The Inspiration from Applying *Scenario Analysis* in European Union Energy Efficiency Renovation of Existing Residential Buildings

——A Case Study in Italy

Thesis Submitted to

Tsinghua University Politecnico di Turino

in partial fulfillment of the requirement

for the professional degree of

Master of Architecture

by

Yang Yuqi

Thesis Supervisor Professor Cheng Xiaoqing

Associate Supervisor Professor Michele Bonino

April, 2020

Keywords: Existing residence; Simulation transformation; Scene analysis; Classification and classification; European Union

Abstract

China's housing construction has entered the stock era, which means most of the residential buildings are built during last 30 years. The existing residential building's energy saving renovation is an important field related to the national economy and people's livelihood.

Through research and analysis, this paper integrates the development of the *Scenario Analysis*method in the past 10 years, and summarizes its technical route into the following four aspects: 1) The principle of constructing a unified residential classification system that can be used for complex residential energy consumption situations; 2) Research on the energy consumption characteristics of specific types of existing residences, and the principle of generating a targeted alternative library; 3) The proposal of global cost, the principle of "cost-energy efficiency optimization method" to select a suitable renovation plan; 4) Principles of measuring the social and economic benefits of the program. Taking the actual case as an example, the following four implementation steps of the "scenario analysis method" were analyzed using theoretical calculation methods: 1) Using "standard residence" to study the energy consumption characteristics of a certain type of residence, using simulation transformation methods, combined with energy saving Reconstruction standards, using the control variable method to generate a library of alternatives; 2) Build global costs, use the "cost-energy efficiency optimization method" to select the appropriate transformation plan; 3) Various cost analysis and sensitivity analysis of the plan; 4) Carry out social and economic benefit analysis of the appropriate transformation plan.

On the basis of this, some reference suggestions are put forward for the reconstruction of existing residential buildings in China.

The introduction

The residential building stock is huge, distributed in different climate zones in China. During the 11th Five-Year Plan period, China began to inplement a huge amount of measures aiming at energy-saving renovation of existing residential buildings in northern cities and towns.

According to the *Eergy Saving Renovation Guide for Existing Residential Buildings* issued by the Ministry of Housing and Urban-Rural Development in 2012, the total area worth renovation in northern cities is about 3.5 billion square meters, which is an arduous task. After 10 years of overall planning and implementation, by 2015, about 990 million square meters of urban areas in northern China had been renovated. During the 13th Five-Year Plan period, more than 500 million square meters of renovation will be completed, and energy saving renovation will be basically realized in northern cities.

However, this is only part of the renovation of existing housing across the country. During the 12th Five-Year Plan period, the renovation of existing houses was expanded to the hot-summer and cold-winter zone. Demonstrative projects began to be renovated in this climate zone during the 13th Five-Year Plan period.

The current renovation work mainly based on the "*Guide to Energy Conservation Renovation of Existing Residential Buildings*" issued by the Ministry of Housing and Urban-Rural Development in 2012. The renovation could be divided into the following five parts: (1) renovation of thermal insulation structure, (2) heat metering control system, maintenance of thermal station and thermal pipe network, (3) refurbishment of old buildings, (4) improvement of architectural design and (5) usage of renewable energy.

However, there are still many problems in practice: first of all, the situation of the residential buildings to be refurbished varies greatly, which means a unified refurbishing scheme is difficult to adapt to those different buildings; Secondly, because of a lack of overall planning, the total investment budget is difficult to made; Third, using square meters to measure the completion of renovation, the actual energy-saving effect can not be expected; Fourth, facing the complex housing situation, there is no corresponding plan library.

In 2010, Italy began to adopt *Scenario Analysis*as the main method to control the residential energy saving renovation. In the following nine years, this method was gradually incorporated into the building energy saving planning directive formulated by the European Commission and became the implementation framework for the statistics and management of building energy consumption in member states. In this paper, the implementation framework, principle and practical application of "Scene Analysis" are deeply studied, and the reference function of this method to the existing residential energy conservation renovation work in China is discussed.

1 The method of *Scenario Analysis* in the residential energy saving reconstruction

The *Scenario Analysis* approach began as a research project funded by the European Union and was later put into practice by a policy directive issued by the Energy Commission.

In 2009, the Politechnico di Turino began to classify existing residential buildings and study their energy consumption features. In 2010, the European Union's research programme "Intelligent Energy Efficiency" organized research institutions in member states to carry out researches related to residential energy use. Based on the existing data of the Energy Bureau, Italy uses this method to construct the classification system of the existing houses, puts forward the concept of Average building , conducts the research on the current situation of energy consumption, sets the graded energy efficiency saving target, and establishes the graded energy saving plan library.

1.1 Application area of *Scenario Analysis*

Scenario Analysis can be applied at macro and micro levels. At macro level, it is used to count the total energy consumption of existing residential buildings, establish long-term building energy consumption targets, and evaluate the economic benefits of residential energy saving transformation. At the micro level, it can provide targeted technical solutions for energy saving transformation of individual houses.

（1）**Count the total energy consumption of existing buildings.** The *Scenario*

Analysis provides a method to standardize the building energy consumption management in the European Union.

In 2010, the new eu building energy performance instruction based on *Scenario Analysis*established a framework for the member states as a guidebook for their periodic building energy consumption report, in which participants were asked to select a building to represent all buildings of the same type and provide its basic parameters, including parameters about the envelope system and energy supply system. The parameters should be calculated using specific formulas so that the energy consumption data is converted into energy consumption per square meter and the primary energy consumption per square meter. Then the result is multiplied by the total floor area, and the energy consumption of a certain type of buildings could be got.

This process not only avoids the difficulties caused by the differences in climate zones and building types, but also provides the estimation data of existing building energy consumption, providing a simple and effective method for the government to control building energy consumption.

（2）**Develop long-term building energy targets**. *Scenario Analysis* provides an important reference for formulating long-term building energy consumption targets. Under article 4 of the EU's 2012 Energy Efficiency Directive, member states are required to develop 10-year and three-year building energy saving plans to achieve full decarbonisation by 2050. According to the guidance provided by the European Commission, the 3-year building energy efficiency plan should be based on the *Scenario Analysis* method to specify the energy efficiency indicators of building envelope and plan the energy consumption of such type of buildings.

（3）**Evaluate the economic benefit after reconstruction.** *Scenario Analysis* provides a means to evaluate the social and economic benefits of the renovation. The Building Energy Performance Directive and the Energy Efficiency Directive extend the evaluation phase of energy saving effects to the whole life cycle of the building and introduce the concept of global costs and economic benefits. The global cost represents the resources invested by the society, and the economic benefit represents the reinvestment of the energy cost saved.

（4）**The library of transformation schemes generated by *Scenario Analysis*is displayed in the form of web pages.** The library of transformation schemes generated by *Scenario Analysis* is displayed in the form of web pages.

By selecting the construction period, residential type and energy supply system, the refurbishing participants can obtain two different energy saving effect renovation schemes for envelope structure and energy supply system, and obtain the comparison results of energy consumption and energy cost of different renovation schemes before and after refurbishing, which greatly reduces the participation threshold of energy saving renovation and facilitates the implementation of residential refurbishment

1.2 Technical route of Scenario Analysis

Based on the scientific research plan and energy directive of the European Union, this paper summarizes the technical route of *Scenario Analysis*as the following four steps, among which the first three correspond to the refurbishing plan of two different energy saving levels, and article (4) corresponds to the evaluation of the refurbishing plan:

（1）establish a building typology classification system

（2）theoretical refurbishing

（3）choosing the most appropriate refurbishment

（4）comparing the benefits pf refurbishment.

2 To establish a building typology classification system

Classification is an important method to simplify the total energy consumption of residential buildings and establish scheme database.

Residential classification refers to the classification of residential energy consumption characteristics. Classifying residential buildings into different energy consumption characteristics and studying the energy-saving renovation methods of this category rather than specific individual buildings can greatly reduce the difficulty and workload of work.

