POLITECNICO DI MILANO
SCHOOL OF ARCHITECTURE URBAN PLANNING CONSTRUCTION ENGINEERING
M.Sc in BUILDING AND ARCHITECTURAL ENGINEERING

Contemporary Renewal Strategies Experiment of Chinese Vernacular Housing

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Abstract

With the rapid development of green low-carbon building technology in China, the design of livability and sustainable renovation of traditional Chinese vernacular buildings with wooden load-bearing structures has become an important issue in the current strategy of revitalisation of the Chinese countryside. The article takes into account the development of green building technology in the context of double carbon, and from the current situation of the renewal and renovation of traditional Chinese vernacular dwellings, it analyses and studies the characteristics and problems of traditional vernacular dwelling buildings, and outlines a reasonable solution concept. The article selects a typical timber-frame brickwork vernacular house in Quzhou, China, as the object of study, which leads to a consideration of the development of the timber from material to a mature type of modern timber-frame load-bearing system, and then to a detailed study of the characteristics and differences between different timber-frame load-bearing systems. The article attempts to design an update and renovation strategy for the research object, in terms of Aesthetic strategies, Engineering strategies and Environmental strategies, through the reshaping of the timber bearing system of the building, the increase of secondary structure The paper aims to reconstruct and reuse the abandoned and damaged vernacular residential buildings through the reshaping of the timber bearing system, the addition of secondary structure, the redesign of structural parts such as walls, roofs and ground floors, and the incorporation of active building techniques. Finally, the paper combines the life cycle assessment and the criteria of the green building evaluation system to simulate and assess the value of the design project in terms of building insulation, energy consumption and light environment, as well as the Active House Radar score.

Key Words: Timber, Traditional Chinese Vernacular Architecture , Renewal Strategies, Active House Technology, Green Building , Low Carbon, Life Cycle Assessment

Contents

0 Introduction

In recent years, with the development and construction of newer green buildings, China has shifted the focus of quality architectural development from the cities to the countryside, with an unprecedented increase in the attention paid to the design of rural vernacular building renovation, and a spurt of architectural design and renovation projects for vernacular buildings. This has led to a huge number of building projects, prompting architectural engineers to explore and find better solutions for the renovation of traditional vernacular buildings that are more in line with modern green building requirements, and to expand, summarise and optimise their design ideas for traditional vernacular buildings.

This study is based on the current development of the renovation of Chinese traditional vernacular houses. Through in-depth analysis and research of Chinese traditional vernacular houses, the common characteristics and problems of traditional vernacular buildings are sorted out and summarised, and reasonable solutions are proposed for these characteristics and problems. In this way, the needs for the renewal and renovation of Chinese traditional vernacular houses are further extended.

The article selects a traditional timber-brick vernacular house in Quzhou, southern China, as the object of study, and conducts an in-depth and detailed study of timber construction: firstly, the material characteristics of timber itself are described, and the advantages of using timber as a construction material are summarised. The article then progresses from 'material to product', 'product to system' and 'system to type', discussing in depth and detail the transformation of timber from a material to a category of The article is an in-depth and detailed account of the process of the timber's transformation from a material to a large system of building types.

The article presents an analysis of the current state of the selected Chinese traditional vernacular dwellings and a creative, in-depth and detailed renovation design for the selected object of study. The aim is to optimise the current state of the building in order to reuse it in a modern way. The design is based on 'Aesthetic strategies', 'Engineering strategies', 'Environmental strategies', 'engineering strategies', 'environmental strategies', and a combination of theoretical descriptions and drawings to provide a detailed and complete design strategy for the building. The paper concludes with a comprehensive assessment of the value of the renewal strategies in terms of structural renewal of the building envelope, calculation of the building energy consumption and simulation of the building light environment, in conjunction with the active green building evaluation criteria system.

The most innovative aspect of this study is the creative design of the regeneration strategy for traditional Chinese vernacular buildings, taking into account their characteristics. The design strategy combines wood-frame buildings with a green building regeneration strategy, which is a modern interpretation of the application of the traditional Chinese wood-frame system in line with green building standards. The innovative incorporation of active building techniques for in-depth design also provides a methodology for the future renewal of a large number of traditional vernacular dwellings in China.

The shortcomings of this study are that the design cannot be implemented in practice, and it is not possible to test and evaluate the regeneration strategy through actual construction. The design is more of a theoretical approach that is grounded, rational and feasible through data calculations, realistic simulations and some actual case studies, and the expected results and the results of the analysis obtained are bound to differ to some extent from the actual situation.

1 Development of Low Carbon Green Architectures

In recent years, the huge global carbon emissions have led to environmental degradation and climate warming, jeopardising normal human production activities and seriously affecting the quality of life. Statistics show that 73% of global carbon emissions come from energy consumption, of which 38% comes from the energy supply sector, while 35% comes from the energy consumption sectors of buildings, industry and transport, which are recognised as the world's three biggest "energy consumers".

As a major gateway to carbon emissions and energy consumption, the exploration of the energy saving, ecological improvement and sustainable development impact of green buildings has attracted the attention of the construction industry and market worldwide, based on the excessive consumption of global energy and the harmful effects on climate warming caused by the energy consumption of crude technical buildings. Green building is a systemic project that encompasses design, construction, operation as well as property and future renovation, and is a building development concept that considers the whole life cycle. The concept was first introduced in the 1960s by Italian architect Paolo Soleri with the concept of 'eco-building'.

According to the World Bank, 70% of the reduction potential to achieve global energy efficiency and emissions reduction targets by 2030 lies in building energy efficiency. Of the approximately 1.7 billion buildings in the world today, a very small percentage are net-zero carbon buildings. All buildings consume 13.6% of the world's water, and green buildings are expected to use water-efficient systems to reduce building water use by 15%. At the same time, to keep global temperature rise below 2°C, every factory, every building, every home, etc. should be net-zero carbon by 2050. in 2017, the World Green Building Council (WGC) issued its first ever net-zero building pledge, calling on businesses in the built environment to ensure that all existing buildings operate at net-zero carbon by 2050. in September 2021, the WGC called on In September 2021, the World Green Building Council called on companies to consider the full life-cycle impacts of all new buildings and major refurbishments, with the aim of initiating an 'emissions reduction first' approach to decarbonisation, halving carbon emissions by 2030 and addressing full life-cycle emissions.

With this in mind, in 2020 the European Commission launched the 'Innovation Wave' initiative, which aims to achieve near-zero energy consumption in all buildings by 2030. For example, Italy and some German cities are developing energy-positive buildings; in April 2020, France adopted its National Low Carbon Strategy, which aims to achieve carbon neutrality by 2050; in October 2020, Japan announced that it would achieve net zero greenhouse gas emissions by 2050, and in December of the same year, it released its The "Green Growth Strategy" will promote emission reduction in 14 key areas such as residential buildings, offshore wind power, electric vehicles and hydrogen energy; the UK launched a "green bill" scheme in 2020 to encourage people to install emission reduction facilities in old buildings by means of tax rebates and subsidies, and to install emission reduction facilities in new green buildings. The UK will launch a "green bill" scheme in 2020, with tax rebates and subsidies to encourage people to install emission reduction facilities in older buildings.

1.1 Development of vernacular buildings in China under the dual carbon policy

In 2021, China has incorporated carbon peaking and carbon neutrality into the overall layout of ecological civilization construction: carbon dioxide emissions will not increase until 2030, and will gradually decline after reaching the peak; carbon dioxide or greenhouse gas emissions will be offset in the form of energy saving and reforestation to achieve zero emissions and carbon neutrality by 2060. Unlike developed countries such as the UK and the US, which have 60 to 70 years from peak carbon to carbon neutral, China only has about 30 years from peak carbon to carbon neutral, so the time is tight and the task is heavy to achieve the "double carbon" target. The State Council issued the "Action Plan for Achieving Carbon Peaks by 2030" in October 2021. It calls for promoting green and low-carbon transformation in urban and rural construction and energy use, improving the energy efficiency of buildings, optimising the structure of building energy use, and accelerating the implementation of green and low-carbon development in urban and rural construction, urban renewal and rural revitalisation.

1.2 Characteristics of traditional Chinese vernacular architecture

Traditional Chinese rural vernacular architecture is an important part of ancient Chinese culture, and its design and construction pay particular attention to regional characteristics, environmental adaptability and humanistic concerns, mainly in the following aspects:

Architectural layout: Traditional Chinese rural architecture is usually dominated by courtyards, surrounded by houses. The layout is symmetrical, balanced and open, with the buildings echoing and illuminating each other. This layout makes full use of space and also provides a private and quiet living environment for the occupants. Courtyards often have natural light and air circulation and can be used for daily rest and social activities.

(1) Construction: Traditional Chinese village buildings are often constructed using local natural materials such as earth, bamboo and wood, which are not only environmentally friendly but also provide good insulation and thermal insulation. For this reason, traditional Chinese village buildings are often constructed of wood, masonry or mixed structures. Of these, timber-frame buildings are one of the most common forms of construction. Using materials such as wood, bamboo and straw, timber-frame buildings are not only light in weight but also have good durability and seismic resistance. In addition, the wood itself carries a certain aesthetic appeal, which accentuates the natural and rustic style of rural architecture.

(2) Architectural decoration: The architectural decoration of traditional Chinese rural vernacular architecture pays great attention to detail and refinement. Usually, the eaves, door frames and windows of a building are carved with various fine patterns or designs. In addition, certain areas of the building are painted and decorated. These decorative elements usually reflect the local cultural traditions and ethnic characteristics.

(3) Environmental adaptability: Traditional Chinese rural vernacular buildings are usually in harmony with their natural surroundings and are an important feature of them. Traditional rural buildings are usually designed according to topography, climate and other factors, using reasonable ventilation, lighting and drainage systems to make the indoor environment comfortable and, to a certain extent, harmonious with the surrounding natural environment. The location, orientation and height of these buildings need to take into account the surrounding natural environment in order to achieve the best possible landscape effect. The design of the buildings also needs to make full use of the local natural resources, such as rocks, water flow, grass and trees, in order to meet people's needs for an ecological environment.

These features make traditional Chinese rural vernacular architecture highly valuable in terms of functionality, practicality, artistry and cultural connotation, demonstrating the high degree of integration between architecture and the natural environment that people in ancient China have developed, and is an important part of China's cultural and historical heritage.

1.3 Existing problems and strategies of traditional Chinese vernacular architecture

As mentioned in the previous section, there are some inherent problems in traditional Chinese vernacular houses, among which lighting, ventilation and thermal insulation of the walls are the main problems. In this section, these problems will be analysed and discussed in depth, and the direction and methods of solving them will be proposed.

Traditional Chinese vernacular buildings have common and acute problems in terms of light and ventilation, which are manifested in two areas:

(1) The problem of lighting: traditional vernacular buildings are mostly built with thick walls and wooden windows, resulting in insufficient indoor lighting, which affects the comfort of living. In addition, as many traditional vernacular buildings are triple or quadruple courtyard structures, the lack of natural light in the centre also makes indoor lighting more difficult.

(2) Ventilation: Ventilation in traditional vernacular buildings is relatively poor, especially during the hot summer months. This is mainly due to the fact that traditional vernacular buildings mostly use closed doors and windows, and there are few vents on the roof, making it impossible for hot air to flow smoothly.

A summary and collation reveals that the main reasons for these problems are the following:

(1) Irrational building layout: The layout of many traditional buildings was not designed to suit the needs of everyday life, but to meet the needs of specific activities, such as rituals and storage. As a result, in some traditional buildings, the main activity areas are often located deep in the house, without doors and windows that open to the outdoors, resulting in poor indoor lighting and ventilation.

(2) Limited number and size of windows: The number and size of windows in traditional buildings are often limited due to symmetrical aesthetics and safety concerns of the inhabitants. Also, some traditional buildings have poorly placed windows, for example, in houses facing north, the windows are mostly set on the south side, resulting in insufficient light entry and poor ventilation.

(3) Lack of scientific design: Many traditional buildings are designed on the basis of experience and tradition, without scientific means of monitoring and improvement, and therefore lack

effective technical support for solving light problems. For example, traditional buildings are mostly built of masonry and other materials, and the external walls are often heavy. This structure makes it difficult for light to penetrate into the interior of the building, making it less effective.

The above problems reflect the fact that traditional Chinese vernacular buildings have many lighting problems, which result in a dark and damp interior environment, affecting the comfort and health of the occupants. For the renovation of vernacular buildings, light and ventilation are issues that need to be addressed in these traditional buildings. Based on this, the scientific measures that can be taken to address these problems are multifaceted and multifaceted:

(1) Increasing the number and size of windows: without damaging the overall aesthetics of the building, increase the number of windows or change their size to open them to take advantage of natural light and air circulation to improve the indoor environment.
(2) Installing lighting devices: Light devices such as skylights and glass curtain walls can be used to promote natural lighting and increase indoor light. The construction of skylights or the installation of ventilation equipment can also improve air circulation and make the indoor air fresher.
(3) Use new materials: Use lightweight, breathable materials such as bamboo and timber processed with new technology to meet the requirements of low carbon green building to improve ventilation.
(4) Preserve traditional features: While improving ventilation and lighting, the features and cultural values of traditional vernacular architecture should be preserved as far as possible without losing the original form and beauty.

The problem of thermal insulation in walls is another problem that has existed for a long time in traditional Chinese vernacular architecture and is manifested in two main areas:

(1) Insulation problem: Traditional vernacular buildings are mostly made of thick brick, stone or earth walls, which are effective in blocking out the cold air from the outside, but they lack an insulation layer of their own, which can easily cause the indoor temperature to be too low and lead to discomfort for the occupants.
(2) Thermal insulation problems: As the wall materials of traditional vernacular buildings are usually stone, earth walls or bricks, the high thermal conductivity of these materials allows the outside temperature to be transferred to the interior relatively quickly, affecting the stability and comfort of the interior temperature.

A summary of the causes of these problems can be found in the following areas:

(1) Inappropriate choice of materials: Most traditional vernacular buildings are built using natural materials such as earth, stone and wood, which have poor thermal insulation properties, easily leading to problems such as temperature fluctuations and high humidity inside the house.
(2) The building structure is unreasonable: many traditional buildings have relatively large wall thicknesses and do not use thermal insulation materials, which makes the insulation performance of the walls poor. At the same time, traditional buildings often have the problem of poor sealing performance of doors and windows, which also leads to poor indoor thermal insulation.
(3) Lack of scientific design: Many traditional buildings are designed based on experience and tradition, lacking scientific means of monitoring and improvement, and therefore lacking effective technical support for solving wall insulation problems.

The above-mentioned problems lead to problems with wall insulation in traditional buildings. The poor thermal insulation of traditional buildings leads to fluctuations in indoor temperatures, increasing the use of heating and air conditioning, as well as affecting indoor comfort and health. The measures that can be taken to address these problems are also multifaceted and multifaceted:
(1) Use of new insulation materials: e.g. polystyrene panels, polyurethane foam panels, rock wool, etc. These materials have a good thermal insulation effect and are very effective for the renovation of wall insulation in traditional vernacular buildings.
(2) Internal and external wall insulation: in terms of external wall insulation, insulation materials can be added to the external walls of traditional vernacular buildings to form a layer of thermal insulation to reduce the transfer of temperature between the interior and exterior; in terms of internal wall insulation, insulation materials can be added to the internal walls of traditional vernacular buildings to effectively improve the insulation effect of the indoor space.
(3) Transformation of balconies and windows: balconies and windows of traditional vernacular buildings are also parts that are more prone to heat dissipation and heat leakage, and can be transformed by using new materials such as double or triple glazing and break-bridge aluminium.
(4) Designing a reasonable ventilation system: adopt a scientific and reasonable ventilation system design to reduce energy consumption while ensuring indoor air quality, so as to achieve energy saving and consumption reduction.

In conclusion, for the wall insulation of traditional vernacular buildings, it is necessary to consider the structure, environment and cultural characteristics of the building and take corresponding measures to improve the living comfort and retain its traditional characteristics.

1.4 Existing problems and strategies of traditional Chinese vernacular architecture

In recent years, against the backdrop of China's rapid urbanisation, the country's urbanisation rate has increased from 36.2% in the early 2000s to 65.22% today. As the pace of urban construction has gradually slowed, the state and government have shifted the focus of development and construction from the cities to the countryside and suburbs, modernising and building in these relatively more backward parts of the country.

In contrast to the massive construction and rapid development of urban buildings, in the rural and suburban areas of China, which are far from urban areas, traditional residential buildings are generally of poor architectural specifications and quality due to historical and economic constraints, and the living environment and conditions can hardly meet the modern needs of people. The reason for this is that most of these existing vernacular buildings use the traditional Chinese timber structure load-bearing system, which has been subjected to the storms of history. The envelope of these houses was also very simple and could hardly meet the basic requirements of thermal insulation. With the increasing awareness of global climate change and environmental protection, the Chinese government has started to implement a double carbon target, which has had a positive impact on the development of the renovation of traditional vernacular buildings and has led to a higher and clearer direction of renovation:

(1) Structural safety: Many traditional vernacular buildings have a long history of ageing or fragility, especially in the case of traditional timber-framed buildings, where the corrosion of traditional building timbers is a particular problem. Therefore, when renewing and renovating, the structure needs to be optimised, strengthened and repaired to improve the safety of the building.

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(3) Comfortable to use: Many traditional vernacular buildings are not reasonably designed and have problems with ventilation and heat insulation, making the living environment less comfortable. These problems therefore require consideration of comfort factors when

carrying out renovation, including improving light, ventilation and sound insulation to improve the quality and comfort of living use.

