy efficiency renovation

In this paper, the energy efficiency effects of different renovation measures are analyzed after the energy simulation under five circumstances: original building, renewing external walls only, rebuilding roof only, renewing windows only and rebuilding all envelops (Table 3). Then the optimal sorting of solutions has been summarized. Seen from single renovation measure the effect on reconstructing exterior wall is most obvious, which may reduce 18 % of original building comprehensive energy consumption; while the effects on reconstructing exterior window and roof are relatively low.

Combining current situation, three renovation plans has been selected after combination optimization of reconstruction of different parts of buildings. The energy saving rate simulated by the software PKPM provides the basis of theoretical effect of design A11. On the other hand, the total investment A31 is based on the cost of unit area, which is calculated according to the current market price of energy-saving materials (China Building
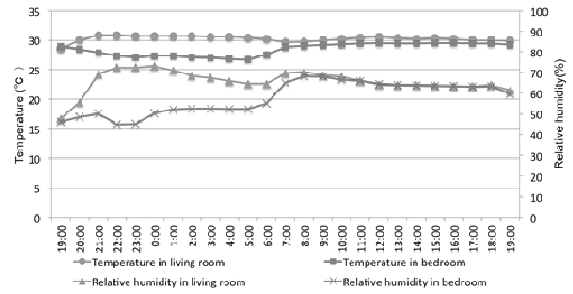

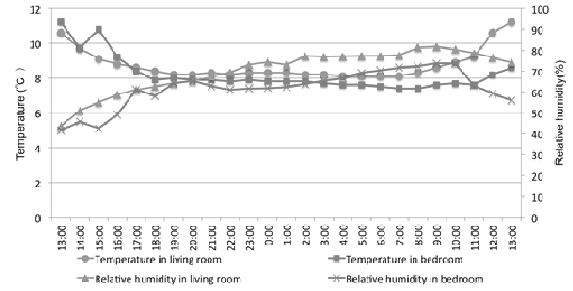Fig. 11. The temperature and humidity of measuring points in summer.

Fig. 12. The temperature and humidity of measuring points in winter.
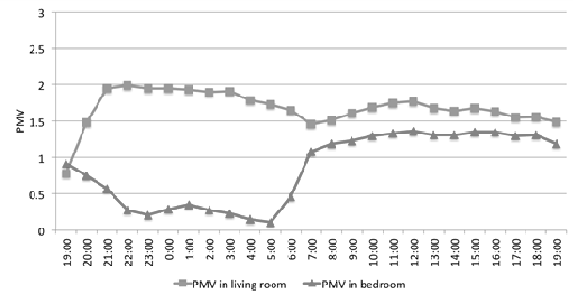

Fig. 13. The PMV of measuring points in summer.

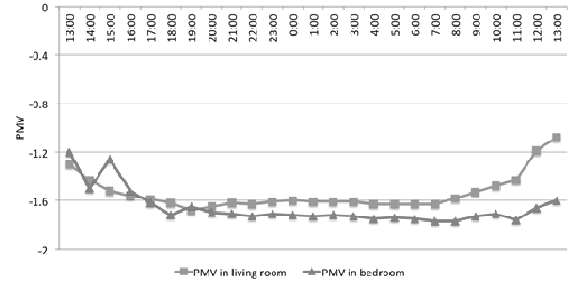Fig. 14. The PMV of measuring points in winter.

Material Network, 2012). Three plans are shown in the Table 4.

5.3 Evaluation results of plans

The evaluation indexes of each plan are graded by government managers, architects and residents respectively, and the scores were calculated according to the different proportions. The average of these scores would be the final score (see in Table 5).

Table 3. The energy efficiency rate of different renovation strategies.