In the *Scenario Analysis* method, three classification parameters and one energy consumption system parameter (optional parameter) are set, among which the classification parameters are climate zone, housing type and construction period. The spatial energy consumption demand of residential buildings can be determined by selecting the classification parameters successively. The optional parameter refers to the energy supply system, including heating, refrigeration and domestic hot water system. The optional parameter determines the refurbishing plan of the energy supply system, the final energy carrier and the consumption of non-renewable primary energy. According to the actual situation of Italy, there are a total of 192 housing categories in 6 climate zones, 4 housing types, and 8 construction periods.

2.1 Parameter 1： 6 climate zones

The European Energy Agency uses heat days (HDD) and cold degree-days (CDD) as climate zoning indicators for building energy consumption, which can compare the energy consumption of heating and cooling for a particular building in a particular climate. Taking HDD as an example, the greater the daily heat, the greater the winter heating demand of buildings in this region. The heating demand of a particular building at a particular location is proportional to the amount of HDDS in that location, and the cooling demand is also proportional to the amount of CDD in that location. That is, for a house with similar envelope structure, the energy consumption for heating in an area with 5000 HDDS is five times that in an area with 1000 HDDS. Heat days and cold degree-days provide only a very simple way of comparing energy consumption, and a more detailed classification is needed for buildings of different structures. According to Presidential Decree No. 412/1933, Italy can be divided into six climate zones. figure 1 shows a schematic diagram of climate zones corresponding to administrative regions.

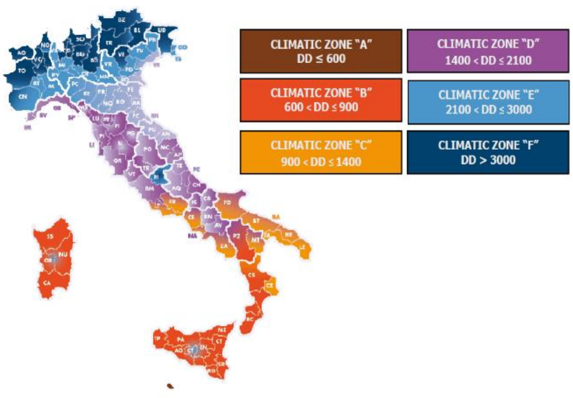

figure 1 Climate zones in Italy

2.2 Parameter 2： 4 housing types

table 1: **4** building types

Building tope	Gross heated volume （m³）	Net floor area （㎡）	Gross floor area （㎡）	Compactness factor	Number of floors	Number of apartments
Single family house	500-750	100-200		0.7-0.8	2 层	1 户
Terraced houses	300-500	100-150		0.5-0.6	2 层	1 户
Multi family houses	3000-5000		500-2000	0.4-0.5	2-4 层	5 至 15 户
apartment	＞5000		＞2000	0.3-0.5	＞4 层	＞16 户

Each climate zone corresponds to multiple housing types.

Housing type can simply reflect the physical characteristics, technology and engineering practices of housing in different periods. In the practice of Italy, there are four types of housing: single-family house, terraced houses, multi-family houses and apartment. The impact of residential type on energy consumption is mainly in three aspects.

First of all, the difference of residential type affects the area, volume and shape coefficient, among which the shape coefficient has a greater impact on energy consumption characteristics. In Italy, for example, the figure coefficients for single-family houses range from 0.72 to 0.77, for terraced houses from 0.49 to 0.69, for multi-family houses from 0.48 to 0.54, and for apartment from 0.35 to 0.47.

In addition, different types of houses have different heat exchange with surrounding buildings. Compared to multi-family houses, apartments have larger stairwells due to the elevator, so the heat exchange between living space and traffic space needs to be considered. Third, the difference of housing type leads to the choice of energy supply system and the efficiency of subsystems. Single-family houses and terraced houses typically use centralized power systems, while multi-family homes and apartments use either central or separate systems. The efficiency of heat pipes is inversely proportional to the height of the building. The physical characteristics of four housing types in Piemonte, Italy are shown in table 1.

住宅类型能够对能耗特性进行初级划分，但同一住宅类型下的个体差异较大，因此对于区别各类住宅的能耗特征的贡献有限，需要引入其他参数进行进一步的划分。Residential types can make primary division of energy consumption characteristics, but individual differences within the same residential type are large, so the contribution to distinguish the energy consumption characteristics of various types of residential is limited, and it is necessary to introduce other parameters for further division.

2.3 Parameter 3： 8 construction periods

Construction period is the key parameter of housing classification, which determines the spatial layout, construction technology and efficiency of energy supply equipment system. In the classification of construction period, related construction laws and regulations should be taken into account. In Practice in Italy, housing is divided into 8 construction periods, as shown in table 2.

table 2 construction age classes in Italy

time	features
Up to 1900	The Nineteenth Century
1901-1920	The beginning of the Twentieth Century
1921-1945	The period between the two World Wars
1945-1960	The Post war period and the Reconstruction
1961-1975	Towards the oil crisis
1976-1990	First Italian regulations on energy efficiency
1991-2005	Recent regulations on the energy performance of buildings in Italy(from LAW.NO.10/1991 to the legislative Decree no.192/2005
2005 年后	More restrictive energy performance requirements(implementation decrees of Legislative Decree no. 192/2005 and regional laws)

Among them, before 1961, the main materials of the envelope structure were used to divide the residential buildings in each period.

Hollow brick began to be used in residences after 1921. Hollow bricks were first used in the walls of the multi-story houses from 1921 to 1945. Hollow brick masonry also began to be used in townhouses from 1945 to 1960. At the same time, the need for low-cost mass-produced materials for post-war reconstruction led to the reuse of solid bricks for multi-storey houses. Apartments also began to use hollow brick and concrete walls.

After 1961, hollow brick replaced solid brick to become the mainstream structure of residential wall. The classification after 1975 was mainly based on building energy consumption characteristics. After 1975, the government advocated the improvement of energy efficiency, allowing the use of thermal insulation layer and double glazing on the residential envelope. In 1991, No. 10/1991 was issued to regulate the thermal performance of the building envelope. In 2005, legislation 192/2005 was adopted for stricter revision, which met the national building energy consumption standards.

Scenario Analysis explains the relationship between climate zone, residential type and construction period and residential space energy consumption demand. When these three parameters are determined in turn, the spatial net energy consumption demand of residential space can be estimated.

2.4 Energy consumption system parameter (optional parameter)

The energy supply system determines the type and amount of energy carrier, and then determines the amount of non-renewable primary energy. Since the energy supply system does not affect the net energy consumption demand of the residential indoor environment, and in a single case, the property will replace all parts of the aging energy supply system, which does not necessarily maintain the original state, it is taken as an independent optional parameter in the design of the residential reconstruction scheme library. Users who need a specific renovation plan for a single house can obtain a more accurate renovation plan, while the energy supply system corresponding to the construction period of one type of house can be used for the overall evaluation of this type of house.

The energy supply system can be divided into heating, cooling and domastic hot water system three parts. The following uses heating system as an example to illustrate the classification principle of each component.

（1）Heat source equipment: the difference of heat source equipment affects the energy conversion efficiency. Heat source equipment can be further classified according to the use of energy, heating mode and location. According to the use of energy, it can be divided into natural gas, oil and electricity, etc. According to the heating method can be divided into heat pump (ground source heat pump, air source heat pump, etc.) and boiler (atmospheric pressure burner and blast burner, etc.); According to the location, the equipment can be divided into those placed in the heating area, the others placed in the non-heating area.

（2）Heat distribution equipment: The layout, distribution and insulation of heat distribution equipment determine the heat loss during transportation.

Heat distribution equipment can be classified according to the system heating method (centralized or household), the arrangement of the main parts (horizontal or vertical), and whether the pipes are insulated.

（3）Radiator: the residential construction standard of Italy gave the type selection of radiator and installation position, have in common radiator and heat radiation board these two types, vertical installation and horizontal installation of two kinds of installation means.

（4）Water storage tank: consider whether the domestic hot water system shares the heating system with the energy supply system. Classification is carried out according to layout (household or centralized) and location (heating and non-heating areas). Customer - installed domestic hot water system is not considered for renovation.

In conclusion, the energy consumption characteristics of residential buildings can be determined by climate zone, construction period and residential classification, and the type of residential energy supply system determines the energy utilization efficiency and energy consumption.