(4) Environmental friendliness: limited by the technical means of construction, the materials and techniques used in the construction of traditional vernacular buildings are mostly direct-use resources, and these resource materials cannot meet the requirements of green environmental protection and are prone to pollution and waste of resources. Therefore, when renewing vernacular buildings, environmentally friendly and sustainable materials and technologies need to be chosen and the impact on the natural environment needs to be minimised. Renewable energy sources such as solar and wind power can be used to replace traditional energy supply methods and reduce carbon dioxide emissions. At the same time, the choice of building materials can be made by using natural materials or by recycling old materials to avoid using materials that are harmful to the environment, for example by using green materials such as bamboo and adobe.

(5) Cultural heritage: As an important heritage of Chinese history and culture, many traditional vernacular buildings need to retain their unique cultural flavour during the renovation process, focusing on preserving the rural fabric, rural culture and rural characteristics. Therefore, when carrying out renewal and renovation, attention should be paid to protecting the architecture, layout and texture formed by history, focusing on the vernacular atmosphere and watery countryside charm, retaining the original countryside ecology as far as possible and keeping the countryside culture; the cultural value of the protected buildings should be fully considered, retaining the original historical style and characteristics as far as possible, paying attention to reflecting the unique cultural connotation of traditional buildings, identifying the historical, cultural and artistic values of traditional buildings, and in the design The design of the buildings is designed to incorporate new elements so that they not only have a traditional style but also adapt to the needs of modern people. For example, old features such as the arch structure or the flying eaves can be preserved or reproduced in modern architectural design language during renovation.

In conclusion, the renewal of vernacular buildings is becoming increasingly important under the dual carbon policy, which requires the joint efforts of the government, residents and architects to integrate the concept of sustainable development throughout the renewal process.

2 Timber

Wood is a building material that has been widely used throughout the world throughout history, especially in China, where it has been one of the most important building systems in the history of Chinese architecture for thousands of years, combining history, art and science, with great ornamental value, and leaving numerous architectural treasures for the world's wood construction history. And now with the development of green building around the world, there is a significant increase in interest and demand for green building materials. This has led to a renewed boom in wood as a traditional building material with low-carbon and environmentally friendly features, which has been a part of the construction industry's development in recent decades.

This change between 'historical' and 'modern' can be not only in terms of form, but also in terms of production methods. This means that in contemporary times even a new building with a close relationship to traditional timber forms can still be included in the category of 'modern timber frame'. In contrast to traditional timber construction, modern timber construction relies on new technologies from the wood industry to redefine and recreate new building materials - Engineered Wood Products (EWPs). By processing raw materials (logs) into new wood-based building materials that overcome the dimensional boundaries, natural defects, biological defects and anisotropy of the wood itself, engineered wood products allow the application of wood without the limitations of a single material itself. The native timber forms new 'material combinations' and building 'component assemblies', which develop into product systems and in turn lead to the creation of 'construction systems'. This chapter therefore discusses the characteristics of timber as a structural building material in comparison with other building materials, and in the context of its contemporary development seeks to discuss how timber has evolved from a 'primary' material, through a 'product type', to a 'construction type' system. "It also discusses how timber has been systematised from a 'native' material, through 'product types', to 'construction types', and provides a brief assessment and analysis of these types of systems.

2.1 Existing problems and strategies of traditional Chinese vernacular architecture

The use of timber in construction can be divided into three main phases; before the 19th century, logs were an irreplaceable material in construction and were often used in unprocessed or simply polished structures. For example, in the surviving ancient wooden buildings in China, log house structures are still preserved (Figure 2-1).

Figure 2-1 ChaShou/Inverted V-shaped brace of FoGuang and NanChan Temple

(https://new.qq.com/omn/20201106/20201106A0HR2G00.html)

After the 19th century, new building materials and structural forms gradually replaced timber until the 1970s, when timber was again valued for its renewable and diverse properties, and a new phase of light wood construction and wood products was initiated, with glued laminated timber as the main material form. Over the past 10-15 years, a new construction system and design strategy has gradually emerged for timber buildings. The heavy-duty timber construction system has elevated timber from its original limitations of only being able to construct small buildings to a wider range of building types, including high-rise, large-span prefabricated processing and assembled modular buildings, able to compete with concrete and steel buildings. It is in response to this trend that the industrial design and construction of buildings has in recent years incorporated timber buildings with new innovations in construction methods.

Modern timber frame construction has been significantly enhanced in all aspects through technological improvements. These include improvements in fire resistance, durability and joint performance.

2.1.1 Fire resistance

The fire resistance of traditional timber has always been one of the greatest barriers to its use as a building material. To ensure the fire resistance of timber buildings, timber walls and floors are often covered with a layer of plasterboard or other non-combustible material, which is further combined with active fire control systems (e.g. sprinkler systems) to reduce the threat of fire to safety. The fire resistance of wood is significantly higher than that of steel and concrete, with the heat transfer capacity of wood being about 1/8th that of concrete and 1/400th that of steel, and in terms of the combustion mechanism of wood, wood will burn when exposed to a flame with a temperature of 220ºC ~ 250ºC. The combustion process goes through four stages: at temperatures <110^{o} C ~ 115^{o} C, the mechanical properties of the wood remain unchanged; at ⩾110^{o} C ~ 115^{o} C, the combustion enters the propagation stage; at ⩾200^{o} C, the wood produces a flame; during the combustion process, as the surface wood is burned and carbonised, the carbonised layer naturally isolates the wood from the outside world, making it an excellent flame retardant layer, increasing the internal temperature that the wood structure can This increases the temperature that the interior of the timber structure can withstand, protecting the timber inside from burning and, moreover, the wood inside the charred section still has structural strength. Therefore, compared to other major building materials, modern timber structures already have a good fire safety profile.

2.1.2 Durability

The durability of timber in construction is influenced by both water resistance and corrosion resistance. Measures to improve the durability of modern timber in construction include the following three main aspects:

(1) Selecting the right timber for the building site. The shorter the age of the timber, the better it is for processing and painting, but the lower the strength; the older the timber, the harder it is, and the less it is for processing.

(2) To improve the durability of timber, full consideration must be given to the detailed design of the components. Wood shrinkage is minimal in the down-grain direction, at 0.1% to 0.35%, and maximum in the chord direction, at 6% to 12%. In the design of outdoor elements, direct contact with water in the chord direction is avoided. The waterproofing and preservation of timber also focuses on measures such as the anti-corrosion painting of the surface layer and ventilation.

(3) Modern timber preservation also uses full chemical impregnation and carbonisation to prevent corrosion, mould, moth and termite infestation and to improve the durability of timber in outdoor use.

2.1.3 Connection performance Durability

Whereas traditional timber frame buildings were mainly built using mortise and tenon joints and nail joints, modern timber frame construction has a wider variety of joints with improved strength, durability and appearance. There are many different types of modern timber frame connections, including dowel glued joints, L-formed nailing and gluing joints, nailing and gluing joints, metal connectors, pre-stressed glued joints and finger glued joints (Figure 2-2). These connections break the dimensional limitations of the logs, enabling integrated glued timber to reach spans of 40m and beam thicknesses of 180 ~ 2000mm as required, greatly increasing the application of timber in construction.

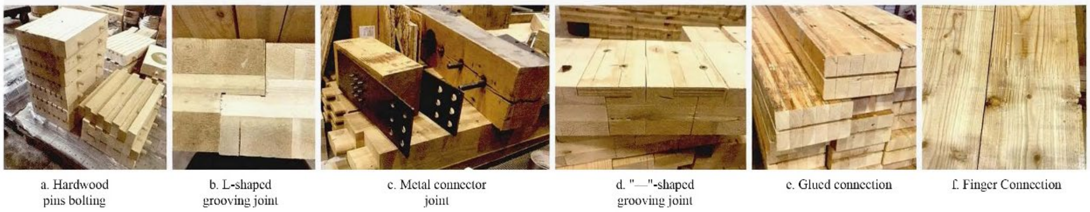

Figure 2-2 Types of connection nodes in timber structure

(Relations Between Construction Process of Modern Timber Buildings and Prefabrication Design)

2.2 Wood: a "carbon-negative" material

Steel, concrete, wood and stone are the four most commonly used materials for building construction, of which wood is the only renewable building material. The production of 1 tonne of steel and 1 tonne of cement releases 1.6 tonnes and 1.0 tonnes of CO_2 respectively, while the production of cement produces particulate matter, SO_2 and nitrogen oxides, and the production of steel produces dust and SO_2, all of which are sources of air pollution. In contrast, for every tonne of wood grown, 1.6 tonnes of carbon dioxide is absorbed and 1.2 tonnes of oxygen is produced, making wood the only "carbon-negative" building material with significant ecological benefits.

In a 2010 Life Cycle Impact Assessment (LCIA) study of different building materials, researchers from the Beijing Institute of Technology, in collaboration with Wood Canada, analysed the environmental impacts of three different types of civil buildings, including concrete frame construction (CFC), light steel frame construction (SFC) and wood frame construction (WFC), during the stages of building materials production, construction and use. In this analytical study, the environmental impact of the building structures of three different types of civil buildings, including CFC, SFC and WFC, during the stages of building materials production, construction and use. In this analytical study, the life cycle inventory of a wide range of materials, including metal materials, gypsum materials, cement and concrete materials, materials for doors and windows and vinyl materials, as well as fossil energy, electricity and transportation are all derived from the SinoCenter database. Through the calculation of characteristic indicators of 11 types of environmental impacts as well as the uncertainty and sensitivity analysis of the results, as well as the presentation of the statistical figure of the data(Figure 2-3), allow it to be determined that among these three different kinds of construction structures, wood structure shows very obvious advantages because it ranks lowest in 8 kinds of environmental impact category, especially in the climate change, radiation effects, ozone depletion and land resources damages, all of 4 are closely related to human survival and life.

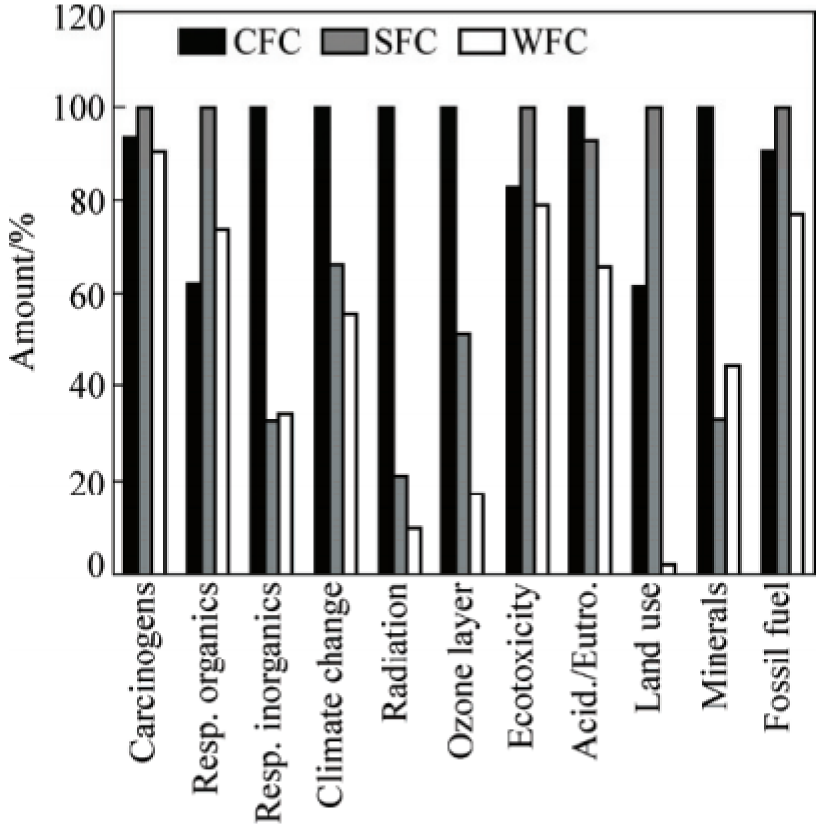

Figure 2-3 LCIA comparison of impact categories for CFC, SFC and WFC in their life cycle

(Recent progress and application of materials life cycle assessment in China, 2010)

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2.3 Towards a standardized and systematic approach to timber materials

For timber, with the continuous improvement of the processing technology of contemporary building materials and the change of construction systems, it has not been abandoned by the times, but rather a modern, standardised approach to wood construction has been established from the industrial product of timber, engineered wood. Engineered wood materials use new technologies to recombine raw materials to produce more controllable wood materials, for example by re-cutting, blending and gluing techniques to produce beams that eliminate all anisotropy, are free from knot defects and can be considered as homogeneous rods. These products, controlled by a variety of standards, form a "product system", which in turn becomes the basis for the creation of a "construction system". The architect and engineer Friedrich Zollinger developed the Zollinger system for the construction of curved timber-framed building shell roofs (Figure 2-4).

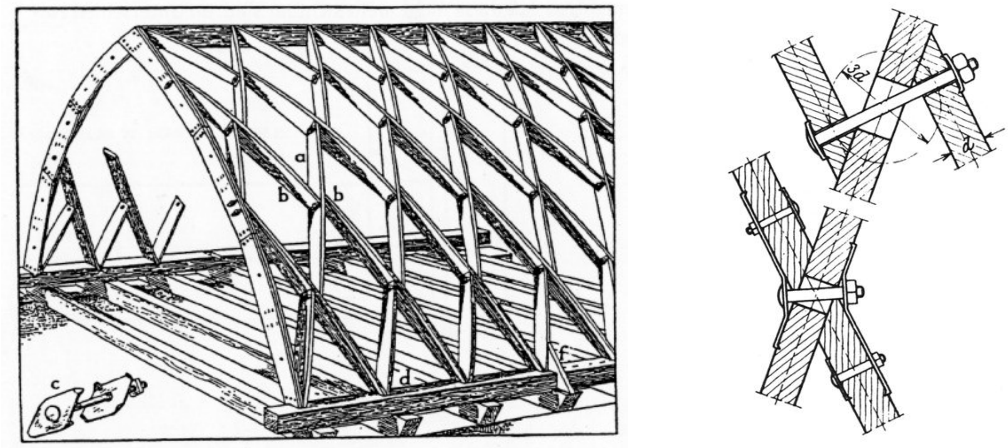


Figure 2-4 Diagram of the roof with the Zollinger system and its connection details

(https://roofstructures.tumblr.com and reference)

The diamond-shaped units of the roof are interwoven with repeated short timbers. An important advantage of this roof construction system is that even if a small number of short timbers or joints are damaged, the roof as a whole maintains a certain structural strength. The material used for the short timber poles can be selected from a wide range of engineered timber subsystems, thus enhancing the reliability of the roof. This means that the multi-layered system enhances the adaptability and stability of the timber structure, and that the dependence of the individual elements reinforces their original effectiveness. In other words, the 'system' allows the various elements of the construction to have a common purpose.

2.4 From Materials to Systems

2.4.1 Material to product

Engineered wood materials include the simplest and most readily available solid sawn timber and new wood products processed using blending and gluing techniques. In the 1970s, the emergence of "finger-joining" technology for solid sawn timber enabled the application of CNC machines to produce larger building elements by pushing the limits of tree boundaries. This was the beginning and the basis for many innovations in EWPs. Solid sawn timber is produced by direct processing of the logs, but in the EWPs system it is subject to strict grades and specifications in order to obtain a stable and uniform product composition.

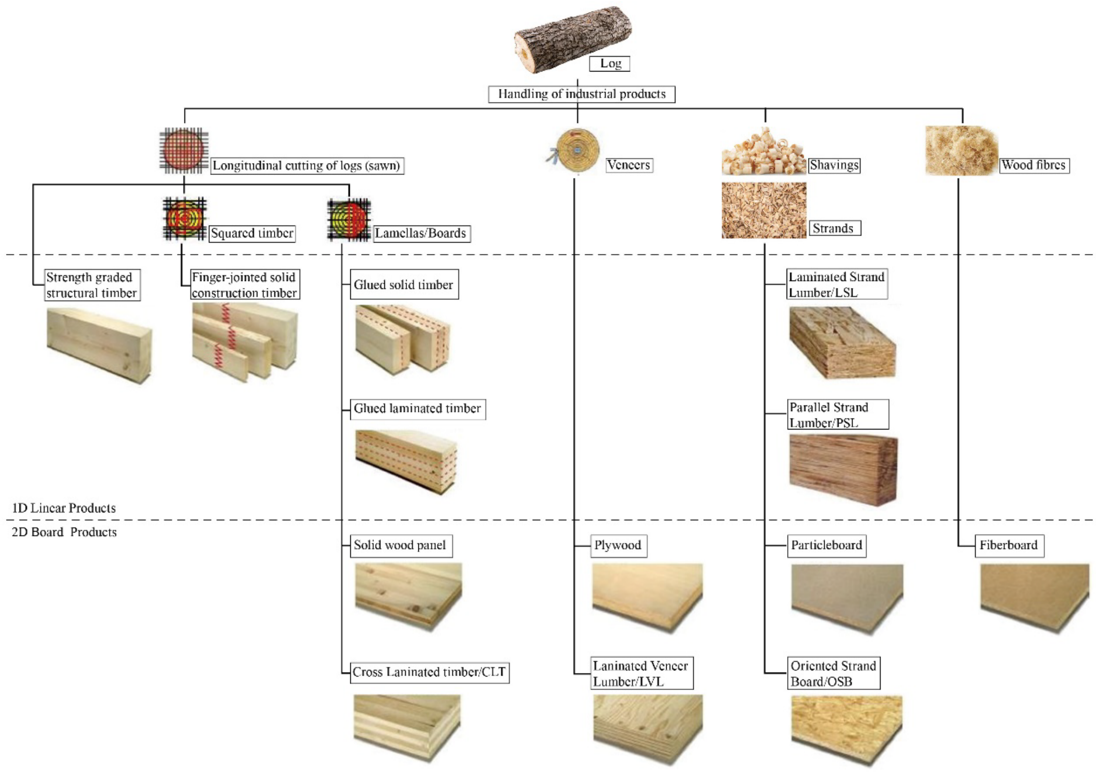


Figure 2-5 Engineered wood material product system (Self-drawn by the author)

EWPs begin with the primary processing of logs and end up as raw products for building components that can be used on demand. Depending on the degree of treatment, logs can be processed into several secondary materials such as longitudinal sawn timber (square and strip lumber), rotary cut veneer, shavings or chips and wood fibre. Depending on the two spatial elements most commonly used in architecture - line and surface - these substrates are eventually processed into two main categories: linear timber and lumber. The relationship between EWPs can therefore be mapped on the basis of two dimensions: the 'treatment of the log' and the 'spatial form of the product'. Most of the products in Figure 2-5 have a complete and well established system of grading, processing and application, and the following is a brief overview of the definitions of each product and how they are differentiated from their counterparts. Some of the materials are to some extent polymorphic and are included in a common subset, for example, veneer laminated products (linear or panel), finger-joined and glued solid wood (square or laminated, based on "length/width = 3").