	Original building	20 mm	30 mm	40 mm	50 mm	60 mm
Different thickness of exterior walls' insulation layer (PPPIM)	Original building	20 mm	30 mm	40 mm	50 mm	60 mm
Rate of energy efficiency	—	11.7 %	14.9 %	17.3 %	19.2 %	20.5 %
Different types of insulation layer	Original building	Powder polystyrene particles insulation mortar 30 mm	Polystyrene foamed plastic board 30 mm	Spraying rigid polyurethane foam 30 mm		
Rate of energy efficiency	—	14.9 %	18.8 %	21.1 %		
Different types of roofs	Original building	Planted roof	Adding insulation layer	Overhead roof	Ventilated roof	
Rate of energy efficiency	—	6.76 %	7.68 %	7.40 %	8.10 %	
Different types of windows	Original building	Double-decked glass with ordinary aluminum frame	Double-decked glass with break heat aluminum	Low-E glass with break heat aluminum		
Rate of energy efficiency	—	2.30 %	3.40 %	4.10 %		
Different colors of walls	Original building	Gray surface	Light color surface	Lime plaster		
Rate of energy efficiency	—	0.64 %	0.72 %	0.78 %		

*PPPIM means Powder Polystyrene Particles Insulation Mortar.

Table 4. Three optimized plans.

		Case 1	Case 2	Case 3
Building envelops	Exterior walls	Mineral binder and expanded polystyrene granule (30 mm)	Polystyrene foam board (30 mm)	Spraying rigid polyurethane foam (30 mm)
	Roof	Ventilated overhead roof	Planted roof (Sedum lineare)	Ventilated sloping roof
	Exterior windows	Energy saving glass membrane	Setting plastic-steel single glazed window outside (inside) original window	Changing original window to hollow plastic-steel frame window
	Solar Shading	—	Setting movable shading device outside the south window	Setting aluminum grille level shading outside the south window
	Stairwell	—	Closing stairwell	Closing stairwell
Environmental Improvements	Greening	—	Planting tall deciduous trees in west area	Planting tall deciduous trees in west area; vertical greening in western wall
Rate of energy efficiency		22.1 %	37.4 %	42.7 %
Cost of per floor area (RMB/m²)		73.88	125.23	292.64

The result shows that $ESEI_2 > ESEI_1 > ESEI_3$, so plan 2 would be the most suitable one for the energy efficiency renovation of the case building.

6. Conclusions

On the basis of research about the existing buildings' renovation measures at home and abroad, this paper summarizes the energy efficiency renovation technologies of ERBs in HSCW zone from four parts, including energy saving design of envelops, improvement of external environment, users' energy saving behaviors and utilization of renewable energy. And they are shown in menu type, which is convenient for architects to choose. Of which, the improving of thermal performance of envelope can obtain remarkable effect. Otherwise, improving external environment and guiding the energy efficiency behavior of residents also can bring better energy efficiency effect.

Moreover, by referring to the relevant system of green building evaluation, and by virtue of the evaluation

opinion of government administrators, designers and residents to the influence factors of energy efficiency renovation scheme of ERBs in this region, this paper establishes the index system of comprehensive evaluation from three aspects (including building design, building operations and economic benefit), and designs an intuitive evaluation method on energy efficiency renovation scheme. The ESEI of the evaluation system can simply and intuitively evaluates the effect of renovation schemes. Moreover, it can be understood and used by most people, and the government and owner could have a reference index to the benefit and expense of investment based on reasonable analysis before deciding renovation.

A typical residential building in Huzhou has been selected as a study case and rebuilt by using the four

Table 5. Evaluation Results of Three plans.

	Managers	Architects	Residents	Average
Case 1	4.990	4.742	5.284	5.005
Case 2	5.198	5.098	4.900	5.065
Case 3	4.480	4.698	3.960	4.379

major technologies. Then those renovation schemes are evaluated. The scheme finally selected in this case is not the simplest in operation and not the least in cost, even not the optimum in theoretical energy efficiency effect, while the preferential scheme selected under the conditions of fully respecting the will and benefit of administrators, designers and users. It is also the scheme with the highest cost performance, which shall achieve the optimal economic and social benefit.

Due to the limitation of objective conditions, this study has some unsatisfactory aspects, such as the evaluation indexes are not detailed enough and the assessment of the building's full life cycle is lacked. In the future study, the evaluation system should be further perfected, and each relevant index should have its corresponding evaluation index. Meanwhile, the study on the economic benefit and environmental influence should be paid more attention to in the whole life cycle of the building.

Acknowledgement

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