The numbers of the above four kinds of parameters also provide the corresponding technical direction for the transformation.

3　Theoretical refurbishing method introduction

3.1　Outputs

The evaluation index system is set up in "Scenario Analysis", which includes energy saving performance index and energy consumption index.

（1）The energy-saving performance index

The energy-saving performance index is mainly used to evaluate the indoor energy consumption and the efficiency of energy supply system after the renovation of enclosure structure. The former is determined by the heat transfer coefficient of wall, door and window, roof, basement ceiling and attic ceiling, while the latter is determined by the energy transfer efficiency or energy loss of each subsystem of the energy supply system. The theoretical refurbishing of *Scenario Analysis*focuses on five energy saving performance indicators, which can be divided into indoor heat demand, energy efficiency of cooling end, energy efficiency of heat distribution system, energy efficiency of heating end and additional energy loss according to the distance from indoor occupants (see 表).

表 3　Energy-saving performance index

index	units
Indoor heating need	Q （kWh/㎡ y）
Indoor cooling need	Q （kWh/㎡ y）
Efficiency of panels	η1
Efficiency of distribution system	η2
Efficiency of generator	η3
Auxiliary energy loss	Q （kWh/㎡ y）

（2）Energy consumption index

所示。

Energy consumption index is the energy consumption result obtained by simulation calculation, and is an important index to evaluate the energy saving effect. It can reflect the energy consumption characteristics of the existing situation or the energy saving potential of the transformation scheme.

Energy consumption includes energy consumption for each purpose, actual consumption of energy carriers, consumption of non-renewable primary energy and carbon dioxide emissions. Among them, the energy consumption of various purposes mainly includes heating system, domestic hot water system and household electrical appliances; Energy carriers include traditional energy carriers, such as electricity, natural gas, fuel oil and other biomass energy, as well as clean energy such as solar energy and wind energy. When the solar panels generate excess electricity that can be fed into the national grid, it means the building has achieved energy output, and energy consumption is recorded as negative. All energy units are converted to consumption per square metre per year for comparison between different housing types and different building types. Energy consumption indicators and measurement methods are shown in 表 .

表 4 Energy consumption index

index	unit
Domestic hot watwer use	Q （kWh/㎡ y）
Heating energy use	Q （kWh/㎡ y）
Cooling energy use	Q （kWh/㎡ y）
Indoor energy need	Q （kWh/㎡ y）
Energy use	Q （kWh/㎡ y）
Primary energy use	Q （kWh/㎡ y）

3.2 Average building and its representative energy system

Average building is the calculation object of the theoretical refurbishment scheme, and the representative system is the energy saving performance parameters of the mainstream envelope and energy supply system under the specific housing classification. By selecting the "standard house" and the representative system, the energy consumption of the building's existing state can be calculated and simulated to evaluate the overall energy performance and energy saving potential of all this kind of buildings.

Average building represents the physical characteristics of a specific type of house, and the form of Average building can be determined according to its proximity to theoretical models built in Sketchup, a computer architecture modeling program designed by Google. In the Practice in PoliTo, the multi-family houses and apartments ‘s Average building of is based on real buildings and simplified in form to some extent to have the common characteristics of such houses; Single-family houses and townhouses have a relatively free form, so theoretical models with common characteristics of these houses are used as "Average building ".

3.3 Determine the task and method of theoretical refurbishing

Energy-saving simulation renovation therefore needs to follow three principles: first, on the basis of the existing structure, no additional building components, choose the appropriate way of reconstruction of the envelope structure; secondly, on the basis of the existing energy supply system, the transformation mode of wall and space with little change is selected; third, consider using renewable energy sources such as solar.

（1）The main task of simulation transformation

The main task of the simulation transformation is to improve the insulation layer and energy supply system of the envelope, and to consider the distribution of heat in winter and summer and the distribution of energy use types.

The envelope structure determines the net energy demand of the interior, so it is necessary to further divide it into "heating zone" (such as part of the external wall, roof, ground floor) and "non-heating zone" (such as elevator room, underground storage room, etc.) for the design of insulation layer thickness respectively.

An energy supply system determines what kind of energy is used and how much it costs. Also heating system for example, heat source and water storage tank are the easiest to retrofit, radiator involves floor heating or ceiling heat dissipation, whose refurbishing difficulty ranks the second. The heat pipe of the old residence is buried in the envelope structure, and the refurbishing workload is the largest. Therefore, the replacement or maintenance of heat source and water storage tank is mainly considered in the reconstruction work. What kind of energy carrier to use by the heat source also needs to be considered. For example, electricity is a kind of clean energy, but the efficiency of converting primary energy into electricity is low, and electricity is more expensive than other energy.

In order to make full use of solar energy, solar panels can be installed on roofs and walls to provide the heat and electricity needed by the house, but the efficiency of converting solar energy into heat and electricity is different, so the certain proportion of how much the solar energy should be converted into electricity is very improtant.

（2）Mode of execution

Based on the relationship between input parameter, calculation formula and output index, the combination of theoretical refurbishing methods that meet the requirements of energy saving standards were selected by designing control group schemes, and the output indexes were analyzed. This method of implementation has the following advantages: First, the unified model can be used for the calculation of all housing classification through reasonable model; secondly, the parameters are easy to modify and can quickly generate several schemes for later comparison; third, the computational model can be connected with web page production for more people to study and use.

4 According to the "cost - energy efficiency" optimal method to determine the appropriate renovation scheme

After several alternative renovation schemes are generated, two renovation schemes that balance each other's cost and performance are screened out for 192 types of residential buildings using "cost-energy optimization method", forming a technology library containing 384 renovation schemes.

4.1 Select the basis and target of energy efficiency evaluation

The energy efficiency targets in "Scenario Analysis" are set based on the building energy classification system of each country certified by the European Union. The European Union assigns the unit of classification index as non-renewable primary energy consumption per square meter per year, namely kWh/ square meter Y), and requires at least A to G7 grades. Take the building energy consumption classification established in Italy as an example. There are two more grades of A, B and C respectively, and the energy consumption of space and hot water is stipulated respectively, as it shows in table

table 5 energy consumption classification standards in Italy

kWh/㎡ y

grades	Energy consumption	Domestic hot water	total
A+	≤22	≤9	≤30
A	≤22	≤18	≤40
B+	≤35	≤18	≤50

B	**≤45**	**≤18**	**≤60**
C+	≤60	≤18	≤80
C	**≤100**	**≤21**	**≤120**
D	≤155	≤21	≤180
E	≤195	≤24	≤225
F	≤230	≤36	≤270
G	＞230	＞36	＞270

The *Scenario Analysis* method identifies the energy efficiency targets of residential buildings as "Standard" and "Excellent", which correspond to grade C (annual energy consumption of 80-120 kWh per square meter) and grade B (annual energy consumption of less than 60 kWh per square meter) respectively.

The energy conservation goals can be classified to meet different energy conservation needs, and the energy consumption requirements of the two levels are energy consumption interval, which has great flexibility. Considering the actual different energy conservation transformation effects that can be achieved by the residential buildings in different built years, it also provides space for comparison and selection of numerous schemes generated by energy conservation simulation transformation.

4.2 Cost-efficiency optimal selection method（

The existing residential simulation renovation method provides energy consumption data for comparison and selection, and the next step requires cost data to construct the "cost-energy efficiency" relationship.

The cost in the "scenario analysis" method is the global cost (€/㎡). In the case of existing residential renovation, the global cost refers to renovation cost, equipment maintenance cost, components, equipment replacement cost, energy cost, and the assumed disposal benefit in the last year of the life cycle. The relationship between global cost and various costs is as follows:

Global cost = (transformation cost + replacement cost + maintenance cost + energy consumption cost - disposal cost) ÷ the use area;

"Cost - efficiency optimal method" first of all need to the cost of the alternative - energy consumption relationship curve fitting, and then analyze its marginal utility, according to a certain level of energy saving goal, choose the retrofit scheme of fitting curve slope absolute minimum, means that compared with the scheme, put more or reduce overall costs per unit of the same, The amount of energy saved is less than the previous unit of capital invested or reduced.