Product Type	Form	Function	Dimensional specifications	Application areas
Dimension Lumber	Linear	Load-bearing	Length <5.4m Width 25-75mm Thickness <250mm	Structural frame, beams, columns
Laminated Log	Linear	Load-bearing	Length no limit Cross-sectional <280x280 mm^2	Trusses, beams, columns
Glued laminated timber/GLT	Linear	Load-bearing	Length no limit Width <280mm Thickness <1300mm	Trusses, beams, columns
Laminated Strand Lumber/LSL	Linear	Load-bearing	Length <20m(Transport need) Width 30-90mm Thickness 90-1000mm	Beams, columns
Parallel Strand Lumber/PSL	Linear	Load-bearing	Length <20m(Transport need) Width 45-200mm Thickness 68-457mm	Beams, columns
Cross Laminated Timber/CLT	Board Linear	Load-bearing/ Shea-resistance	Length <20m(Transport need) Width <4.8m Thickness 50-300mm	Beams, columns, load-bearing walls, shear walls, floor slabs, etc.
Laminated Veneer Lumber/LVL	Board Linear	Load-bearing/ Shea-resistance	Length <20m(Transport need) Width 200-2500mm Thickness 19-200mm	Beams, columns, trusses, shear walls, edge plates, webs, etc.
Oriented Strand Board/OSB	Board	Load-bearing/ Non-load-bearing	1220x2440mm Width 9-25mm	Envelope, I-beam webs, floor laminates
Particleboard	Board	Non-load-bearing	1220x2440mm Width 9-25mm	Flooring, ceilings, infill, trim, etc.
Fiberboard	Board	Non-load-bearing	1220x2440mm Width 3-25mm	Flooring, ceilings, infill, trim, etc.

Note: The dimensions in the table are general, some materials can be custom sized according to patents and actual needs.

Table 2-1 Dimensional specifications and application areas of some wooden materials

(drawn by the author)

The various products made from engineered wood materials have a positive impact on overcoming the natural imperfections of solid wood itself. In addition to eliminating dimensional stability problems, structural stability problems due to the anisotropy of wood, these engineered materials upgrade a raw material to a product system where the density and dimensions of the product can be tightly controlled, thus creating a transition and basis for higher level systems, such as 1D wire product systems and 2D panel product systems. Table 2-1 provides information on some of the main 1D wire and 2D sheet products and their applications. Wood is a traditional material in its own right, and a view of the history of technology expresses the interdependence and non-disconnectedness of cultural phenomena and technological innovation. If the technology of wood applications in antiquity was a collective unconscious evolution of processes, innovation in processes and products, guided by benign mechanisms, has led to a collective imaginative renewal of wood - from a crude material associated with traditional architecture and practice to a modern high-tech product that continues to offer possibilities for the future.

2.4.2 From product to system

With engineered wood material products in place, the design of modern timber structures needs to decide how to combine these products. Deciding which strategy to use requires a combination of the structure of the building and the way it is built to make an effective system. For example, a heavy timber (massive timber) such as a CLT structure uses continuous slab structural members, so that the continuous structural layer itself has a high vapour penetration resistance (Figure2-6(a)); conversely, if the building is constructed as a lightweight frame system, there is great connectivity between the interior and exterior, and the structural elements have an impact on the continuity of the vapour barrier insulation (Figure2-6(b)).

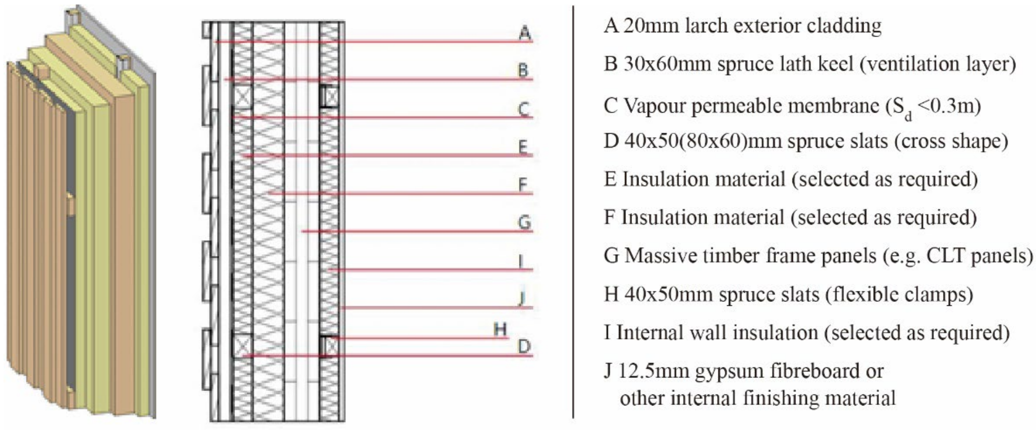


Figure2-6a Example of a heavy timber frame wall

(Redrawn from dataholz database - facades - awmohi01a)

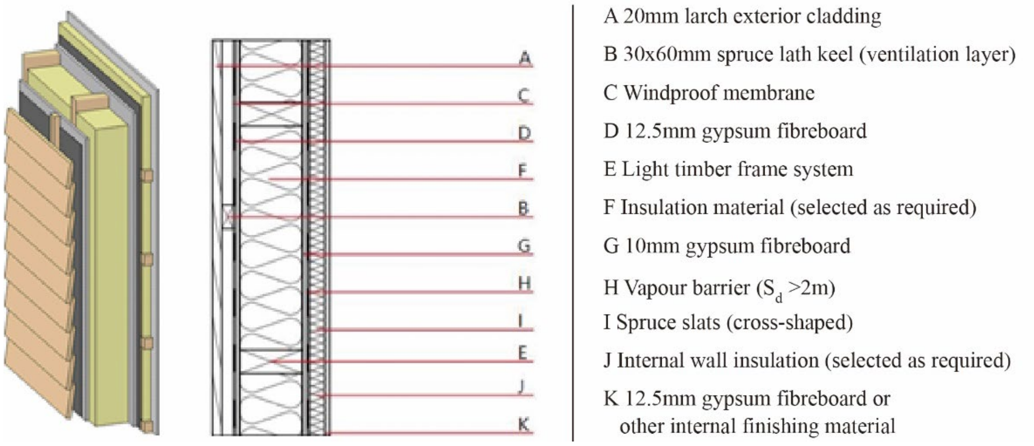


Figure2-6b Example of a light timber frame wall

(Redrawn from dataholz database - facades - awmohi01a)

Unlike reinforced concrete, which is poured on site, modern timber structures rely on the capabilities of forestry engineering and wood product production, are a reflection of modern industrial technology and continue the sequence of traditional timber structures in terms of process logic, i.e. a certain degree of pre-fabrication of the various components before installation on site. Depending on the project, the highly prefabricated nature of the process thus enables modern timber structures to achieve the most suitable solutions to practical problems such as the external environment (humidity, heat and ventilation), building form, accessibility and transport conditions, outside the site and before construction.

Generally speaking, their prefabricated elements can be divided into the following broad categories according to their spatial form (Figure2-7):

-Independent structural elements: these refer to individually prefabricated structural elements such as beams, columns and frames, which are designed, calculated and processed and then transported directly to the site for installation. Processes very similar to those of our ancient grand woodwork;

-Two-dimensional elements: these contain both structural elements such as load-bearing walls and elements such as internal and external maintenance, floor slabs and roofs. Often the two-dimensional elements can be highly integrated, with the whole wall already prefabricated with a complete structure, insulation and waterproofing, electrical equipment, etc;

-Three-dimensional components: spatial units that have been produced and constructed, and can be highly pre-integrated with complete structures, insulation and waterproofing layers, electrical equipment and even furniture decoration, etc;

-On-site processed prefabricated components: mainly components with special dimensional forms, non-standard or unable to meet transport requirements.

All types of building structures and construction products, including engineered wood products, are integrated into a holistic system through prefabricated design and production processes, providing a traceable, analysable and controllable pool of rational experience and solutions for problem solving and requirement fulfilment (Figure 2-7 shows an example of the dataholz modern wood construction database). The designer can extract existing 'ingredients' and 'recipes' without having to create potentially unworkable solutions from scratch, and this system does not exclude innovation; the mastery of processes, the combination of ingredients, the discovery of new problems, etc. can all lead to unique solutions.

a. 1D structural components

b. 2D panel components

c. 3D space units

Figure2-7 Prefabricated building elements (image credit b: rothoblass website, a/c: courtesy of Federica Brunone)

2.5 From system to type

The technical literature, as well as various national and international standards, have always tried to explain the complexity and clear picture of building systems based on a variety of different approaches. Analysing the various approaches, it is easy to see that materials are always the primary criterion for construction: wood, stone, concrete, metal, fabric, etc. define the technical characteristics and types of construction systems in terms of the main structural elements and cladding construction. In the case of timber-framed buildings, some traditional construction methods can be carried over into the present day and become the reference and basis for modern timber construction, to the extent that the historical definition of some system types is ambiguous. However, when it comes to 'modern timber construction', modern theoretical and technical systems should be the dominant factor, i.e. the use of modern thinking and technical approaches to solve current construction problems (e.g. thinking about the distinction between building structure and construction). According to the available technical literature, modern timber frame systems can be divided into the following types according to the way they are built:

·Structural Frame System

a. China: Raised-beam Frame System
   Traverse-bracket Frame System

·Timber Frame Systems：

a. Europe: Timber-frame system/Fachwerkbau

b. North American：Balloon-frame System
   Platform-frame System

c. Integrated Panel System)

·Massive Timber Systems：

a. Log system/Blockbau

b. Slab/Plate/Solid Timber System)

·Thin Shell System

·Diffusive Lattice System

·Other Digitalized Structural System

The above classification is based on general theoretical types and the basis for the classification will be discussed in this section. In practical construction, although some of the types are standardised and generalised, mixed applications are also common in complex project conditions. The classification in this paper has been guided by several principles:

(1) Light and heavy

"Light and heavy" can be used to divide a material system into two broad categories, for example "light steel" and "heavy steel". In modern timber construction 'light and heavy' is also not based on the absolute weight of the building. In terms of semantics, 'light' corresponds to 'light/timber-frame' and 'heavy' to 'massive'. "In terms of component size, light timber structures are mainly classified as structural systems consisting of a larger number of smaller timber components, while heavy timber structures are mainly classified as structural systems consisting of a smaller number of larger timber components joined together. In complex situations, the boundary between light and heavy is also blurred.

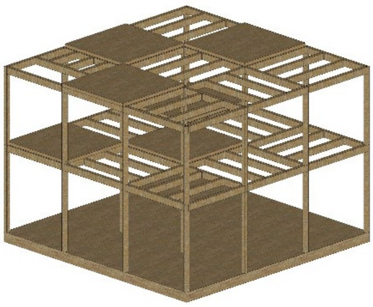
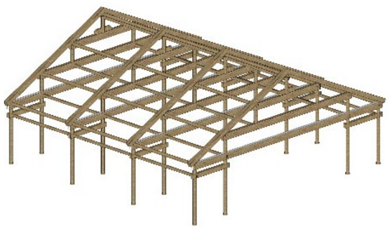
(2) Rods and panels

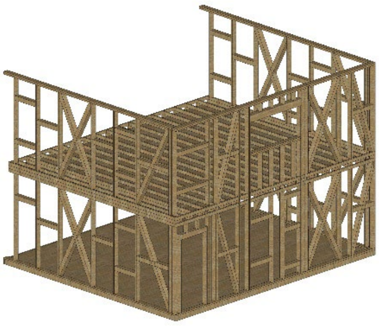
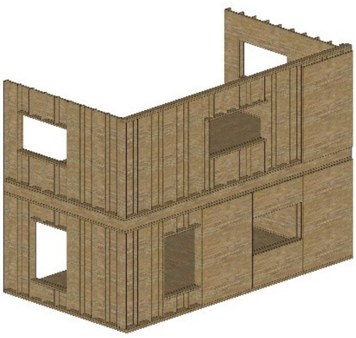
The modern timber frame product system defines two basic spatial features of timber elements: rods and slabs. In framed structural systems made up of poles, a clear distinction is made between the position of the structural and structural layers: structures such as insulation fill the space between the structural poles, which allows for a lighter and thinner structure but means more airtightness problems. In continuous structures made up of panels, the structural layer is often integrated with the structural layer to form a complete layered structure, so that the effect will be the opposite of that of a rod structure.

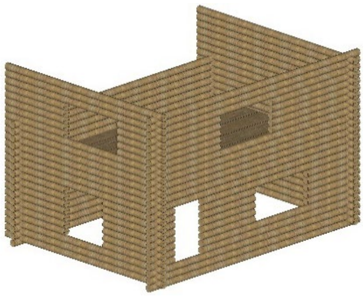
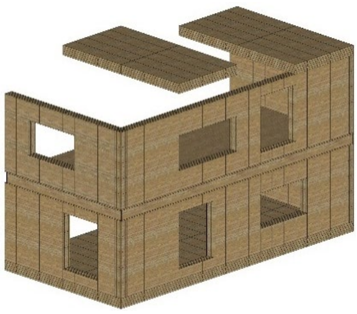
(3) Standards and customisation

The standardisation of modern timber frame products has led to the standardisation of most structural systems. Within the standardised structural systems, "walls and roofs" are the complementary systems for wrapping structures. The following points should be noted: (i) walls can be a marker for defining and distinguishing structural systems; (ii) horizontal elements such as floor slabs are generally integrated into the wall system because they have a similar technical solution; (iii) roofs are generally discussed separately as a separate system because of their association with key words such as "traditional", "regional" and "style". The development of modern timber structures in terms of design and material technology has led to highly customised architectural applications, particularly in some landscape buildings. The classification therefore lists non-standardised structural systems in accordance with the prevailing logic of customisation.

Based on the above principles and rationale, this section summarises and explains in some detail each of the types of modern timber frame systems listed, with the aim of providing a clear and systematic understanding of each type of timber frame construction (Table 2-2):

Type	**Name & Schematic**	**Available Products**	**Features and Significance**
Structural Frame System	 Structural Frame System	Dimension Lumber Glued laminated timber/GLT Laminated Strand Lumber/LSL Parallel Strand Lumber/PSL	**Connection:** mortise and tenon / joints **Protection:** Structural elements wrapped in interior
Timber Frame Systems	 Raised-beam Frame	Laminated Log Dimension Lumber Laminated Strand Lumber/LSL Parallel Strand Lumber/PSL	Less columns; Interior space integrity
	 Traverse-bracket Frame	Laminated Log Dimension Lumber Laminated Strand Lumber/LSL Parallel Strand Lumber/PSL	High degree of structural freedom; No requirements for proportions

	 Timber-frame System	Dimension Lumber Laminated Strand Lumber/LSL	Short diagonal brace; Exposed timber frame
	 Balloon-frame system	Dimension Lumber Laminated Strand Lumber/LSL	Walls with top and bottom penetrating timber studs
	 Platform-frame system	Dimension Lumber Laminated Strand Lumber/LSL	Vertical timber studs disconnected at all levels; Frames can be pre-assembled and modular
Timber Frame Systems	 Integrated Panel System	**Wooden Skeleton：** Dimension Lumber Laminated Strand Lumber/LSL **Wood Cover:** Oriented Strand Board/OSB Particleboard	**Vertical load-bearing:** timber studs; **Resisting horizontal loads:** panel engineered wood products

		Fiberboard	
Massive Timber Systems	 Log system/Blockbau	Logs Laminated Logs	The logs are stacked directly or after simple treatment, and are mortised and tenoned together. Ideal for extreme weather conditions
	 Slab/Plate/Solid Timber System	Solid Wood Panel Cross Laminated Timber/CLT Glued Laminated Timber/GLT Nail Laminated Timber/NLT	Structural panels with excellent performance; A wide range of building types can be achieved
Thin Shell System	 Thin Shell System	Laminated Veneer Lumber/LVL Oriented Strand Board/OSB	Mostly non-standard structures; Mostly experimental buildings, landscape buildings
Diffusive Lattice System	 Diffusive Lattice System	——	Shaping space with regular and repetitive 'parts' and 'nodes' that combine to form surfaces or bodies

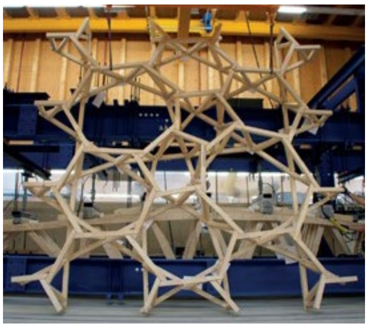
Other Digitalized Structural System	 Other Digitalized Structural System	——	Wood as a medium and a tool to explore future possibilities

Table 2-2 Summary of modern timber frame systems (Self-drawn by the author)

(1) Structural Frame System

The structural frame system uses mainly linear structural elements to achieve an open spatial form. It is probably one of the oldest forms of structure, from the early days of cave dwellings or simple huts, when logs or branches were used for vertical and horizontal support structures. In China and its neighbours, the beam and column system has been the dominant structural form throughout the history of architecture, and although the information contained in traditional timber structures cannot be summarised from an archaeological or architectural history point of view, from a systematic point of view, beams and columns can be used as a basic logic to group these subsystems together.