The cost-efficiency optimization method has the following three advantages: First, compared with using the percentage of energy consumption reduction as the energy saving target, using the primary energy consumption as the energy saving target can more intuitively reflect the impact of total residential energy consumption on natural resource use and carbon emission; Secondly, provide two levels of energy saving renovation program, and provide capital investment budget under the premise of meeting the energy consumption target, so that the renovation can make a choice between energy saving and capital investment, easy to formulate the renovation budget; Third, it is convenient to estimate the energy saving potential, which helps to formulate the housing energy saving plan rationally at the macro level.

5 Theoretical refurbishing cases

5.1 Energy saving transformation scheme

（1）Average building and input parameters

Through field visits to the project, combined with maps to obtain the surrounding environment of the house. By contacting the apartment manager, enter the equipment room of the apartment to determine the type and model of the energy supply system, and refer to the standards to obtain the energy efficiency of this type of equipment. By contacting the Urban Planning Institute to obtain the construction age information, building elevation drawings and envelope structure information. Finally, the general plan of the building is drawn based on the online map for the analysis of illumination and occlusion. The plan and general drawing information of the project are shown in figure 2.

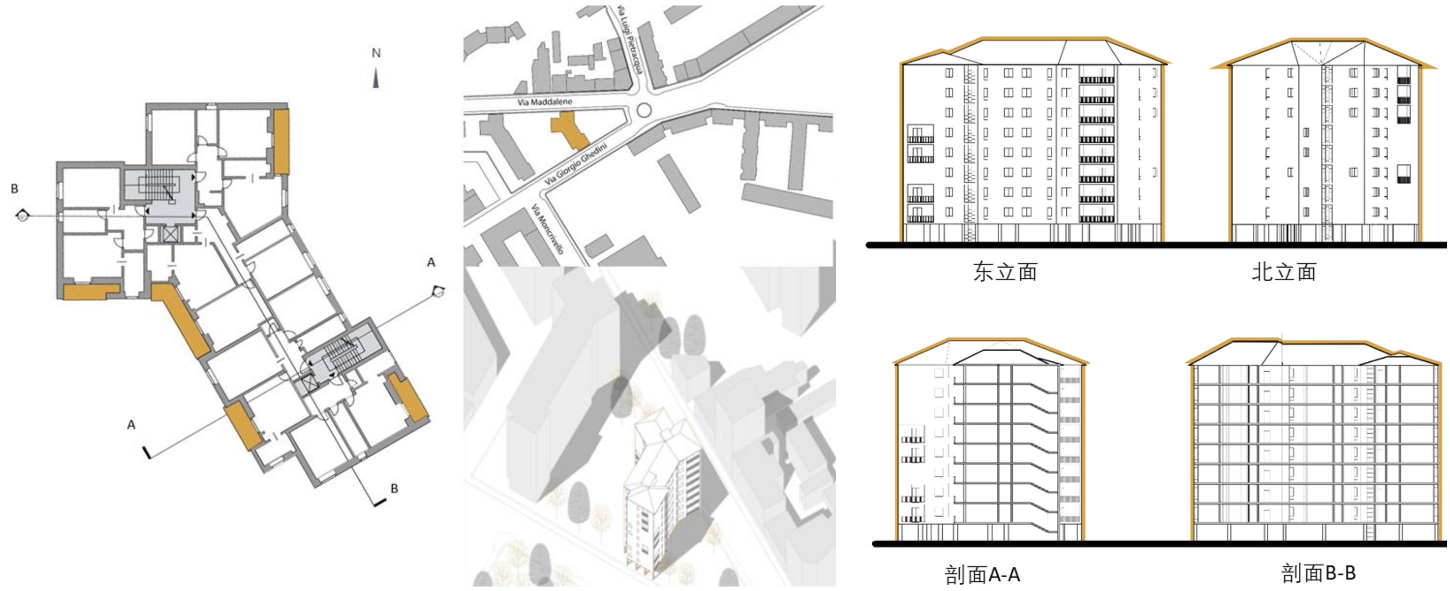

figure 2　Standard floor plans, elevations, sections and general drawings

The input indexes of three types of parameters of average building are shown in table 3 to table 10:

table 3　Climatic zone parameter

Central climatic region（＞3001 HDD）Outdoor temperature data												
month	1 月	2 月	3 月	4 月	5 月	6 月	7 月	8 月	9 月	10 月	11 月	12 月
MTCO（℃）	1.3	3.2	8.4	12	18.1	22.2	23.7	22.7	19.2	12.4	6.9	2.7

Shadow coefficients for each orientation*i*,w/day ㎡												
orientation	**1 月**	**2 月**	**3 月**	**4 月**	**5 月**	**6 月**	**7 月**	**8 月**	**9 月**	**10 月**	**11 月**	**12 月**
north	1.66	2.67	3.62	5.08	7.79	9.74	9.62	6.93	4.51	3.05	1.88	1.39
west	3.69	5.85	8.53	11.05	12.91	14.68	15.64	13.64	10.35	6.68	3.64	3.2
South	8.04	10.05	11.21	10.48	9.9	10.13	10.96	11.49	11.62	10.22	6.86	7.53
East	3.69	5.85	8.53	11.05	12.91	14.68	15.64	13.64	10.35	6.68	3.64	3.2
East west	6.33	8.49	10.64	11.7	12.03	12.81	13.91	13.53	11.92	9.03	5.6	5.83
North west	1.82	3.27	5.27	7.88	10.54	12.54	12.96	10.31	6.9	3.96	2.08	1.49

table 4　Housing Type parameters

Form	
Total area ㎡	4000

Numbers of apartments	40
Average area per floor ㎡	100
Total area of heating area facade wall ㎡	3320.6
Total area of facade Windows in heating area ㎡	60.2
Total perimeter of facade Windows in heating area m	323.4
Total area of non-heating area facade wall ㎡	1045.7
Total area of non - heating area facade window ㎡	89.8
Total perimeter of non - heating area facade window m	112.4

table 5 construction period

type	**The structural parts of the outer envelope**	**Thermal performance parameters**
1961-1975, 4 floors above (riser length > 10m), collective residence Outer envelope	Roof	U=2.22 w/㎡ K
	The attic floor	U=1.65 w/㎡ K
	墙体	U=1.10 w/㎡ K
	Floors	U=1.56 w/㎡ K
	winodws	U=4.9 w/㎡ K， g=0.98
	subfloor	U=1.30 w/㎡ K

table 6 energy supply system input index

content	**The subsystem**	**效率/损失量**
1961-1975, 4 floors or above (risers of length over 10m, conglomeration house) Power system	Heat source (natural gas boiler)	η=0.71
	Heat pipe	η=0.925
	Domestic hot water pipe	Q=13.4 kWh/.㎡ y
	The radiator	η=0.925
	Water Storage tank	Q=0.8 kWh/.㎡ y

（2）Energy consumption assessment methods and assumptions

The energy consumption assessment is carried out by the simulation calculation table built in EXCEL. The indoor environment hypothesis before the energy consumption assessment is shown in table 7. The calculation method and formula reference standards are shown in table 8. The reference standards for the calculation of structural details are shown in table 9

table 7 Assumptions for energy consumption assessment

No.	Assumptions

1	The indoor air exchange rate of the house under natural conditions is 0.3/h
2	Use area to calculate indoor heat gain
3	Assume that you don't use shading devices such as curtains to reduce indoor heat gain
4	According to the heating requirements of climate zone, the heating season is from October 15th to April 15th of the next year, and the rest time is the cooling season, and the heating system and refrigeration system run daily during the corresponding period
5	The indoor temperature of heating season is 20℃, and that of refrigeration season is 26℃
6	Household equipment power consumption is 30kWh/㎡ Y
7	The starting temperature of domestic hot water is 15℃, and it can only be used by heating it to 40℃

table 8 Reference table for calculation of indoor environment and energy consumption of power supply system

UNI	**The main content**	**EN ISO**
UNI/TS 11300-1	A monthly quasi-stabilization method used to calculate the net energy requirements for building space heating and cooling	EN ISO 13790
UNI/TS 11300-2	Energy consumption calculation for space heating system and domestic hot water system	EN ISO 15316
UNI/TS 11300-4	Heat source calculation method for combustion boilers using liquid and gas fuels	EN ISO 15316

table 9 Standards for calculation details

Details	Standards	institutions
Thermal bridge	EN ISO 14683（2007d）	CEN / CENELEC
Groundheat conduction	EN ISO 13370（2007d）	CEN / CENELEC
Shading coefficient	UNI 11300-1	Italian National Standards Agency