Modernist architectural thinking has also influenced the way modern timber structures are built. In the modern beam-and-column system, timber structures can essentially realise spatial forms similar to those of reinforced concrete frames and share similar spatial design principles, such as the open horizontal spaces and modular floor plans embodied in the 'domino' system. In the beam and column system, the load-bearing structure is therefore clearly separated from the envelope. However, in contrast to reinforced concrete frame construction, modern timber beam and column systems generally enclose the structural elements within the interior, mainly for reasons of airtightness and component protection. The structural elements are often exposed directly to the interior, becoming part of the interior effect and even eliminating the need for interior decoration.

Another difference from reinforced concrete or steel framed structures is the way in which the timber elements are joined, which is what makes timber construction unique. Wood cannot be fused together as rigidly as concrete or steel at the joints, but must rely on mortise and tenon joints or connectors to form logical, clearly defined "joints". The components of the "joint" need to share the space within the joint. Whether mortise and tenon or joint is used, in most cases it cannot be fully identified as a 'rigid' or 'articulated' joint (although the joint can be deliberately designed for a precise and clear rigid/articulated joint). In modern timber frame systems there is therefore a great variety and scope for innovation, and it may even be argued that the primary constraint on the structural and spatial form of the beam-column system is the way in which the members are connected. Overall, the beam-and-column system is efficient, covering a large space area with fewer structural columns and allowing for free interior space, with the ability to develop into a multi-storey building.

(2) Traditional Chinese Timber Frame Systems

The Chinese traditional timber frame system is a unique type of timber structure with Chinese characteristics. It is an important foundation and source of light timber structures due to its long history and is discussed in this paper as a sub-system of the light timber structure system. Traditional Chinese timber structures are divided into the raised-beam frame and the traverse-bracket frame. The building unit consists of three main parts: the platform, the main body of the building and the roof, of which the platform is mainly made of rammed earth. The timber frame, consisting of beams, columns, purlins and rafters, is the most important part of the building structure, carrying the load, while the timber or masonry walls only serve as infill and maintenance, and do not carry the load. Based on the requirements of this role, traditional Chinese timber structures have the following characteristics:

- Roof with large weight and large stiffness
- The bearing frame is the timber frame composed by beams and columns
- The timber frame is connected by mortise-tenon
- The bracket set is unique form of Chinese ancient timber structure
- Column and pillar base is floating planar contact

The traditional Chinese timber frame system, whether it is a beam-bearing frame or a bucket-bearing frame system, is limited by the process and the size of the material, making it difficult to form multi-storey living spaces (and to some extent, tightly enclosed spaces).

(3) European: Timber-frame System

Timber-frame System made extensive use of short diagonal braces in the construction of timber frames, which were often square in cross-section. Although this made the process time-consuming and difficult, it was easier to join with infill materials and allowed for the construction of multi-storey houses.

Throughout Europe (with the exception of southern Europe), traditional timber frame construction has a strong tendency to be stylised when analysed from a contemporary perspective. Despite the obvious regional variations, they often follow a commonality, namely the exposed timber frame 'bones' on the façade, and it is the distribution and texture of these frames that form the very distinctive local language of the building façade. In European cities, with the exception of religious buildings, the majority of dwellings were in fact timber-framed, and in Britain, for example, timber was used extensively to build cities up to the 18th century, with the developed craft of woodwork having both a profound impact on this form of construction (introduced to the American continent and other colonies) and a further shortage of local forest resources. The distribution of forest resources shows that most of these traditional timber frame structures originated in areas where timber was in short supply and where the population was relatively dense. In Northern Europe and Russia, for example, there is a predominance of dry-well or stave construction.

Traditional European timber frame construction has a distinctive style of diagonal bracing attached to the horizontal and vertical structural framing elements to create a stable framework for the house as a whole. In regions where hardwoods are abundant, they are also used. The gaps in the structural framework are then filled with plastered hedge walls or bricks and finally painted. This is why the structure is sometimes called 'half-timbered'. When this type of regional architecture is stylised, the traditional forms are also seen as a symbolic reference for modern timber structures. In addition to residential buildings, traditional timber frame structures are also used in functional buildings such as barns and barnyards. They require both a relatively open and free interior space and a certain span and area, so the larger sloping roofs bring a more complex system of trusses and a neater network of columns. This type of structural system with trusses at its core can therefore also be included in traditional frame construction. This is not an absolute classification, of course, but in modern timber construction many large-span buildings also use laminated laminated timber trusses, which should be considered as heavy timber structures.

The traditional period frame construction has more obvious traces of craftsmanship. Modernly constructed 'traditional timber frame structures' are often of uniform specification or engineered timber materials and are produced on a pre-assembled basis. A construction system supported by an industrial product system is more economical in modern times than handicraft, so this modern 'traditional timber frame construction' may be a stylised 'tradition', but the original aim of economy and fitness for purpose remains unchanged.

(4) North American Light Timber Frame Systems

The centuries of European colonisation in North America brought with it a more stylised light timber frame architecture, meaning that the origins of light timber frame architecture in North America are a deliberate attempt by European colonists to mimic the look and construction of European architecture in order to create a familiar living and cultural environment. By the mid-19th century, the industrial revolution had replaced much of the craft industry with mechanized production. The growing capital markets and real estate industries in North America created a huge demand for housing. Standardised screws produced by steam engines were the first to be used in North America for these light timber frames, which were derived from traditional styles. This gave rise to two sophisticated timber framing systems: the balloon-frame system and the platform-frame system. They are widely used today in North America and later in Australia. Although the technology of modern timber construction is constantly being refined, the basic construction methods and the logic of using dimensionally fixed dimensional timber have not changed. From the first half of the 20th century onwards, this efficient and successful approach to timber frame construction also influenced Europe in turn. However, Europe itself had a well-established and stable wood construction industry, and the structural methods introduced from North America gradually resulted in lighter wood construction systems that were more suited to the European environment and code requirements. In summary, both North American structural systems still retain a relatively high degree of craftsmanship, particularly in the joining of members, and do not require high grade engineered wood materials. They still require longer construction times and more labour costs than the more prefabricated and more intensively manufactured European light timber systems.

Balloon-frame system

The use of the dramatic term 'balloon' is controversial and has not been explained with certainty; on the other hand, its origin is not clear. French settlements already had houses of this structure. The most distinctive feature of the balloon frame system is the use of studs running up and down the perimeter walls, the tops of which are linked to the bottoms by horizontal fixing plates (binders). The horizontal joists, which are used to support the floor slab, are inserted into the vertical ribs and fixed in place.

Platform-frame system

While the height of a balloon-frame system is limited by the length of the through-ribs, the platform-frame system solves the problem of height and number of storeys and can be used in multi-storey buildings. The most important feature of the platform frame system is therefore that the vertical timber ribs are disconnected at each level and the building is constructed layer by layer, so that when the ground floor is completed, a level platform is formed and the upper floors continue to be built on in a similar way, hence the name of the system. As it does not contain long timber ribs, the platform framing system can be prefabricated and modular. And because all levels have the same construction method, it even retains the possibility of later additions.

(5) Integrated panel system

The integrated panel system is a structural system of light modern timber construction that has matured in a European environment. It has a higher degree of manufacture and pre-fabrication than North American light timber structures. From a structural point of view, the integrated panel system is similar to the North American light timber frame system in that it uses square section timber skeletons as vertical load-bearing elements. The difference is that this structural system has additional board-engineered timber products on either side of the load-bearing timber ribs as structural elements to resist horizontal loads. With the additional panels on both sides, the rest of the wall structure and even the windows and doors are prefabricated together in the factory, making the wall a single panel that can be assembled directly on site, hence the name of this structural system. Prefabricated building elements are generally produced indoors, with stable temperature and humidity, and construction can be completed quickly in a short period of time, so that building elements are hardly damaged by external factors such as the weather during construction, ensuring a very high level of technical precision and build quality. Computer-aided design, CNC machine tools and other technologies can play a huge role in this, and although there are more possibilities than in traditional manual construction, the size of the building elements is still affected by the conditions of transport, so that local variations in the design of the elements may arise according to the geography of transport, and in a way this seems to present another possibility of territoriality in a contemporary era where the international style is spreading unchecked. In a way, this seems to present another possibility of territoriality in a contemporary era of internationalism. In fact, all European countries have developed their own national codes based on the EU superordinate codes and have established sophisticated databases, for example Holzrahmenbau in Germany and Switzerland, dataholz in Austria, etc.

(6) Log system/Blockbau

The log system is a construction method with a long history that can be found all over the world, especially in Scandinavia, Russia, the north-east of China and the cold or forested regions of south-west and south-east China. In north-eastern China it is commonly known as "woodcut corrugated" and in German-speaking Central Europe as "Blockbau". In fact, in addition to the construction of monolithic walls, a microcosm of this construction method can also be seen in some large wooden roofs in China, such as the architraves of the Song and Liao dynasties with their stacked layers of squared square. The well-dried construction system is characterised by the stacking of logs directly or after simple treatment, with mortise and tenon bites cut at the intersection of the walls. This structure consumes a very large amount of timber, but allows for the construction of thick walls that take advantage of the excellent insulation properties of the timber itself, creating a relatively enclosed interior space that is positive for dealing with extreme weather.

This method of construction is still in use today and, with the advancement of specifications and construction techniques, it has overcome the traditional image of 'rough craftsmanship' and it is difficult to distinguish between its 'traditional' and 'contemporary' attributes. "It is difficult to distinguish between its 'traditional' and 'contemporary' attributes. Traditionally, the walls of a well-dried building were almost exclusively of the logs themselves. In contemporary times, this stacked log is understood as a masonry core, with modern timber techniques attached to both sides of the wall to make the building more comfortable, a 'contemporary cladding wrapped around a traditional core'; on the other hand, it is seen as a symbol of tradition in contemporary times, and in some buildings where engineered timber is the core of the wall structure, the outer layer of the façade In some buildings where engineered wood is the core of the wall structure, the outer façade finish in turn mimics this traditional language (Figure 2-8), as a 'traditional cladding wrapped around a contemporary core'. This is an interesting phenomenon that has also provoked interest and discussion among European architects.

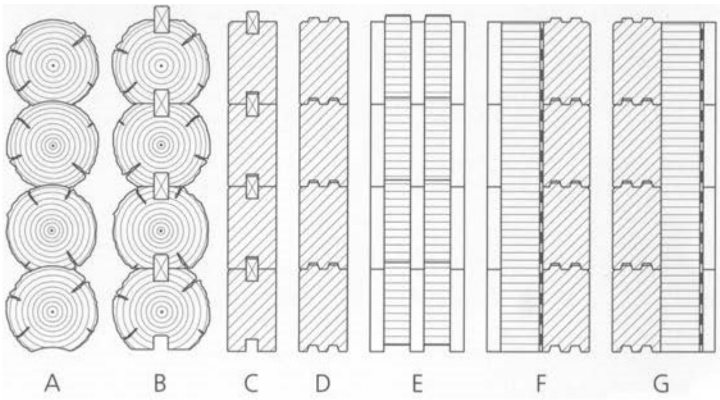


Figure 2-8 Several types of stacking of Log system

(reference Kolb J. Systems in timber engineering)

(7) Slab/Plate/Solid Timber System

The heavy duty slab system is mainly used for building structural elements made of engineered wood, including solid wood panels, Cross Laminated Timber (CLT), Glued Laminated Timber (GLT/Glulam panel) and Nail Laminated Timber (NLT). Nail Laminated Timber (NLT) can be processed into larger, heavier wood products. These panels have good structural properties and can be used in various structural elements such as load-bearing walls, floors and roofs, and can even be cut into linear elements for use as beams and columns - in which case the building should be understood as a beam and column structural system. The basic logic of this structural system is to create a stable and relatively closed 'box', as is often the case with slab elements. On the inside and outside of the external walls, other wall construction layers are attached and can be prefabricated in the factory, which is very similar to the "integrated panel system" and can even be classified as a prefabricated or assembled building, but here there are two types due to the nature of the different structural layer forms.

Depending on the panel product, this type of structural system can be applied in a specific way depending on the subsystem developed for the particular product. Different manufacturers of buildings (or building elements) generally develop their own technical approaches to the production of wooden elements, dimensions, joints, the design and optimisation of the building structure and many other aspects. However, the general direction will follow a common specification standard and design logic. In general, this is a structural system that relies almost entirely on modern woodworking techniques and is largely free from traces of craftsmanship. In the orthogonal system of architecture, this structural form allows for a very wide range of building types and is a widely used structural form for high-rise or large (except for the large-span category) public buildings. And in landscape gardens, architects and gardeners are constantly exploring the possibilities of this type of heavy structure, and in addition to its conventional structural role, the aesthetic properties of the material itself are also being explored and discussed in garden vignettes.

(8) Thin Shell System

The thin-shell system is a non-standard structure that uses various types of wooden panels to form a shell, mostly for experimental buildings, landscape architecture or landscape features. It is not a strict classification criterion and differs from the monolithic shell structures of large span structures in that it is a relatively small volume of individual boards. The basic logic is to create a more closed "surface" to cover a certain space, often with continuous connections. Oriented strand board (OSB) and veneer laminated timber (LVL) can be used in this type of structure. The way in which the boards are connected to each other largely determines the forces and form of the structural body and is often the part of the development that is focused on. A smooth shell surface, for example, allows forces to be transmitted along the axial direction of the planks, while a greater angle between planks results in "folds" at the joints, which have a greater structural effect. For this reason, thin-shell timber systems are also a key area of focus for non-standardised (or advanced) timber systems.

(9) Diffusive Lattice System

Similar to thin shell systems, cellular systems are also a key area of development for advanced timber systems. Its main characteristic is the use of more regular and repetitive 'parts' and 'nodes', which are combined to form surfaces or bodies and thus shape space. It is more diverse than shell construction: the repetitive elements can be formed in a faceted form like a 'shell' or in a three-dimensional form like a 'bucket arch'. The form of the individual components and the way in which the nodes are connected open up unlimited possibilities for this system. In terms of space and form, it can replicate the elements and nodes of traditional timber structures, becoming a symbolic and emblematic motif; in terms of construction technology, it often relies on CNC machining to ensure precision. Thus, in the contradictory topics of 'standard and innovation' and 'tradition and contemporary', this structural system always offers something to explore and refer to.

(10) Other digitalized structural system

Digital computing reigns in contemporary structural design and the same is certainly true of the new wood structure design. With the development of wood science technology, wood is no longer entirely a traditional material; it can be worked into infinite forms, bent and compressed, and even made transparent. These have become an important part of cutting-edge research in modern timber construction. These topics include, but are not limited to, exploring: integrated methods and generative design, digital model characterisation of timber structures, nature and material exploration, environmental construction topics in wood, parametric and morphological design, etc. In short, in computational design, wood becomes a medium, a mapping or a tool that provides interest and ideas for the researcher or observer to explore the possibilities of wood in the future.

2.6 Summary of this chapter

This chapter has presented the evolution of wood as the most basic and commonly used building material from traditional to modern times. The comparison of traditional and modern timber has discussed the optimisation of modern timber in terms of fire resistance, durability and jointing properties. By comparing the impact of steel, stone and concrete on the built environment during production and use, it is concluded that wood is a "carbon-negative" and environmentally friendly material.

As the processing properties of building materials continue to improve, timber materials are becoming standardised and systematised, moving from logs to engineered wood. Logs are processed to form a variety of one-dimensional wire products and two-dimensional panel products.

These engineered wood products, depending on the combined structure, form differentiated modern timber building systems and are eventually subdivided into up to a dozen timber frame types depending on the construction method.

3 Renewal Experiment of Chinese Vernacular Housing

Nowadays in China, both the design of modern timber frame building systems and the development of green building designs based on active building techniques are developing at a rapid pace, and are increasingly being taken into account and applied in practical projects. The results of these studies have been instrumental in the conservation and regeneration of the large number of traditional dwellings that exist in China, both for reference and application.

Based on the research on the characteristics and problems of Chinese vernacular architecture, green building, active building technologies and timber frame building systems under the dual-carbon policy, this chapter presents an analysis of a typical Chinese traditional timber frame vernacular house in Quzhou, Zhejiang Province, in the southeastern coastal region of China, which is in need of renovation. The study analyses the existing problems and renovation needs of this vernacular house, and makes a reasonable attempt to update the design of the house mainly in terms of building structure, lighting and ventilation, and green and low-carbon aspects of the building. In terms of structural design, in order to retain the structural characteristics of the traditional dwelling while incorporating green architectural design ideas, the traditional Chinese pierced wooden structure frame is used as the primary structure system of the sloping roof house, while the secondary structural design uses Structural Insulated panelsSIP(). Insulated panels (SIPs) are used as the main part of the wall structure, which greatly improves the passive energy saving performance of the house. The aim is to achieve a balance between traditional Chinese building forms and new energy technologies, energy efficiency and comfort, and to optimise light, ventilation, thermal insulation and other aspects of the building. Through the design study of this abandoned traditional dwelling, the design aims to provide a method that can be used as a reference and reference for contemporary renewal strategies for traditional Chinese timber-framed vernacular dwellings.

3.1 Basic information about the project building

The project is located on the south side of Fangzhuang (Figure 3-1), Changhong Township, Kaihua County, Quzhou City, Zhejiang Province, China. It is situated within the national 4A-level tourist attraction, the Seven Colours Changhong Scenic Area, with the mountains at its back and the water in its face, and the Taikui Mountain, known as the Potala Palace in Jiangnan, to the west. With excellent natural conditions and a rich and colourful habitat culture, it is a tourist resort, a health resort and an important part of tourism in western Zhejiang.

Figure 3-1 Project Location (Self-drawn by the author)

The building is located in a rainy region of southern China, while the wind rose map of the project site shows that the area is dominated by easterly winds throughout the year and that wind speeds can exceed a maximum of 8 m/s. The analytical map of radiation changes throughout the year shows that the area receives strong radiation intensity, reflecting the abundance of sunshine and high temperatures throughout the year.

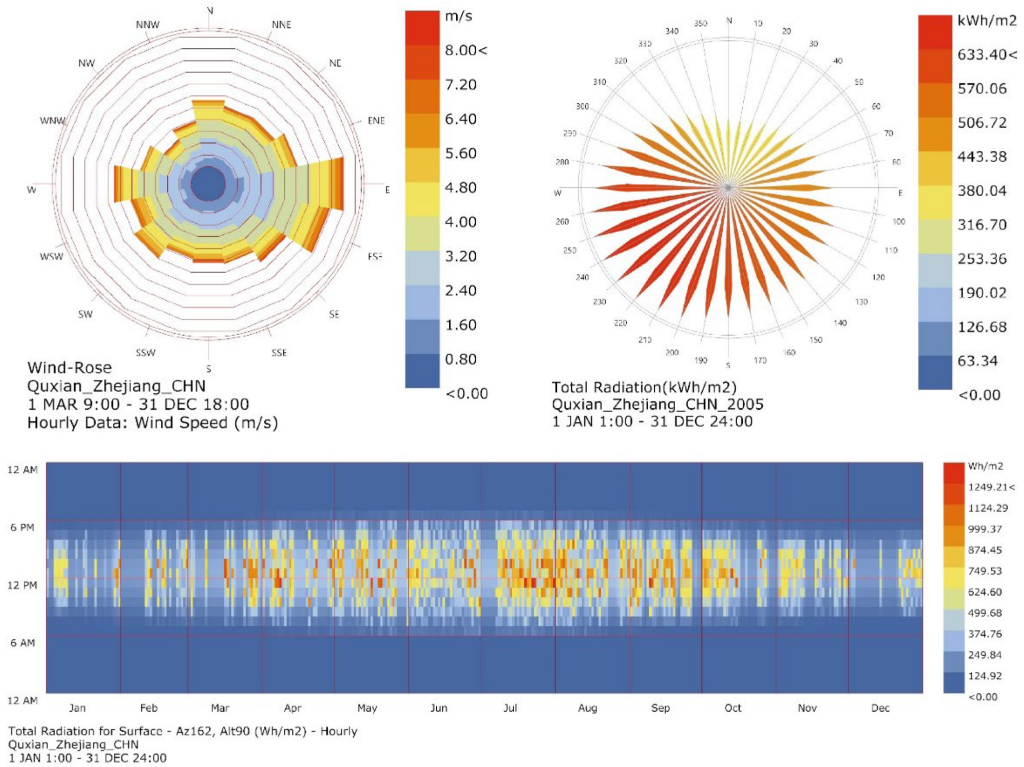


Figure 3-2 Wind Rose and Total Radiation Diagram (Self-drawn by the author)

The project site has a total area of 7059m^2 and the abandoned house chosen for the design is a typical southern Chinese traditional wooden house with a total floor area of approximately 800m^2. The overall form of the brick wall of the house is still relatively intact (Figure 3-3), which facilitates the design and implementation of the regeneration strategy. The design is intended to preserve the residential function of the original building and transform the abandoned traditional dwelling into a hotel-style bed and breakfast integrated into the ecological environment. The project consists of two accommodation buildings, a food service building, a public service hall and a multi-purpose hall, all of which have been converted from existing buildings.

Figure 3-3 Current state of the house (photo from author)

As a typical Chinese traditional vernacular house, the current situation of the houses in this design project also suffers from the same problems of the buildings themselves as discussed in the previous chapters, which are reflected in the following aspects:

(1) Damage to the original traditional timber truss structure of the house

The traditional timber structure of the house is a traditional Chinese load-bearing system, using mainly Horsetail pine timber, which is common in southern China, but due to the construction standards, cost and technology of the house, the performance of these timbers in terms of strength, corrosion resistance, fire safety and sustainability is not comparable to that of modern timbers. For example, the material is not strong enough and has a limited load-bearing capacity; the material is less resistant to corrosion and is susceptible to structural deterioration due to corrosion, and does not have a long service life. This is evidenced by the fact that some of the timber frames of the buildings have been severely damaged due to their age and abandonment, and that the original traditional timber truss load-bearing structure has been extensively damaged and collapsed, making it impossible to support the roofs of the buildings (Figure 3-4).

Figure 3-4 damage of structure (photo from author)

(2) Poor thermal insulation of the building walls

The original wall structure of the building was constructed using rammed clay bricks, which are common in traditional Chinese vernacular architecture. These bricks are hard and have a low water absorption rate, and are able to maintain a stable structure and aesthetic appearance over a long period of time. The wall is usually built using the 'brick through' method, where two bricks are stacked vertically, filled with clay in the middle and coated with clay slurry on both sides to hold the bricks in place. After the wall has been built, it is then decorated with finishes such as plastering, whitewashing or stacking of stones to give a traditional rural architectural appearance with Chinese characteristics. Such clay brick walls have certain problems in terms of their own thermal insulation. Firstly, in terms of material properties, the clay bricks used in traditional vernacular architecture have a high thermal conductivity, usually between 0.8 and 1.3 W/(m-K). In contrast, some modern building materials such as polystyrene panels, rock wool and SIPs (Structural Insulated Panels) have a much lower thermal conductivity, usually between 0.02 and 0.05 W/(m-K). Therefore, the clay brick walls of traditional vernacular buildings have certain shortcomings in terms of thermal insulation; in terms of the wall structure itself, the clay brick walls of traditional vernacular buildings are often constructed in the form of masonry, with a large wall thickness, generally above 30cm. Such a wall structure leads to poor air flow inside the wall, slow heat transfer and poor heat insulation; in addition, due to factors such as wall structure and material characteristics, gaps are easily formed between the clay brick walls of traditional vernacular buildings, leading to the problem of air leakage, making the temperature exchange between the interior and exterior rapid, resulting in a waste of energy.

(3) Lighting and ventilation of the building

As the project site belongs to the subtropical monsoon climate, with high temperature but high rainfall throughout the year, and more rainy days, and frequent thunderstorms and typhoons, natural light is less than in some areas where sunny days are the norm, and the daily climate is more humid with higher air humidity, so there are certain requirements for the consideration of building window openings. However, the project building itself is constrained by the traditional vernacular architecture of southern China, and its original window opening scale is more in the form of small windows, especially on the north side of the building. Due to the small size and insufficient number of small windows, the interior is not sufficiently lit and additional artificial lighting such as lights are required. In addition, if the windows are set too high or too low, this may also result in uneven lighting. In terms of ventilation, although the multi-pane windows of traditional vernacular buildings create natural convection, in some cases this can lead to inadequate ventilation or poor ventilation in places. For example, in humid climates, if windows are set too small or inappropriately positioned, this can lead to problems of indoor dampness and mould growth.

In summary, the main pain points of the traditional dwelling chosen for this design are the deterioration of the timber frame load-bearing system, the performance of the building envelope and the lighting and ventilation of the building. The regeneration strategy for this house will be designed and optimised to address these pain points.

3.2 Renewal technology strategies Overview

The regeneration strategy of the house can be summarised into three main levels of design: aesthetic strategies, engineering strategies and environmental strategies. In terms of aesthetic strategies, the design is based on the symbolic andtectonic aspects of the house, and the rational analysis and discussion of the renovation and renewal of the house; in terms of engineering strategies, the design is based on form & force (primary structure), the choice of secondary structure (SIP), the choice of walls, roof and floor. In terms of engineering strategies, this design presents a comprehensive and detailed presentation of the design research results of the renewal strategies of traditional residential buildings, from form & force (primary structure), the choice of secondary structure (SIP), the structural design practices of walls, roof, floors and foundations, and the use of phase change materials. In the environmental strategies, the design of proactive building strategies and the economical consideration of energy savings are considered, and the results of the design optimisation are simulated and analysed for comparison.

3.3 Aesthetic strategies

The design of the project's aesthetic strategies is reflected in the study of both symbol vocabulary and protectonic aspects. The design is a mapping of the symbol vocabulary of the traditional Chinese wood roof and the modular size of the traditional Chinese dwelling. The design also provides an aesthetic design strategy for the house from a protectonic perspective through the choice of a traditional Chinese timber structure, Traverse-bracket Frame System.

3.3.1 Room modular size

Traditional Chinese timber-frame buildings, whether they are royal buildings or ordinary dwellings, are subject to strict scrutiny in terms of architectural scale and building proportions, and have corresponding terminology to describe and distinguish them. The term 'Opening' in Chinese timber frame architecture refers to the horizontal distance between two adjacent gables on the front of a building, i.e. the distance between two adjacent sets of timber frames. For a building's openings, the position of the building usually determines the number of openings, reflecting the difference in class of the building. The highest of these is usually nine wide openings, with some special buildings reaching eleven wide openings. The highest of these buildings represented a symbol of power and could only be built and used by the emperor, while the average folk house was usually three to five bays. At the same time, the modular size of the openings was also carefully considered in Chinese timber construction, taking into account the needs of the functional use of the space, and the size of the openings was usually taken as a modal number in multiples of 300, such as 3000mm, 3300mm, 3600mm, 3900mm, etc. The size of the openings for folk houses usually did not exceed 3600mm. The two main building volumes (Figure 3-5), Volume 1 is a three-row, three-bay dwelling with each bay measuring 3000mm, Volume 2 is a five-bay, two-storey dwelling with a bay measuring 3600mm, and Volume 3 is a two-bay, two-storey dwelling with an east-west orientation. These three main building volumes are still based on the existing modelled dimensions for the design of the regeneration.

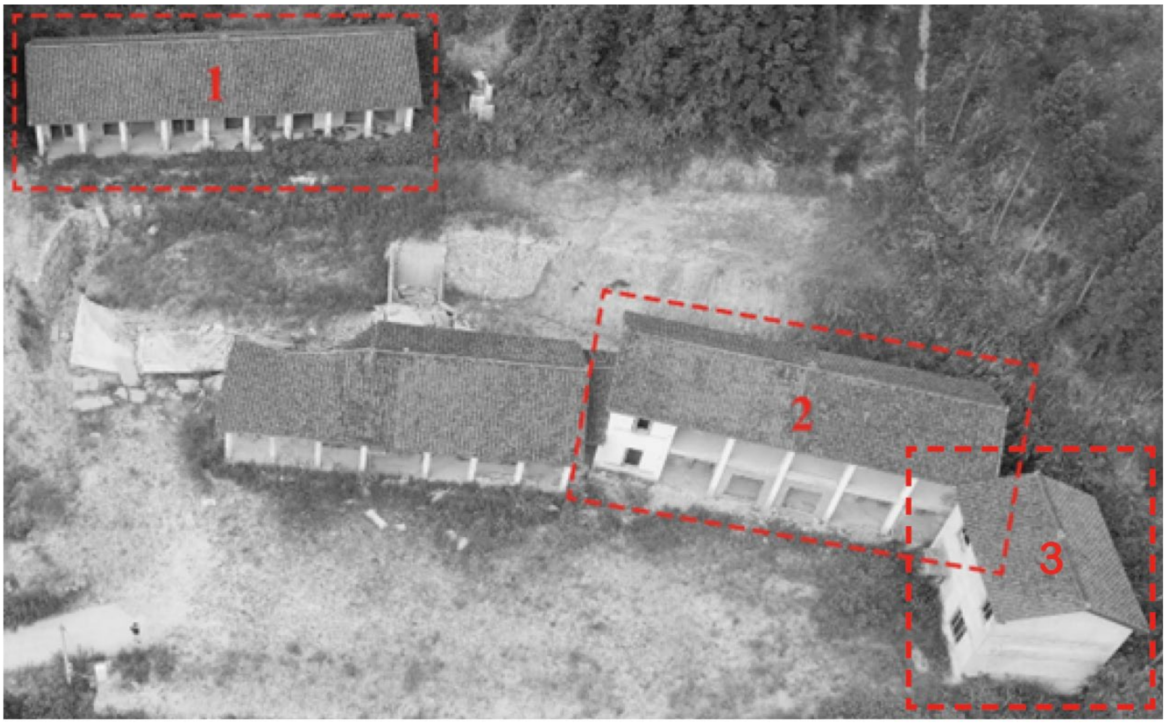


Figure 3-5 Openings of main building volumes (Photograph by author)

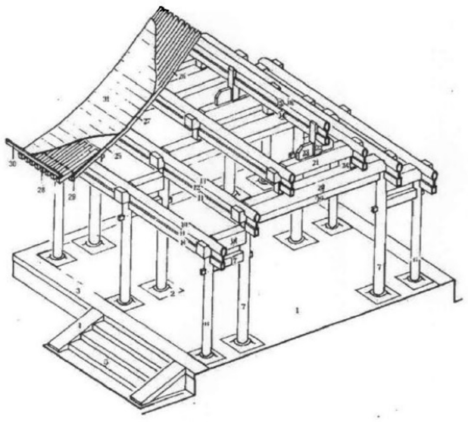
The large woodwork is the main structural part of Chinese timber frame buildings, usually consisting of beams, columns, rafters and squared-off columns, and it is divided into two main types of practice: large and small, the difference between the two being the grade of building created. The large timber building is sometimes referred to as the temple building, which is generally used in palaces, temples, official residences and other wood buildings with more openings, and has strict rules and requirements for the scale of construction, as well as complex and complicated timber structures such as corridors, arches, flying rafters and ridge-bearing timbers. Unlike the Large Style, the Small Style is usually used for general residential buildings and the ancillary buildings of the above-mentioned high-grade buildings, where the scale of the building can be determined according to the width of the sunny side of the room and the diameter of the columns, which is relatively more arbitrary and free. The small-scale approach also ignores the detailed design, simplifying as much as possible the design and construction of ordinary dwellings. As a result, the structural design of the traditional dwellings in the project follows the large wood and small style approach.

3.3.2 Options for traditional timber frame systems

As already described in the previous chapters, Raised-beam frame and Traverse-bracket frame are two main categories of Chinese ancient timber structure buildings.

(1) Raised-beam frame structure:

Raised-beam frame structure is the most widely used form in ancient architecture, not only in large buildings such as palaces and temples, but also in northern Chinese dwellings. This structure sets the beams along the depth of the room at the top of the columns, and then short supporting columns are set on the beams, which serve to support the raised-beams on a higher level. The raised-beams become shorter layer by layer and finally together with the supporting columns form a triangular frame. The purlins are erected starting from the ends of the beams of each layer, and the rafters are built on top of the purlins. So all the loads of the roof are transferred through the rafters, purlins, short supporting columns and beams to the columns set on base stones. This form of construction allows the building itself to have fewer columns, typically from two to six , thus minimising the impact on the interior space and ensures the integrity and continuity.



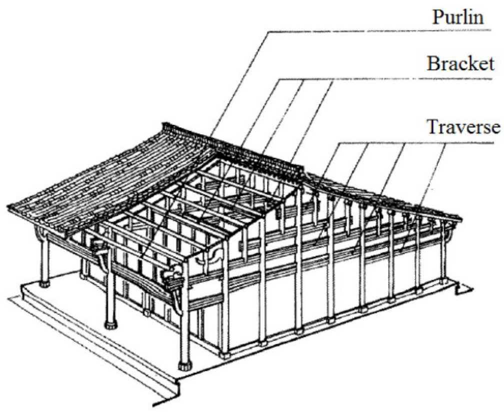


Figure 3-6 Raised-beam frame structure

Figure 3-7 Traverse-bracket frame structure

(Pics from Shukai Ya, 2017)

(2) Traverse-bracket frame structure

Unlike the raised-beam frame structure, the traverse-bracket frame structure does not have beams used for structural supporting, but instead purlins are set directly on top of the columns, and rafters are then constructed over the purlins, with the load of the roof transferred directly to the columns through the rafters and purlins. In this way the units consisting of the columns, purlins and rafters are connected by 'traverse' to form the overall frame, which is then connected by 'bracket'. The number of columns in the traverse-bracket frame is significantly denser and the columns extend directly to the roof, allowing the slope of the roof to be adjusted by changing the height of the columns themselves, which allows more structural freedom and does not require the same strict requirements for the size and proportions of the beams at each floor as in the case of raised-beam frame construction. However, the disadvantages are also obvious, as the large number of columns makes the structure more influential on the interior space and hinders the communication and integrity of the large interior space.

In view of the fact that the traditional dwellings selected in this section are suitable for retrofitting using the large timber and small style approach, the main building space of the timber frame was selected for retrofitting and restoration without affecting the functional use of the interior space, and the through-drawer timber frame, which is more commonly used in southern Chinese dwellings and more in line with the large timber and small style approach, was adopted as the main load-bearing structural system. The span dimensions of the timber frame are harmonised with the opening dimensions of the original house. The design of this timber frame bearing system is explained and analysed in more detail in the Engineering Strategy section.