The calculation process of energy consumption is as follows:

①:Calculate the net energy requirements for heating and cooling when the space reaches the assumed temperature. Net energy requirements are determined by heat conduction of the envelope, indoor and outdoor air convection, indoor heat gain, and heat gain through solar exposure, as shown in formulas a and b

$$Q_{H,nd} = (Q_{H,tr} + Q_{H,ve}) - \eta_{H,gn} \times (Q_{int} + Q_{sol,w}) \qquad \text{公式 a}$$

$Q_{H,nd}$ Represents the heat demand in space, assuming greater than 0 in megajoules

$Q_{H,tr}$ Represents heat conduction loss of the envelope, assumed to be greater than 0, in megajoules

$Q_{H,ve}$ Represents the loss of indoor and outdoor heat, in megajoules

$\eta_{H,gn}$ Represents the thermal efficiency of space, dimensionless

Q_{int} Represents indoor heat gain, in megajoules

$Q_{sol,w}$ Represents the heat of the sun for a given period of time, in megajoules

$$Q_{C,nd} = (Q_{int} + Q_{sol,w}) - \eta_{C,ls} \times (Q_{C,int} + Q_{C,ve}) \qquad \text{公式 b}$$

$Q_{C,nd}$ Represents space cooling demand, assuming greater than 0, in megajoules

Q_{int} Represents the heat gained in the room, let's say greater than 0, in megajoules

$Q_{sol,w}$ Represents the solar heat gain for a given period of time, let's say greater than 0, in megajoules

$\eta_{C,ls}$ A dimensionless coefficient representing loss of heat in space

$Q_{C,int}$ Denotes heat conduction loss of envelope structure

$Q_{C,ve}$ Represents heat loss in space

② Calculate the energy consumption of all power systems. If renewable energy is used, the energy provided by renewable energy should be subtracted from the energy consumption demand. In this practice, according to national requirements, solar energy provides 60% of the energy required to add hot water. The energy dissipation formula provided in the standard is formula c.

$$Q_{X,Y,in} = Q_{X,Y,out} + Q_{X,Y,ls,nrh} - Q_{X,Y,aux,rh} \qquad \text{公式 c}$$

$Q_{X,Y,in}$ Represents the actual energy carrier input by Y subsystem in X system

$Q_{X,Y,out}$ Represents the actual energy output of Y subsystem in system X

$Q_{X,Y,ls,nrh}$ Represents the heat loss that the Y subsystem of system X fails to recover

$Q_{X,Y,aux,rh}$ Represents the heat energy recovered from the electrical energy dissipated in the form of heat energy by the auxiliary equipment of subsystem Y

In this practice, the system efficiency η is used to calculate $Q_{X,Y,ls,nrh}$, and the energy consumption required by the electrical auxiliary equipment is considered, while the reclaimed heat energy is ignored. Taking the heating system as an example, the simplified calculation formula is shown as Formula d

$$Q_{X,Y,in} = \eta_g \times \eta_d \times \eta_e \times Q_{H,nd} + Q_{X,Y,aux} \qquad \text{公式 d}$$

$Q_{X,Y,in}$ Represents the input amount of energy carrier in heating system

$Q_{H,nd}$ Represents the heat demand in space, assuming greater than 0 in megajoules

η_g It's the efficiency of the heat source

η_d Represents the efficiency of heat pipe

η_e Represents the efficiency of the radiator

$Q_{X,Y,aux}$ Represents the energy consumption of auxiliary equipment, in kWh/㎡ Y

③ The consumption of non-renewable primary energy is calculated. Assuming that the prices of service providers providing energy carriers are the same, the consumption of non-renewable primary energy is the sum of all energy carriers multiplied by conversion rate, as shown in Formula e.

$$\sum_i Q_{Y,out,i} = \eta_{Y,P} \times \left(\sum_j E_{Y,in,j} \times f_{P,j} + \sum_j E_{Y,aux,j} \times f_{P,el} \right) \qquad \text{公式 e}$$

$Q_{Y,out,i}$ Represents the primary energy consumption in the ith Y power supply system

$\eta_{Y,P}$ Denotes the use efficiency of non-renewable primary energy in the energy supply system Y, and this calculation takes 1

$E_{Y,in,j}$ Represents the usage of the jth energy carrier in Y energy supply system

$f_{P,j}$ Represents the conversion rate from non-renewable primary energy to jth energy carrier

$E_{Y,aux,j}$ Represents the power demand of auxiliary equipment of power supply system Y

$f_{P,el}$ Represents the conversion factor of non-renewable primary energy into electricity, and the value is 2.7.

（3）Design control group scheme

]The theoretical refurbishing is aimed at the renovation of walls, doors and Windows, heating system and renewable energy. According to Italian energy saving standards and tax saving policies, walls and doors have 2 ways of renovation, namely medium energy efficiency and high energy efficiency. Heating system has 3 ways of renovation, namely medium energy efficiency, high energy efficiency and heat pump. In the utilization of renewable energy, there are 2 ways of renovation, using solar energy and not using solar energy. According to the design principle of the control group, there are 24 transformation schemes.

（4）Calculation results and analysis

According to the above assumptions and calculation methods, the analysis of various net energy demand and non-renewable energy consumption is shown in figure 3 and figure 4.

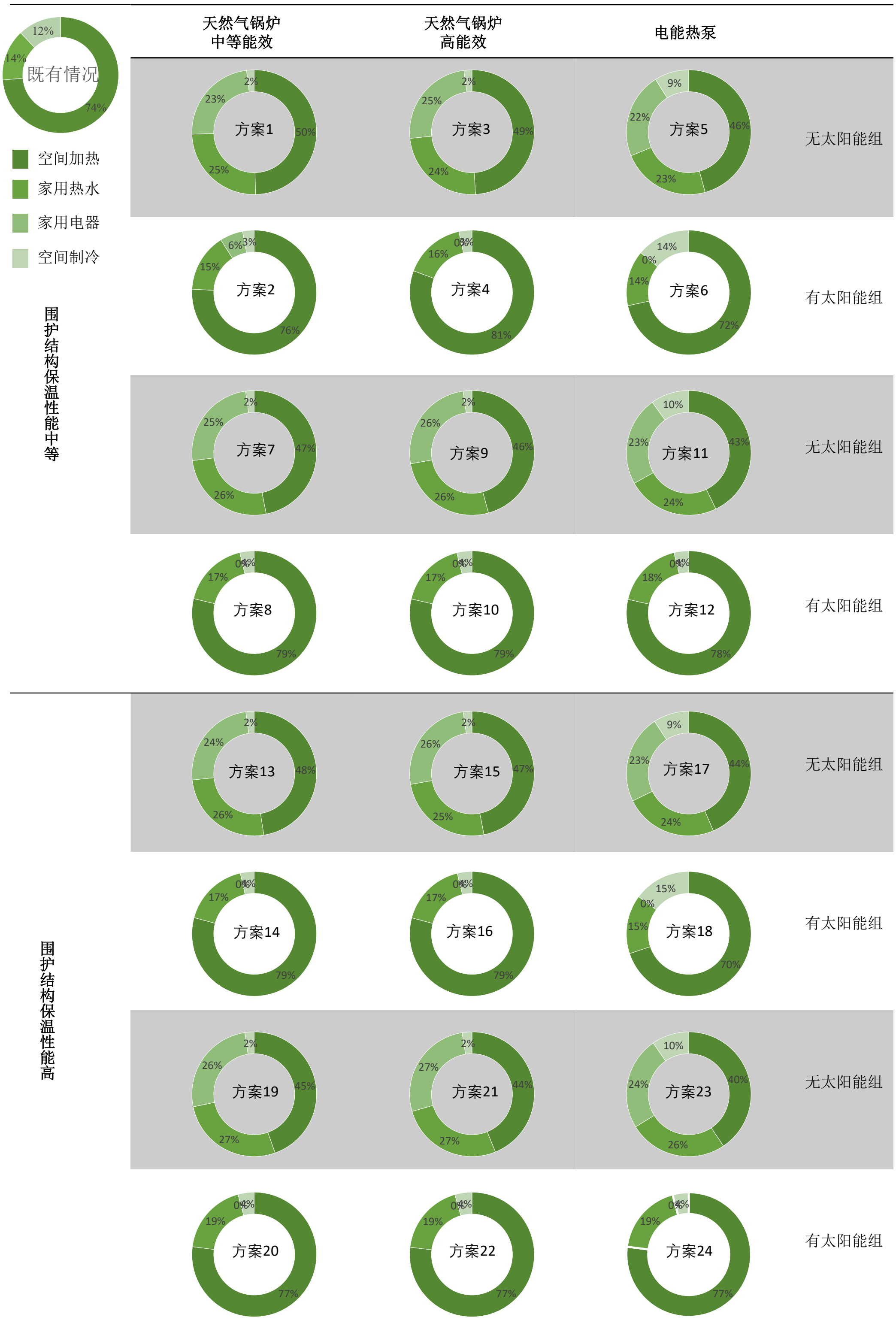

figure 3 Indoor net energy consumption demand analysis diagram of the control scheme

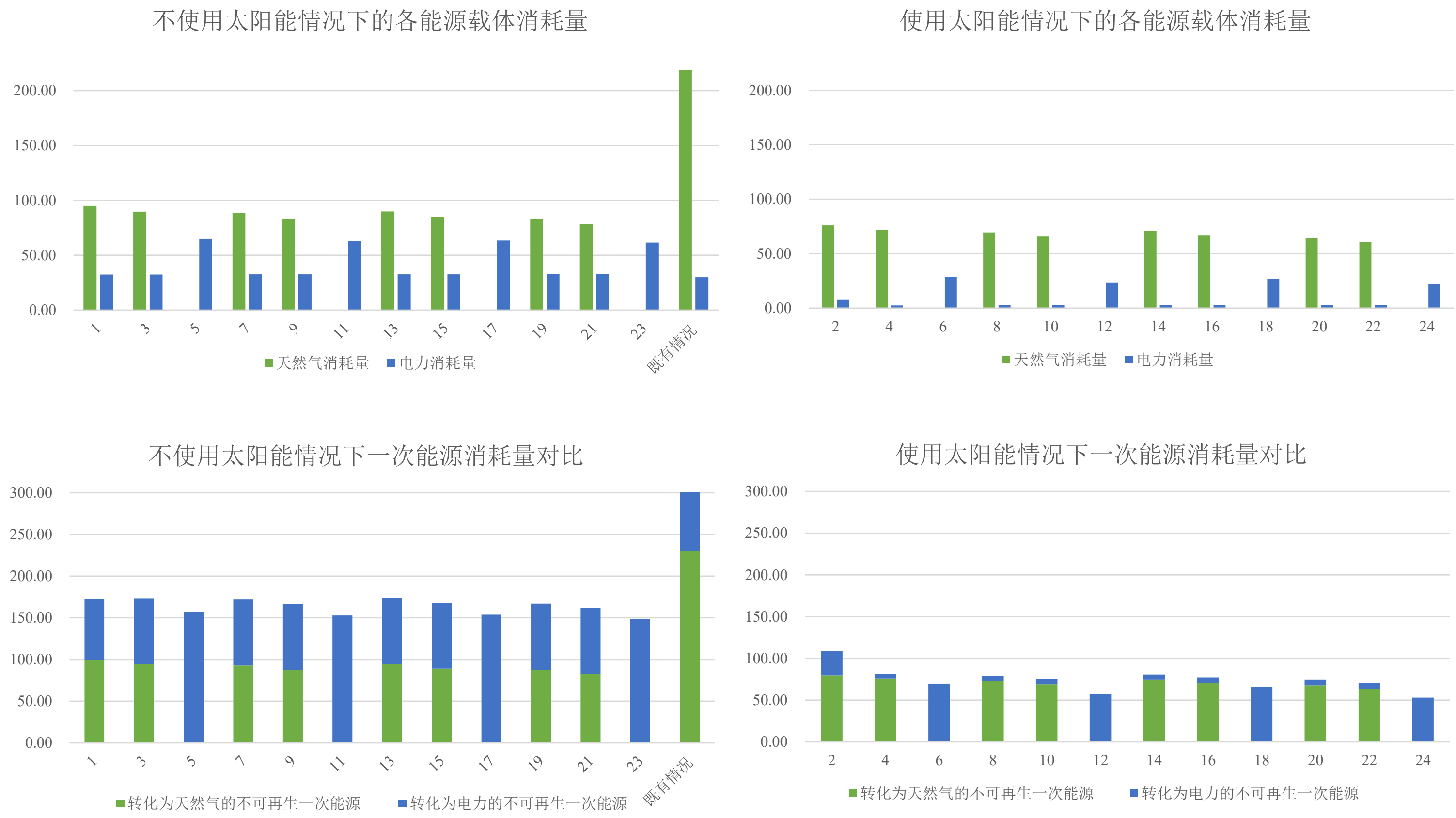

figure 4 Comparison of energy carrier consumption and non-renewable primary energy consumption in 24 control schemes

5.2 According to the "cost-energy efficiency" optimal method to select the appropriate program

（1）Cost assessment methods and assumptions

The calculation formula of global cost refers to THE European Standard EN 15459, as shown in Formula F. Known by the formula, the cost of global C_g（t） and T is directly related to the length of the life cycle, can be obtained by calculating the annual net cash flows, based on the starting year t_0, considering the initial transformation cost C_I, and the maintenance cost for each part since the first year i $C_{M,i}$, replacement cost $C_{R,j}$ and cost of all kinds of energy carrier $C_{E,e}$ and the disposal cost $C_{D,k}$

$$C_g(t) = \left[C_I + \sum_{t=1}^{T}\left(\frac{\sum_i C_{M,i,t} + \sum_j C_{R,j,t} + \sum_e C_{E,e,t}}{(1+r)^t}\right) + \frac{\sum_k C_{D,k}}{(1+r)^T}\right] \div A \quad \text{公式 f}$$

$C_{M,i,t}$Represents the maintenance cost of the reconstruction part i in year

T

$C_{R,j,t}$ Represents the replacement cost of the transformed part j in the t year

$C_{E,e,t}$ Represents the use cost of energy carrier e in the t year

$C_{D,k}$ Represents the disposal income of the refurbished part k at the end of its life cycle

According to European Commission No. 2010/31/EU, the life cycle of housing is 30 years, the data of each renovation part is given by the national price list, and the maintenance cost is between 0.5% and 3% of the renovation cost. The service life of each renovation part refers to European Standard No. 15459, and the replacement cost does not consider the price inflation factor. According to the labor and material costs at the time of transformation, the conversion of disposal income adopts straight-line depreciation method.

（2）A comparison of global costs

According to the above calculation process, the global cost-energy efficiency relationship of 24 control schemes can be obtained, as shown in figure 5.