3.4 Engineering strategies - form and force in building structures

For the renovation of a traditional building, the engineering strategy aims to analyse the structural form and structural detailing of the building, and to restore and improve the parts of the building that have fallen into disrepair or even collapsed with modern architectural techniques, so that the traditional building, which has a sense of age and representativeness, can be used in a more rational and complete manner for the daily use of modern people. The renovation and renewal strategy of this project is based on the engineering strategies, and the scheme has been systematically rationalised in all aspects: the primary structure is Traverse-bracket frame structure system, and the secondary structure has been selected using Structural Insulated Panels. The structural design of walls, roof, floors and foundations is based on the new structural system, and the use of phase change materials is experimented with in the structural design. These engineering strategies have been thoroughly detailed to help achieve the accurate completion of the building.

3.4.1 Redesign of the primary structure - Traverse-bracket frame structure

"The stability and strength of the structures we design derive from their form: it is through their form that they are stable, and not just by a clumsy accumulation of materials." -Eladio Dieste, renowned Uruguayan structural engineer

Any good building is often a perfect unity of form and force, and there is often an inseparable and vital relationship between its architectural form and its technology. The unity of form and structure allows for a mechanically logical building form, while at the same time an efficient and rational structure allows for a balanced control of construction costs. There have been many design practices in the history of architecture that have united form and structure to create successful works of architecture.

From Antonio Gaudi's Sagrada Familia Cathedral to Pierre's Petit Palazzo dello Sport in Rome; from Candela's Orsayano restaurant to Frei Otto's Olympic Stadium in Munich; from Calatrava's World Trade Centre transport hub in New York to Toyo Ito's Sendai Media Centre. In all these successful examples of architecture, the building form and structure present a perfect unity, ensuring structural soundness while producing a very chic effect (Figure 3-8). The Yoyogi National Sports Complex, a collaboration between Kenzo Tange and Yoshikatsu Ippei, is also a good example. The idea of a new structure proposed by Kenzo Tange collided with Yoshiyoshi Ippei's structural ideas, and the creative solution was continually refined, resulting in the building's suspended structural form. In this process, the architectural form and the structural form evolved in tandem, influencing each other and resulting in the final scheme after constant updating and iteration.

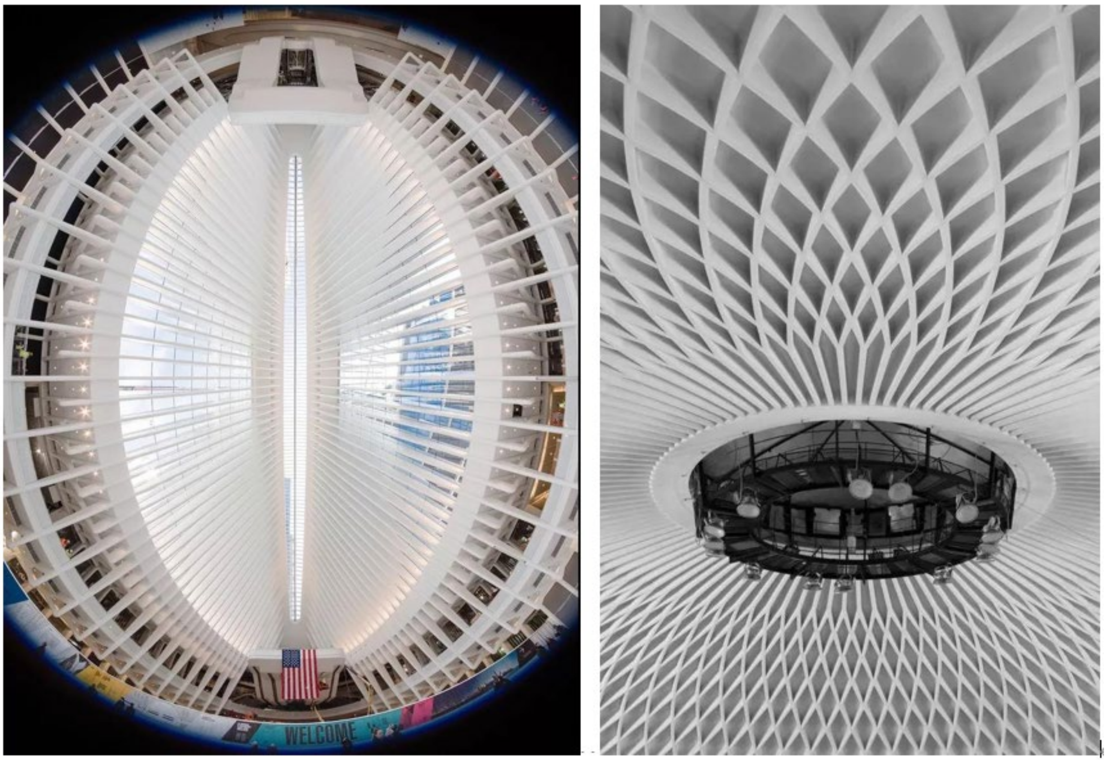


Figure 3-8 The unity of architectural form and structure

(http://image109.360doc.com/DownloadImg/2020/04/2807/189240788_2_20200428074631335)

In the long history of ancient Chinese architectural development, the experience and wisdom accumulated through early building production practices led to the creation of numerous rational structural forms, such as tents, wooden pagodas, arched bridges and other structures with timber or masonry as the main material (Figure 3-9). As the development of basic sciences such as mathematics and mechanics was not mature enough during this period, the determination of rational structural forms was often based on the designer's The determination of reasonable structural forms was often predicated on the experience of the designer. It is clear from these structures that they are a perfect combination of form and force, and that these structural forms still play an irreplaceable role in today's building engineering.

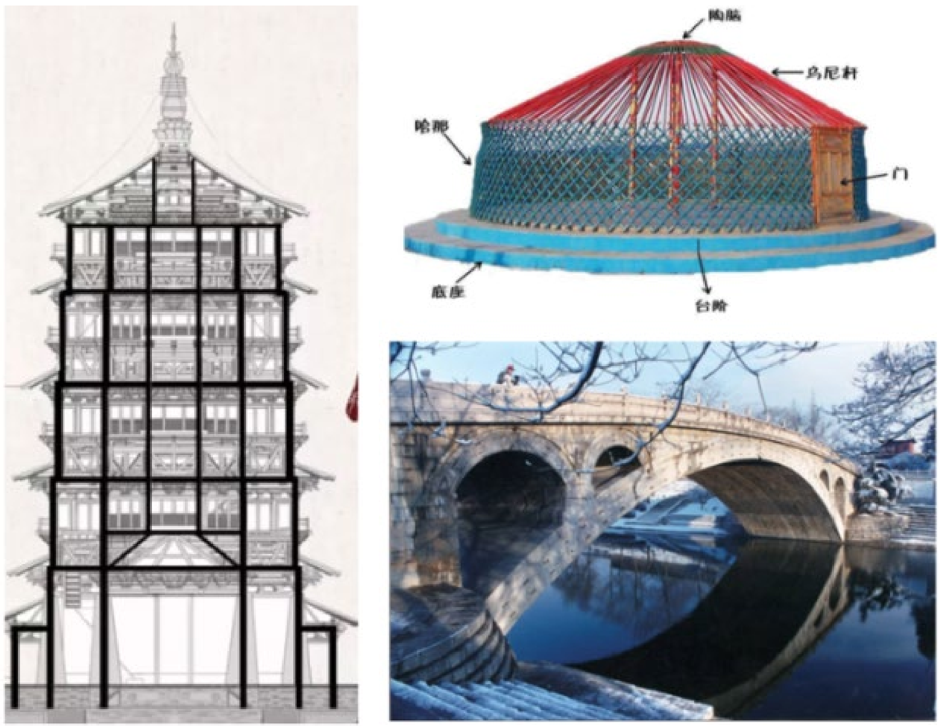


Figure 3-9 Typical early Chinese structural forms: Yingxian Wooden Pagoda - Yurt - Zhaozhou Bridge

(http://www.360doc.com/content/20/0428/07/37299807_908837865.shtml)

From the point of view of consistency between form and force, the invention and application of Traverse-bracket frame structure system was also based on traditional Chinese building forms and structural requirements: a hard sloping roof of traditional Chinese barrel and slate tiles surrounded by rammed earth or brick courtyard walls and herringbone walls. In this form of construction, the weight of the roof has to be distributed to the ground by means of the structural system (Figure 3-10).

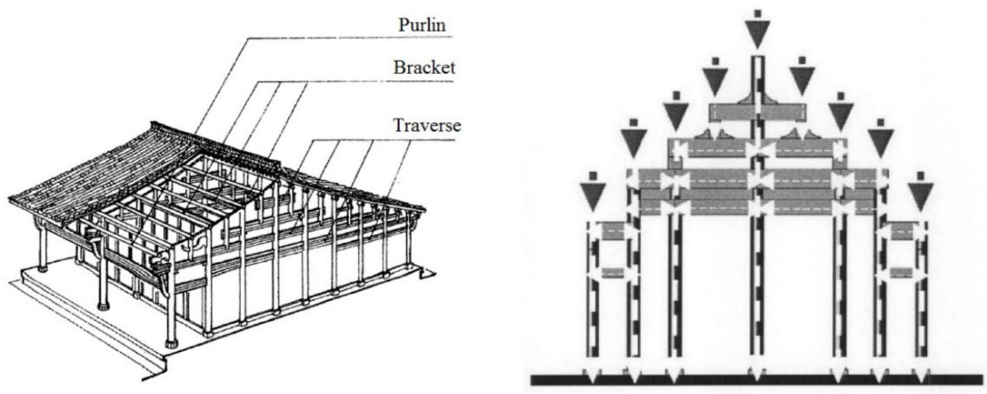


Figure 3-10 Schematic and Loading Transferring Path of Traverse-bracket frame structure

As an important structural form of beam-and-pillar load-bearing frames, Traverse-bracket frame structure consists of four main components: columns, crosspieces, purlins and rafters, with different structural components having different characteristics and practice requirements:

- Columns

The pillars play a pivotal role in the houses, firstly they must bear the weight of the roof slab and resist the main load of the building; secondly they are also the standard for measuring the dimensions of the building, as the woodwork system of the houses uses the central pillar as a reference system, and the height of each pillar and the position of the mortise and tenon joints are marked with the Penny's ruler of the length of the central pillar. The different types of columns each play their own role, with the golden pillar eaves pillar bearing the weight, the child pillar reducing the pressure transmitted by the roof, the compartment pillar bearing the weight of the compartment, and the structural pillars playing the role of connecting joints. The diameter of the columns in a pierced timber structure is between 150 and 500mm, and they are generally the stoutest in the building, being mainly round, but also flat. The columns are thick at the bottom and slightly thinner at the top, and the larger the building, the more regular the material used. As the main building space in the residential part of the scheme is mainly two storeys high, square columns of 400mm in diameter were chosen to ensure that the structure had a stable load-bearing capacity.

- Beams

Beams are the main lateral load-bearing element of the timber frame system of the pierced-wood structure and are often used in the roof structure of a building and in the floor level structure to support the weight of the entire roof and floor slab. The beams are usually connected to the vertical columns, which transfer the load to the columns and from there to the ground, so that together with the columns they form the most significant load-bearing part.

Compared to other types of timber frame beams, the pierced timber frame beam has some unique advantages. For example, the strength and stability of the entire beam is effectively increased due to its interlocking construction. At the same time, the relatively simple production process of the pierced timber beam not only reduces material waste, but also reduces production costs and is therefore widely used in traditional construction.

- Pierced Santalum

The square is the most distinctive element of the piercing system, so called because it runs through the entire roof frame; it has been defined as a two-frame piercing if it passes through two columns, and a four-frame piercing if it passes through four columns. The square is used in a wide range of ways, from the main frame to the trailer frame, to the compartment frame. Combined with the pillars, it forms a number of ladder shapes, forming layers of "terraces" with a sense of rhythm, forming the structural layers of the piercing system. The length of the square is determined by the number of shelves, specifically by the distance between the purlins; however, the cross-section of the square is of a fixed size, with rectangular cross-sections, but also round ones, which are not common;

the width generally varies little, with a minimum of 30mm and a maximum of 50mm; the height varies, with a minimum of 80mm and a majority of 150mm. The height varies from a minimum of 80mm to a maximum of 150mm, with the highest being 300-400mm.

- Purlins

Purlins in residential houses are multifunctional, transmitting weight as well as taking on the role of beams. The rafters transfer the forces to the purlins, which have to bear the intermediate bending moments, the shear forces at the supports and transfer the forces to the columns again, which is the role in the vertical direction. In the horizontal direction, it also plays a key role. It acts as a link between the elements of the building and as a stabiliser against horizontal loads such as earthquakes, wind, etc.

- Rafters

In the simple traditional timber-framed dwellings of the Jiangnan region of China, the rafters are generally used directly to lay tiles, so that the number of rafters can appear rather dense. The spacing between the rafters is between 100 and 110 mm. The rafters are generally rectangular in form and flat in cross-section; each rafter is between 20 and 30mm thick and around 140mm wide.

There are many different types of Traverse-bracket frame structure system. The choice of the form of Traverse-bracket frame structure for the renovation of a house is influenced and determined by the purlins and the square. In general, there are three types of purlins. The first one is the one with only one purlin on each column, which is generally used for small houses and is also the simplest form; the second one is the one with two purlins on each column, which we call compound purlins; the two purlins are round, small on the top and big on the bottom, and there is also the practice of big on the bottom and small on the top; in large houses, you can see the practice of three purlins, which are relatively compound purlins with an extra square wood in the middle; besides these three basic types, there is also the one with a square wood in the middle. three basic types, there is also the common compound practice of using a double purlin in a floor-to-ceiling column and a single purlin on a short column. For this scheme, as the most common traditional dwelling of small openings and volume, the most simple and common form of roof purlin is the single purlin bearing rafters.(Figure 3-11)

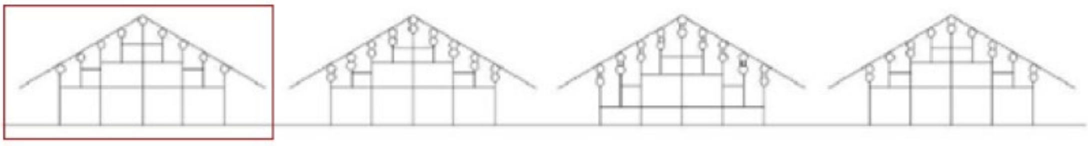


Figure 3-11 Schematic diagram of purlin for roof frame (drawn by the author)

In terms of the form of the pierced square, there are three main common types (Figure 3-12):

Type I: the roof frame has a total of five landing columns, four child columns, nine purlins, three through, nine floor flutings and two wooden square decorative elements. It is the most common type;

Type II: the third column of pierced square in the roof frame, with a change in form; the continuity of the pierced square is removed between the golden pillar and the block pillar.

Type III: also in the third column of the roof frame, the square is not pierced in the middle, but only between the golden column and the eaves column to transfer the load of the eaves boy column.

Compared to the second and third types, the first type is more cost effective in terms of structural penetrations, stability and resistance to horizontal forces, than the second and third types in terms of material economy and construction convenience.

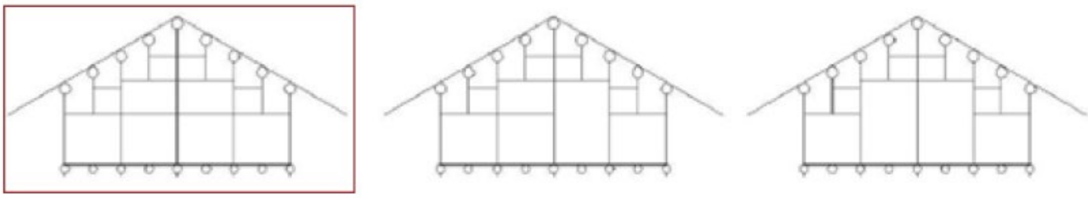
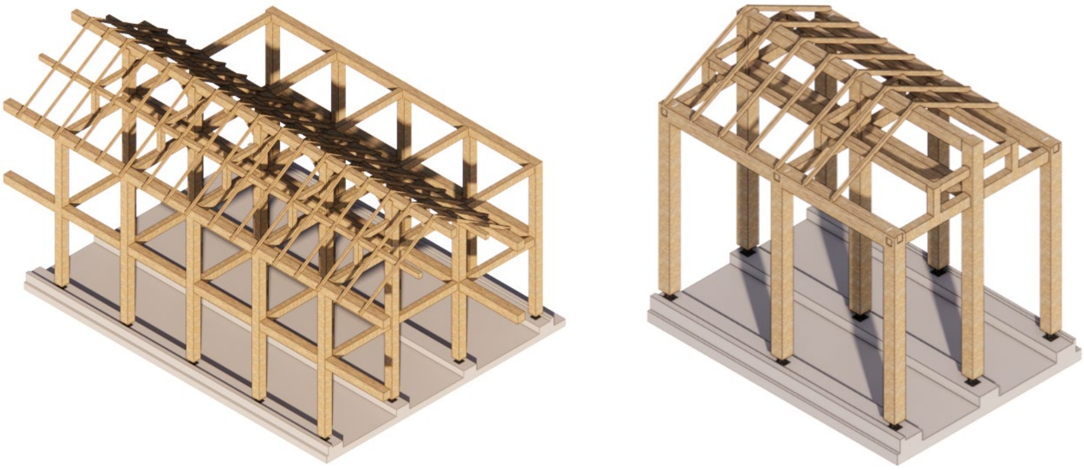


Figure 3-12 Schematic diagram of penetrating tie for roof frame (drawn by the author)

The primary structure of the house was determined through the study of Traverse-bracket frame structure system and the selection of the structural form. Based on the differences in the spatial layout of the renovated building, the primary structure was designed with two different timber frame systems, a and b, for buildings 1 & 2 and 3 respectively, the main difference being that the a timber frame system is a combination of a sloping roof and a flat roof (Figure 3-13).



a b

Figure 3-13 Two types of timber frame construction for the main spaces of the building (drawn by the author)

As a representative example of traditional timber frame construction, the ancient timber frame system of the pierced bucket system used mainly mortise and tenon joints for the connection of structural elements, as shown in Figure 3-14.