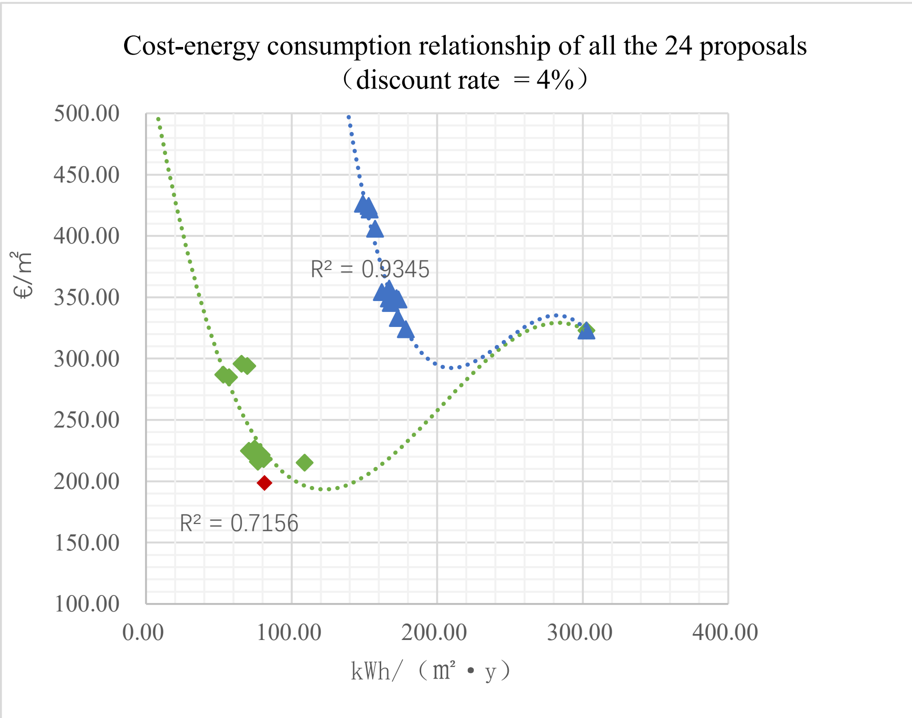

figure 5 Cost-energy efficiency relationship of 24 scenarios

According to the cost-energy efficiency relationship in the figure, scheme No. 4 conforms to the standard energy-saving transformation with the lowest cost; Scheme No.

12 conforms to the excellent energy-saving transformation with the lowest absolute value of slope of fitting curve (that is, the scheme number corresponding to the red mark in the figure).

5.3 Measure and compare economic benefits

（1）A method for measuring economic benefits

The economic benefits are measured in two aspects: the comparison of the global cost level with the pre-renovation global cost level, and the comparison of the net present value of the energy benefits of the scheme. Global cost can be used to represent the amount of social resources used by the renovation work and the housing after renovation, that is, the social benefits. If the overall cost after the transformation is less than the existing situation before the transformation, it means that the transformation can bring about the saving of social resources.

Energy benefit refers to the energy cost saving after renovation, which can be regarded as the hidden benefit of renovation work. In the global cost, except the disposal income, all components are cash outflow. Considering the "energy benefit", there will be saving funds as cash inflow every year, thus reducing the global cost, which means that the saved funds can be used for investment in other projects, bringing the net present value of economic benefits. The relationship between NPV of economic benefits and global costs and energy benefits is as follows:

Net present value of economic benefits = energy benefits - global costs

The net present value of economic benefits is positive, which means that the renovation scheme can realize economic cost savings and thus enable other investments.

Finally, the sensitivity of NPV to the change of renovation cost, maintenance cost, replacement cost, energy cost and disposal income is the source of the change of the analysis of the global cost, and can reflect the risk faced by the renovation project in the life cycle. For example, the global cost change caused by the change of renovation cost is the most obvious, which means that the change of renovation cost under the influence of market factors is the main risk of global cost change.

（2）Calculation results and analysis

①Global cost comparison

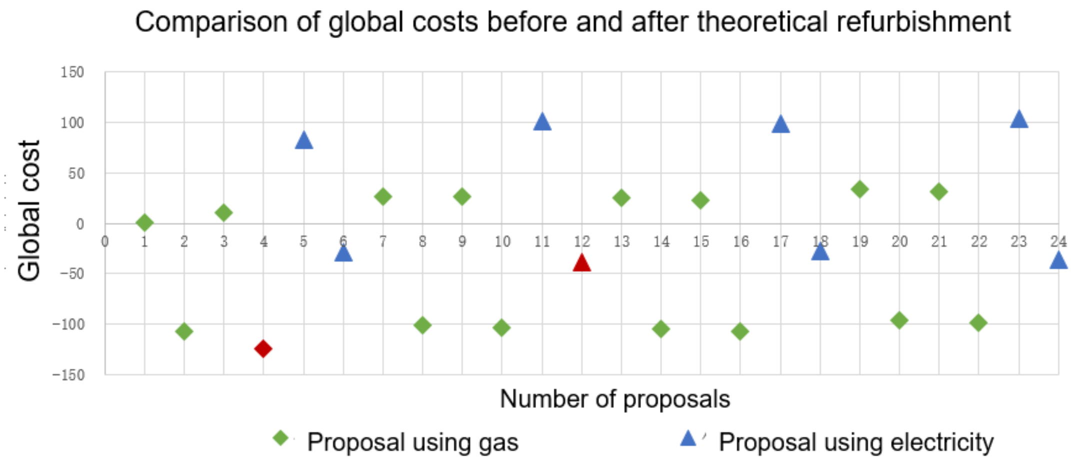

figure 6 Global cost comparison chart

figure 6 shows the difference of global cost before and after renovation.

The triangle is the difference between the transformation plan using an electric heat pump as a heat source and the global cost before the transformation.

Diamond marked is the difference between the transformation plan using natural gas boiler as heat source and the global cost before transformation, diamond marked in red is standard grade transformation plan, triangle marked in red is excellent grade transformation plan.

Through comparative analysis of the global cost difference, it can be found that the global cost reduction of using electric heat pump is significantly lower than that of using natural gas, and the global cost difference of using solar energy as energy supplement (even numbered scheme) is negative, that is, it can realize the saving of social resources.

The global cost composition of all schemes is further analyzed, and the comparison results are shown in figure 7.

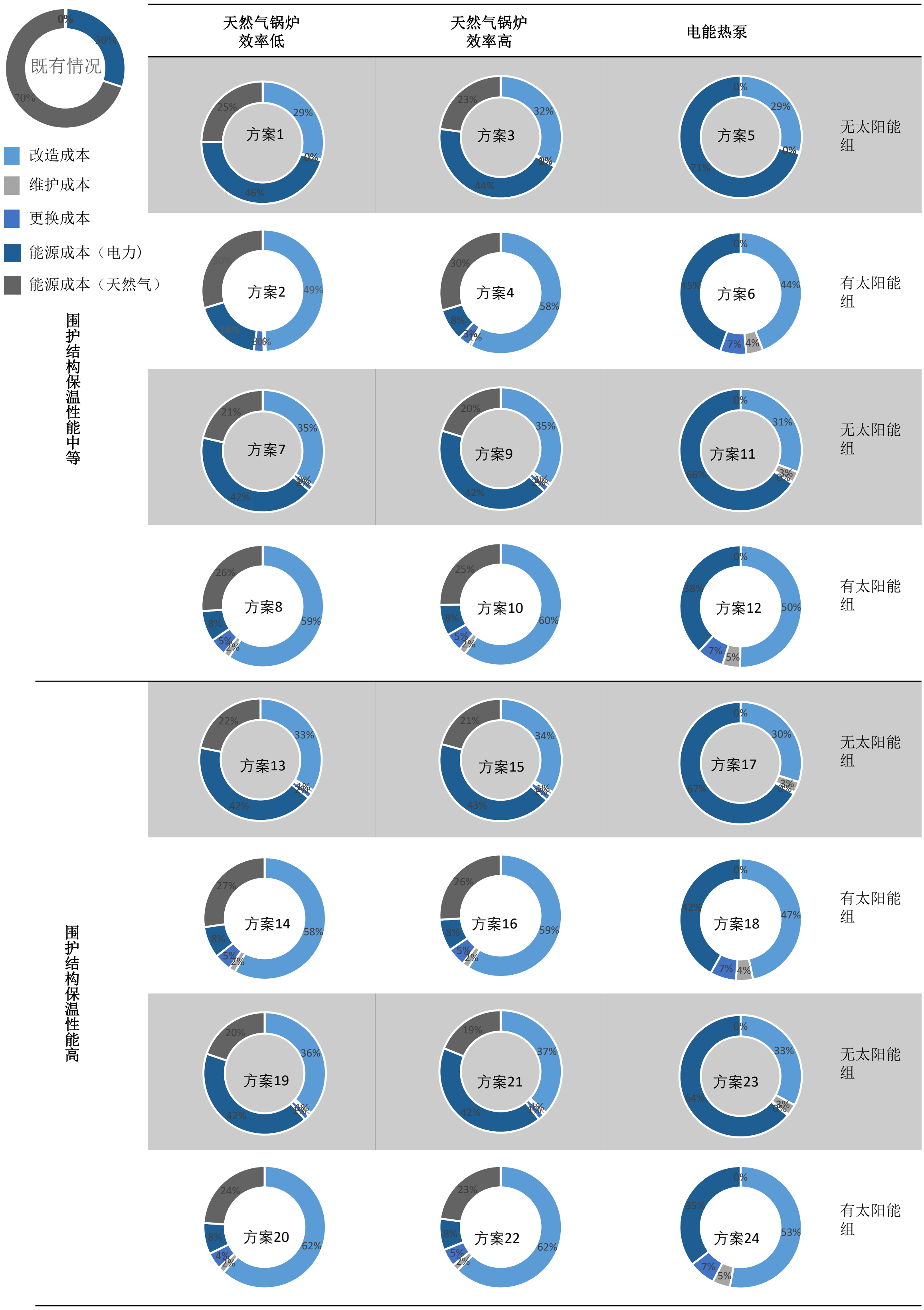

figure 7 The global cost of 24 groups of renovation projects was compared

② Net present value of economic benefits

figure 8 shows the NPV analysis of economic benefits of standard grade and excellent grade transformation plan as well as the control group that does not use renewable energy. Only the energy benefits of standard grade transformation plan are greater than the global cost and economic benefits can be realized.

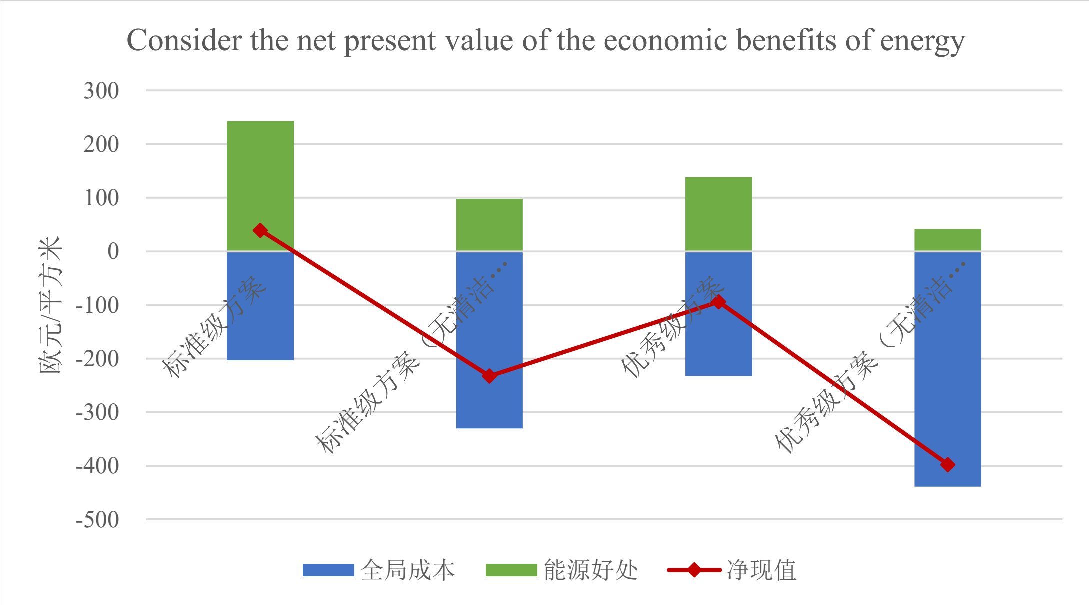

figure 8 The net present value of economic benefits of standard grade and excellent grade renovation schemes

The sensitivity analysis of NPV to various costs is shown in the figure below. The figure 9 shows that the standard of machine, the net present value is most sensitive to the change of energy benefits, and the economic benefits of the control patients who did not use the solar energy solutions for electricity costs change is the most sensitive, due to the energy benefit is both the situation and the retrofit scheme of energy cost difference, means that the same level of energy price changes, The change in energy benefits is smaller than the cost of energy itself, so the change in the net present value of the economic benefits of non-clean energy options is greater. In the excellent renovation scheme, the price of renovation becomes the most influential factor on the

NET present value.

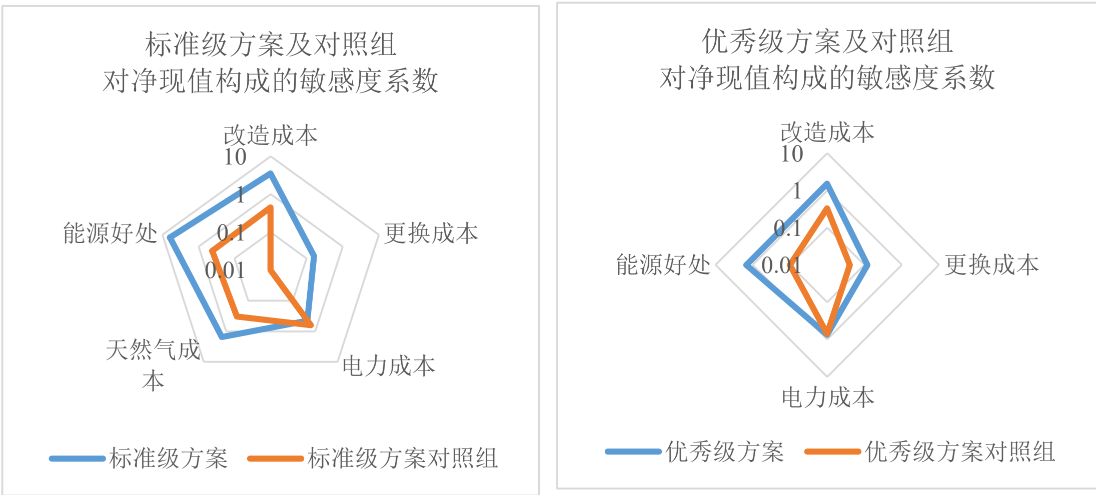

figure 9　Sensitivity analysis of NPV of standard grade and excellent grade renovation scheme to various costs

6　Evelation

6.1 Scientific classification helps to solve the problem of big difference between existing houses

A scientific classification method helps simplify the assessment of energy consumption for China's existing homes, which are located in five different climate zones and are complex to retrofit. Firstly, the "scene classification" method provides a reasonable classification method for residential buildings, that is, four parameters including climate zone, construction time, building type and energy consumption system can be used to locate the energy consumption of residential buildings. Combined with Average building , the energy consumption characteristics of a class of houses can be obtained quickly. This method has been popularized in the practice of eu member states and verified its operability in different climate zones. Secondly, from the perspective of the application of member states, the classification of reconstructed housing can effectively simplify the statistical work of residential energy consumption characteristics, and it is convenient and feasible to implement. Thirdly, this method can provide reference for setting energy consumption target.

Therefore, appropriate classification methods and appropriate average buildings can also be used to evaluate the energy consumption characteristics of existing houses in China, thus greatly simplifying the problems of complex and large number of reconstructed houses in climate zones.

From the micro point of view, the classification system can provide targeted refurbishment scheme, and provide reference for the energy saving renovation for a single case.

6.2 The classification of energy saving goals helps to balance renovation investment and efficiency

Using the total energy consumption as the target of energy saving transformation and classifying the target can improve the predictability of transformation results, and the appropriate energy saving scheme can be selected by comparing the relationship between cost and energy efficiency after transformation.

Different energy saving goals can provide different energy saving effects of the transformation plan. Second, the inclusion of costs in the evaluation of retrofit results enables retrofit participants to balance energy conservation goals with actual capital investment.

6.3 The establishment of dynamic energy consumption database of existing houses is helpful for macro policy making

The basis for *Scenario Analysis* to run for a long time is the establishment of housing stock information database and the timely update of reconstruction information. According to the application of the *Scenario Analysis* method in the EU, each member state needs to update the building energy consumption situation every year, set a 3-year building energy saving target every three years according to the actual renovation work, and make energy consumption planning every 10 years, all of which cannot be separated from the establishment of dynamic database.

By constructing the energy consumption database of housing stock through reasonable classification system, and establishing the evaluation database of energy consumption saving after energy saving transformation of housing through Average building, the database of the whole situation of housing can be formed. On this basis, timely update makes the residential energy consumption situation can be checked and controlled, and provides a feasible method to achieve the building energy conservation goal.

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