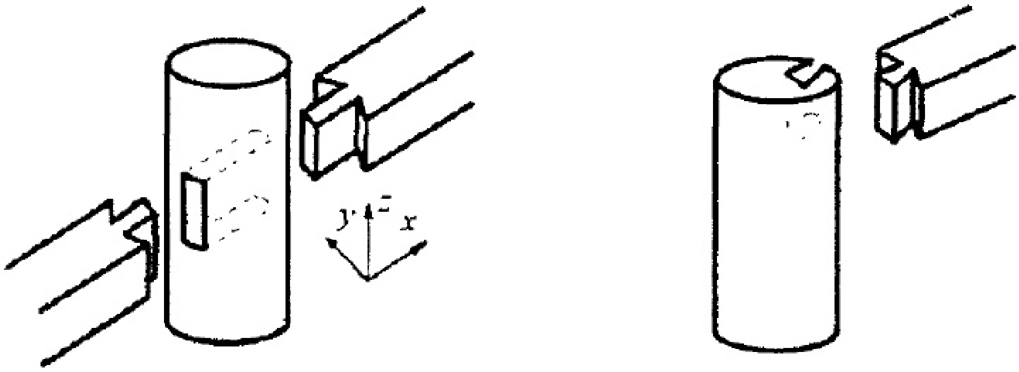


Figure 3-14 Profile of straight tenon & swallowtail tenon (Pics from Shukai Ya, 2017)

This form of connection, without any nail or metal, is one of the main features of Chinese ancient timber architecture. The so-called “mortise”, refers to the holes in the wood components; and “tenon” is the cut part at the end of wood component, which will insert in to the mortise. The function of mortise-tenon is integrating the individual wood elements tightly into a complete structure which is able to withstand various loads. The beam-column timber frame, which is connected by mortise-tenon, is responsible for all the loads from roof; and because of the flexible characteristic of mortise-tenon, the timber frame has good ductility, which contributes to the great aseismatic capability of structure.

The mortise-and-tenon joint is a good solution to the structural stability of traditional timber-framed houses and is the result of the wisdom of ancient house builders in their research into wood construction. However, due to the limited technical conditions, this type of jointing is time-consuming and demanding, and even in modern timber frame construction, mortise and tenon construction is still a technically demanding and time-consuming method of jointing that is not often used.

As industrial technology has improved, the types of connections between the elements of timber frame construction have become different depending on the type of structure. There are now five common types of structural connections in timber frame construction, depending on the configuration and position of the beams and columns, and the Forms of frame construction are shown in Figure 3-15:

a. Columns and compound beams

b. Compound columns and beams

c. Columns and oversailing beams

d. Beams and continuous columns

e. Forked columns

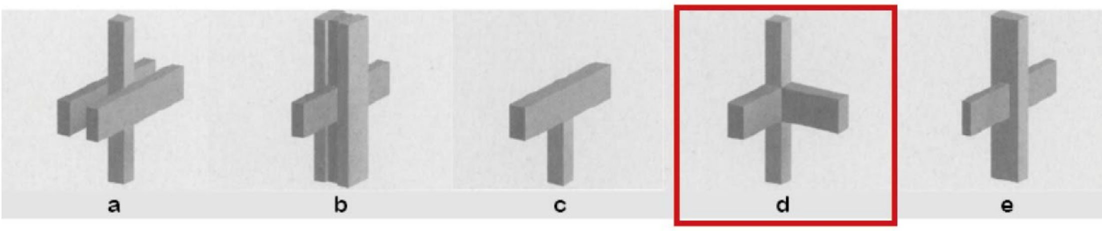


Figure 3-15 Five Forms of frame construction (Pics from Systems in Timber Engineering)

Various forms of frame construction in timber are distinguished, which differ depending on the column and beam configuration plus the types of connection. The choice of form of construction epends on the architectural requirements, the grid, and the loads to be carried. It is therefore best to choose the grid first and establish preliminary dimensions for the primary structure and then select the resulting frame construction form. The modern connection of beams and continuous columns was chosen in conjunction with the characteristics of Traverse-bracket frame structure system.

The primary structure of this form of construction consists of continuous columns and main beams designed as simply supported beams spanning between the columns. In this arrangement both the horizontal beams and the vertical columns are one-part members connected in the same vertical plane. The advantages of this system are that connections to the columns are possible in one plane on all four sides, and at the same time the beams can be connected to the columns at any level. As the columns form the perimeter of the loadbearing system and columns and beams are in the same vertical plane, this system is particularly suitable for structures whose structural frame lies on the inside of the building envelope. The external walls are subsequently fixed to the outside of the structural frame so there are no horizontal loadbearing members penetrating the building envelope.

Constructive connection of primary structure

As mentioned earlier, the primary structure of the project is built using Traverse-bracket frame structure system and the structural connection type is beams and continuous columns, which means that the vertical structural columns are continuous (but joined at each level) and the beams are attached to the sides of the columns. As shown in the Figure 3-16, the columns are notched at the point of attachment to the beams, and metal connectors are inserted in the notches to connect the beams, while a further part of the metal connector is added at the end of the beams to match them, using 15.9mm diameter threaded rods pre-epoxied in the column to secure the beams to the columns. The beams and columns are connected together. The same way of connecting the various parts of the structure with the metal connection elements is used for the connection of the pierced square. The rods and the interlocking metal joints of the primary structure ensure the strength and stability of the connections of the whole structure.

Figure 3-16 Beam and column connections (Self-drawn by the author)

The connection between the primary structure and the foundation is made by means of a column fixed to the concrete foundation, also with the help of metal connectors. A cross-type metal connector was used at the base of the column to support the frame structure with equal strength in all directions, the top and bottom planes of the connector were fitted to the column base and the concrete foundation respectively, and The hold-down nuts for the column-to-foundation connections were tightened using a special tool made from a magnet and a special tool. The hold-down nuts for the column-to-foundation connections were tightened using a special tool made from a magnet and a ratcheting box wrench (Figure3-17).

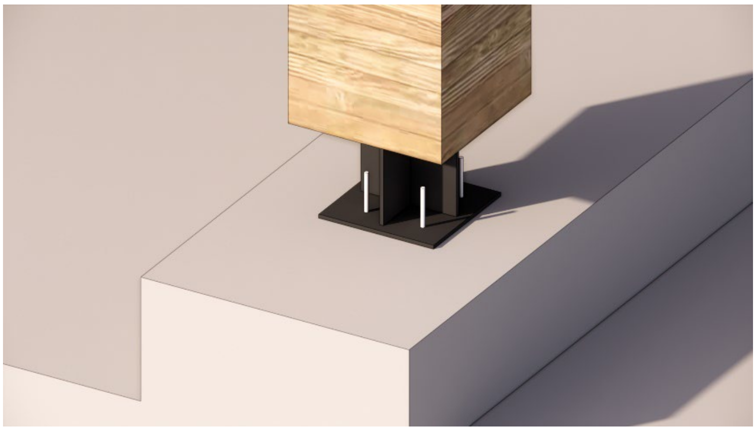


Figure 3-17 Column and foundation connection (Self-drawn by the author)

The project has resulted in the reconstruction and renewal of a much-damaged traditional timber-frame load-bearing system and a more stable and durable primary structure system through the selection of a pierced Traverse-bracket frame structure system and the use of modern, more scientific and reliable metal connectors for the connection and anchoring of the various parts of the structure.

3.4.2 Needs of Bracings in beam and column frame load-bearing structures

Stability is a crucial issue in the design of structures. As a primary structure system, Traverse-bracket frame structure system are mainly strong enough to support vertical loads due to their structural load transfer characteristics. However, the resistance to horizontal loads such as wind loads and earthquake loads is very weak and prone to lateral collapse (Figure 3-18). The post-and-beam structure illustrated in Figure 3-18(a) is apparently stable. However, the structure has no capacity to resist horizontal loads and will collapse when a horizontal force is activated. There are really only a few fundamental ways of converting a self-standing structure of the general type shown in Figure 3-18 (b) from an unstable to a stable configuration.

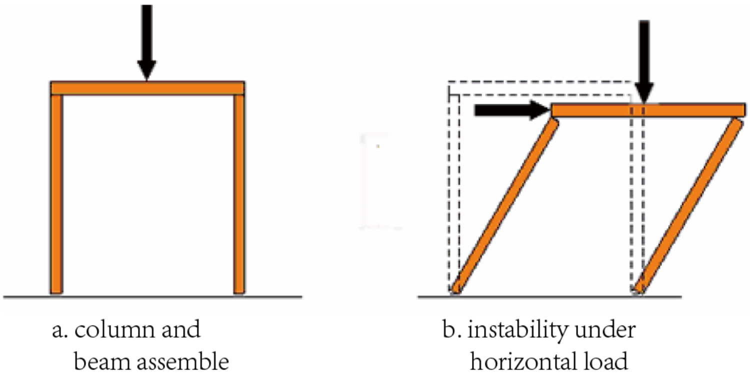


Figure 3-18 Force deformation of primary structure (Self-drawn by the author)

Thus, in order to guarantee the stability of frame structures in three dimensions, it must always be ensured that the wind loads and forces due to bracing can be resisted and transferred to other components. According to the form of action of the elements used for bracings，There are three methods of stabilization (Figure 3-19):

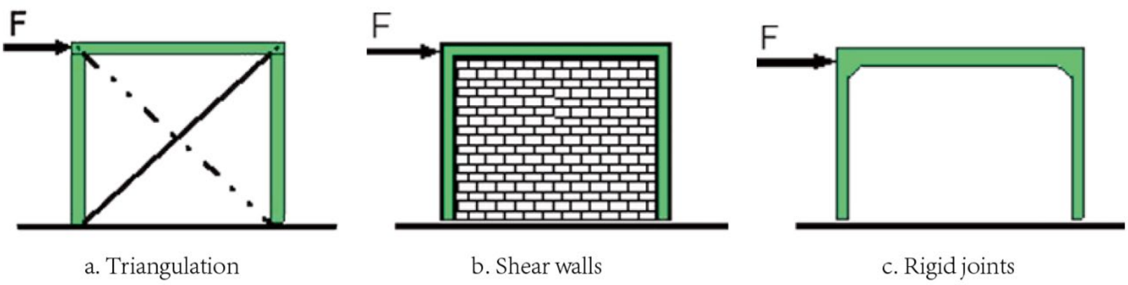


Figure 3-19 Three methods of stabilization (drawn by author)

(1) Triangulation:

Three members pinned at the ends forming a triangle make up a stable structure. As can be seen the load at the apex cannot push the inclined members down because the horizontal member held them together. Triangulation is widely used in timber and steel framing. A post and beam structure can be stabilized by diagonal bracing. Lateral load (usually wind load) can act on both sides of the structure as shown in Figure 3-19(a), cross-bracing the most common type of bracing.

(2) Shear walls

Another method used to ensure stability is through shear walls. These are rigid planar surface elements that resist shape changes of the frame type illustrated in Figure 1. A reinforced concrete or masonry wall can be used as a shear wall (see Figure 3-19(b)). In timber framing different kinds of plywood panels are used in this sense to resist the raking force induced by the wind.

(3) Rigid joints

A final method used to achieve stability is by introducing rigid joints between the members(see Figure 3-19(c)). This is a very common form of joint, especially in timber frame and reinforced concrete construction. A typical table, for example, is a stable structure because there is a rigid joint between each table leg and the top that maintains the 90° angle between the legs and the table top. Structures that provide rigid stability are referred to as frames. Rigid joints could be timber or metal.

In order to guarantee the stability of frame structures in three dimensions, it must always be ensured that the wind loads and forces due to bracing can be resisted and transferred to other components. Frame construction therefore usually relies on a combination of vertical and horizontal plates to brace the structure. Horizontal stability is provided by wind girders or plates in the plane of the floors or roofs, and vertical stability is ensured by bracing elements or plates in the plane of the walls, or by masonry or concrete structures within the building. It is important to remember here that structural connections are required between horizontal and vertical plates to ensure that all forces are transferred.

Horizontal stability can be provided by

- diagonal solid timber planks
- wood-based board products
- diagonal steel bracing (flat or round sections)
- diagonal steel bracing in the plane of the roof
- diagonal solid timber bracing
- shear-resistant flooring elements

Planar or linear bracing constructions are also used for the vertical stability. If walls with a sheathing of flat planks have been specified anyway, it is sensible to use these for the bracing as well. If there are no walls, but instead large expanses of glass, slender diagonal bracing in steel or timber is the best option. In the design of this project, a panel solution was used, using Structural Insulated Panels with support strength in the wall construction.

3.4.3 Structural Insulated Panels – Secondary Structure system

In timber frame construction the loadbearing functions are separated from the space-enclosing functions. The structure is therefore divided into a primary structure and a secondary structure. The former consists of the loadbearing columns and beams and is positioned on the chosen grid. It carries the loads from the secondary structure and transfers these to the foundations as concentrated loads. The secondary structure - consisting of timber joist floors or planar, prefabricated elements - transfers the loads from roof, suspended floors, and walls to the main beams. Besides clear, preferably simple load paths, the straightforward transfer of loads into components and down to the foundations, plus the bracing of the structure, are key aspects.

SIPs were introduced as a building panel concept in the U.S. by the Forest Products Laboratory in Madison Wisconsin in 1935. In an important research project homes built in 1935 were disassembled and tested thirty years later in a study that we cite and link-to below. That study found that the SIPs performed well, having retained their initial strength.

Structural Insulation Panels (SIPs) are a new type of green and sustainable building material. A SIP or Structural Insulated Panel typically has a polystyrene or polyurethane foam core faced on either side with a "skin" - generally plywood, composition board, OSB, or drywall. The SIP insulating foam core is most often Expanded Polystyrene (EPS), Extruded Polystyrene (XPS), or Polyurethane (PUR) but some companies offer other specialty foam insulating products. EPS is least costly, XPS is stronger and has improved moisture resistance, PUR has highest R-value, strength, and water resistance (and is more-expensive and has other drawbacks).

SIPs can work as a structural panel: the panel itself is the main load bearing element in a roof or wall - typically for one-story homes, or SIPs can be used as panels to enclose timber frame (post and beam) constructed buildings. SIPs are also used on more-conventionally framed roofs and walls. In the design of this project, the SIPs are used as a secondary structure together with Traverse-bracket frame structure system to form the complete load-bearing system of the building.

Connection of SIPs to primary structure

As mentioned in the previous sections, the load-bearing function of the secondary structure is achieved by transferring the loads to the primary structure. As part of the secondary structure, the SIPs therefore need to be connected to Traverse-bracket frame structure system, i.e. to the posts and beams.

The SIPs as secondary structure consist of a roof deck and a vertical wall layer, the roof deck of the SIPs is lapped onto the rafters of the pierced timber structure and is anchored to the rafters by means of studs. Where the roof panels of the SIPs meet the SIPs of the vertical wall layers, the two SIPs are also anchored by means of studs, as shown in Figure 3-20:

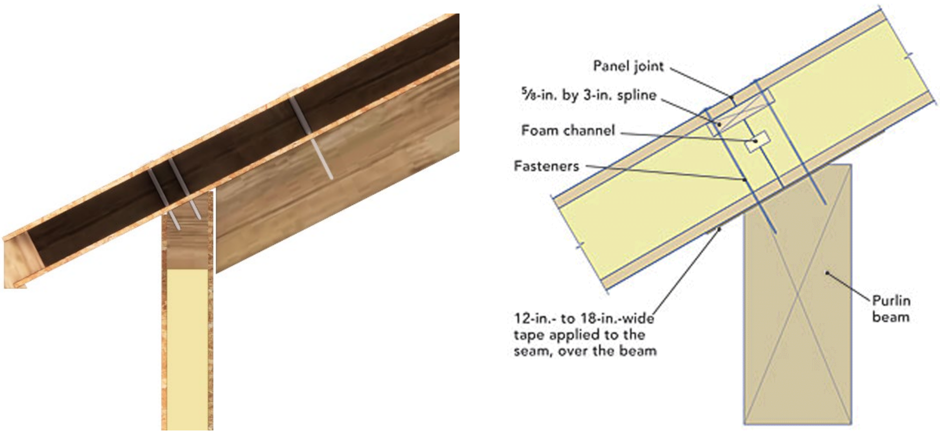


Figure 3-20 Roof SIPs and wall SIPs Connection (Self-drawn by the author)

The SIPs of the vertical wall layers are installed on the outside of the posts of the primary structure, and the 50mm X 150mm framing of the SIPs is fixed to the posts by means of studs at the part where they are attached to the columns. At the base of the SIPs structure, the horizontal cross beam is fitted to the reinforced concrete basement of the building and fixed together by a Hold-Down connection, see Figure 3-21:

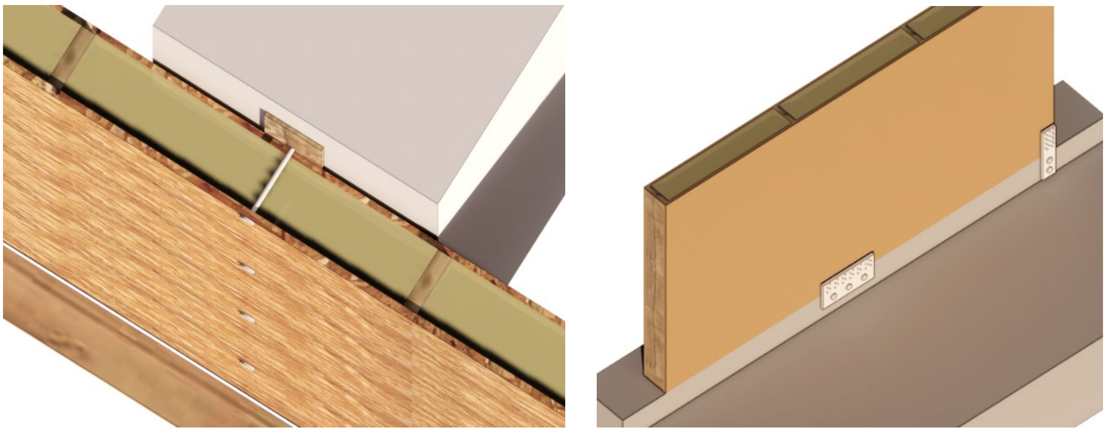


Figure 3-21 SIPs connect with Post and Basement (Self-drawn by the author)

A Hold-Down is a connector in a building structure that includes plates for tensile forces and plates for shear forces. Hold-Downs are used to connect overhanging sections or vertical walls to foundations or framing structures (such as timber or steel structures) to provide seismic and wind load support. Down is usually made of metal, including bolts, plates and angles, and is welded or bolted into the building structure. In weather conditions such as earthquakes or strong winds, Hold-Downs can effectively anchor the structure to the foundation or frame structure, thus protecting the building from the risk of collapse or damage.

The project building is constructed using a primary and secondary structure consisting of a through-hopper timber frame system and SIPs. The design of the new load-bearing system has been updated (Figure 3-22). The new load-bearing system is not only more rational and stable, but also offers a better solution in terms of interior space division and experience.

Figure 3-22 Primary and Secondary Structure Overlook (self-drawn by the author)

Structure Components Design

EXTERNAL WALL

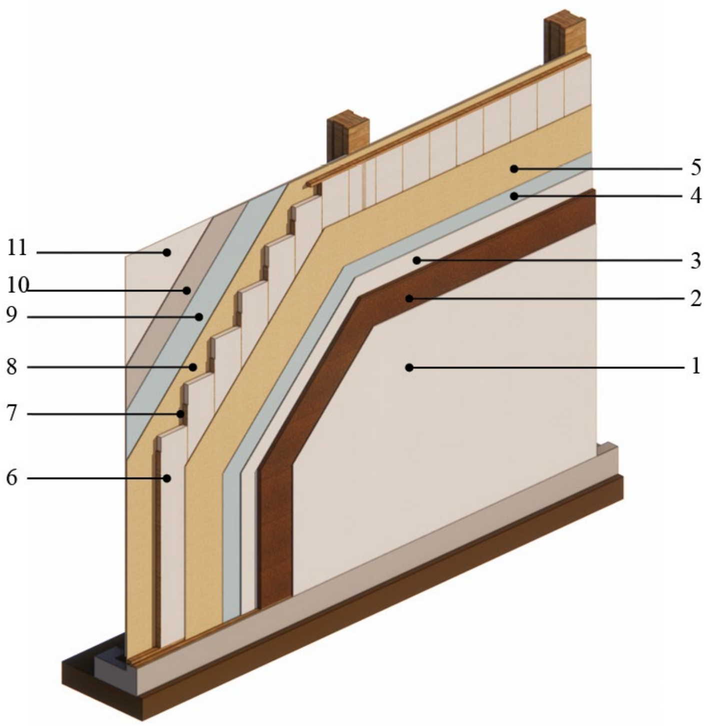


Figure 3-23 External wall layers (Self-drawn by the author)

Table 3-1 External Wall Layers

Layer	Description
1	External Plasterboard Layer, thickness 12.5mm
2	Acoustic and Thermal Insulation Layer with Cork, thickness 70mm
3	Plaster Layer, thickness 12.5mm
4	Waterproofing layer with vapour-permeable sheeting, thickness 0.5mm
5	Outside OSB panel layer of SIPs, thickness 10mm
6	Expanded Polystyrene (EPS) insulating foam core layer of SIPs, 160mm
7	Studs Framing in SIPs, cross section '20 x 160'mm & "80 x 160"mm
8	Inside OSB panel layer of SIPs, thickness 10mm
9	Vapour barrier layer with hygrovariable vapour and air barrier, thickness 0.5mm
10	Fibre Gypsum board layer, thickness 12.5mm
11	Gypsum board layer, thickness 12.5mm

ROOF

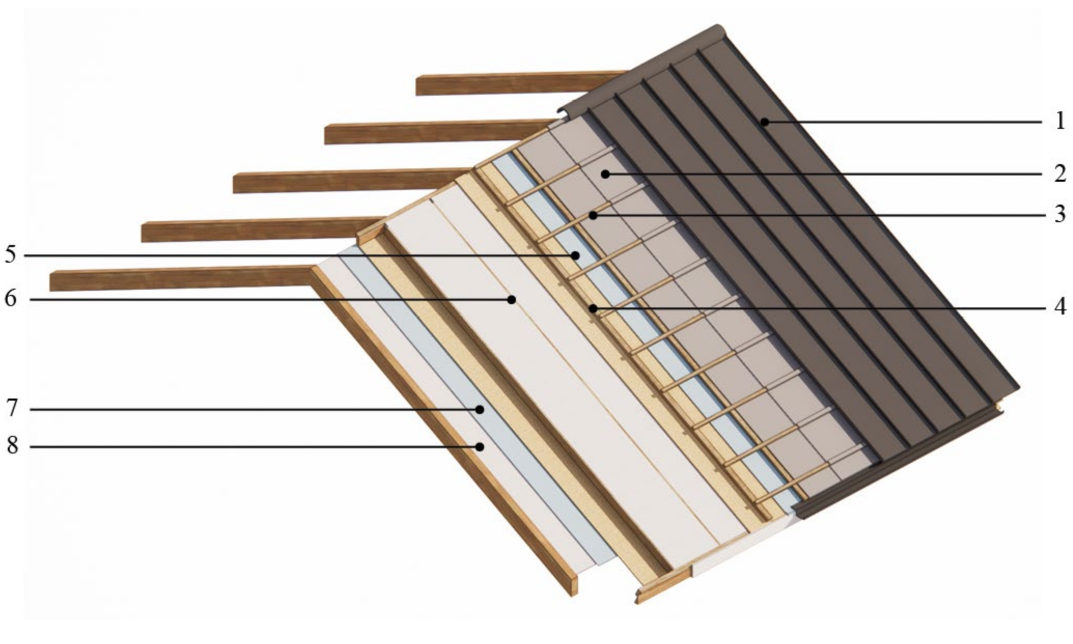


Figure 3-24 Roof layers (Self-drawn by the author)

Table 3-2 Roof Layers

Layer	Description
1	Seamed pre-coated zintek®, fastened with stainless steel screws and washers on the underlying wooden batten support, thickness 0.7mm
2	Waterproofing layer with vapour-permeable sheeting, thickness 0.5mm
3	Horizontal wooden batten support layer, cross section ’20 x 30’ mm
4	Cross wooden batten support layer, cross section ’50 x 30’ mm
5	Vapour barrier layer with hygrovariable vapour and air barrier, thickness 0.5mm
6	Structural Insulated panels layer(OSB- EPS-OSB), connected with Rafters of primary structure, total thickness 180mm
7	Vapour barrier layer with hygrovariable vapour and air barrier, thickness 0.5mm
8	Finishing Ceiling layer with Perforated plasterboard, thickness 12.5mm

FLOOR

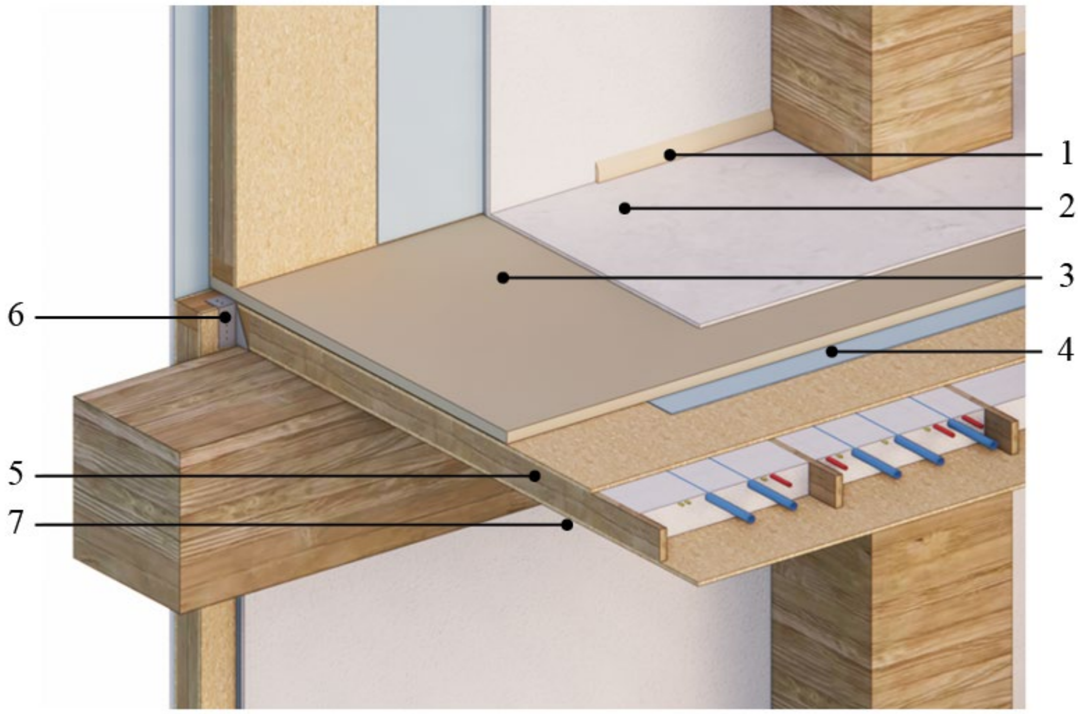


Figure 3-25 Floor layers (Self-drawn by the author)

Table 3-3 Floor Layers

Layer	Description
1	Wooden Skirting, height 120mm
2	Finishing floor layer with ceramic tiles, thickness 10 mm
3	Sub-flooring layer with high-strength boards, type KNAUF BRIO, thickness 30 mm.
4	Vapour barrier layer with hygrovariable vapour and air barrier, thickness 0.5mm
5	Structural Insulated panels layer(OSB- EPS-OSB), connected with SIPs wall layer and Beams, total thickness 180mm
6	Mounted Metal joist hangers
7	Finishing Ceiling layer with Perforated plasterboard, thickness 12.5mm

FOUNDATION

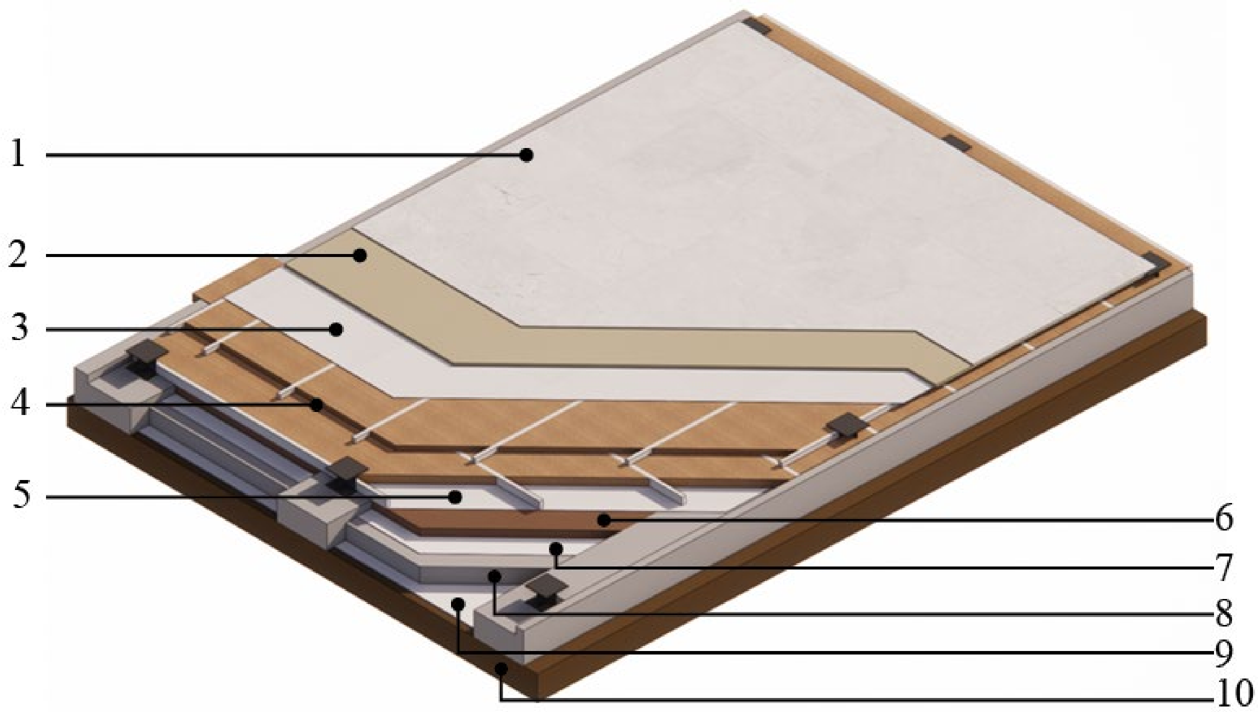


Figure 3-26 Foundation layers (Self-drawn by the author)

Table 3-4 Foundation Layers

Layer	Description
1	Finishing floor layer with ceramic tiles, thickness 10 mm
2	Sub-flooring layer with high-strength boards, type KNAUF BRIO, thickness 30 mm
3	Protective layer made of paper coated with polyethylene, thickness 0.15 mm
4	Double Insulation layers with highly compression-resistant wood fibre insulation boards, Crossover arrangement, thickness 60 + 100 mm
5	Protective layer made of paper coated with polyethylene, thickness 0.15 mm
6	Levelling layer with high strength dry filling, type CEMWOOD, consisting of wood chips with mineral coating, thickness 100 mm
7	Waterproofing layer with synthetic sheeting, thickness 0.5 mm
8	Reinforced concrete foundation slab, thickness 200mm
9	Separation layer from the ground in high density polyethylene
10	Soil

3.4.4 Access to timber materials for construction

The timber used in modern green buildings usually has the following characteristics:

Sustainably harvested: This timber is harvested from sustainable forests, meaning that care is taken not to disturb the ecological balance when harvesting timber. This practice helps to ensure that forest resources are kept in harmony.

Low carbon footprint: Compared to other building materials, timber has a small carbon footprint. Wood stores carbon dioxide efficiently and does not produce large amounts of greenhouse gases during production.

Lightweight and strong: wood has good strength and rigidity and is at the same time lightweight. This makes it an ideal building material as it not only supports the structure, but also reduces the overall weight of the building.

Earthquake resistance: timber also has excellent resistance to earthquakes, as it is inherently flexible and can be bent without breaking. This property makes timber widely used in buildings in earthquake zones.

Renewable: timber is a renewable natural resource that can be reused by replanting trees or recycling abandoned buildings. This makes it a very environmentally friendly building material.

Modern green building timbers used in timber frame construction include: pine, spruce, red pine, birch etc. In the processing and construction of modern timber-frame buildings, the timber used to form the timber frame for the pierced-frame is a large number of beams and columns made from raw timber that has been processed and treated, as well as some of the connecting elements. These timber products, which are used as elements, are usually made from pine. Pine is a common coniferous plant of the pine family, which is diverse and fast-growing, making it an ideal raw material for environmentally friendly wood. Pine for construction purposes is generally made from species with preservative properties, mainly American southern pine, red pine and green pine. Unlike American southern pine, which needs to be imported, red pine and green pine are widely distributed in some areas of China. Red pine, for example, is widely distributed in the Changbai Mountains to the Xiaoxingan Mountains in northeast China. Red pine's resistance to deformation, decay and rot, as well as its good turning properties, also make it a major source of log supply for timber frame construction (Figure 3-27).

Figure 3-27a Red Pine

Figure 3-27b Spruce

(Photographs from Internet)

To ensure that the materials used in the construction were sustainable and ecologically sound, the timber used in the project was sourced from domestic suppliers with Forest Stewardship Council (FSC) certification in China. The purpose of FSC forest certification is to promote the sustainable management of the forest timber industry while minimising the costs of extraction, processing and use of forest resources. As an organisation that promotes wood construction materials, Canada Wood has continued its work in China since 2000 with technical exchanges, project consultation, training and coaching, promotion, business trips and demonstration projects, constantly striving to raise awareness of wood products and modern wood construction technology in the Chinese market, and has identified many partner wood supply companies in the Chinese market. Due to the geographical location of the design project, we chose CROWNHOMES in Suzhou as the timber supplier, taking into account the quality of the timber products and the cost of production and transportation. CROWNHOMES is a national key high-tech enterprise in China, and is also Canada Wood's most important timber supplier in China, with the technology to manufacture timber beam and column structural elements as well as SIPs panels, enabling flexible customisation and factory scale production to meet all the needs of buildings for timber frame products.

3.4.5 The use of new phase change wall materials

In the context of sustainable building development, the reduction of building energy consumption and the achievement of maximum comfort in the living environment are the focus of research in the field of building energy efficiency. Phase change materials can be used for potential energy storage by absorbing and exerting heat during the phase change process and can maintain a constant temperature during the phase change process. The use of phase change materials in wall structures can improve their thermal inertia, reduce indoor temperature fluctuations, improve living comfort and reduce energy consumption for air conditioning.

The new phase change-insulation composite wall structure combines the phase change material into a slab-like component and then with the insulation material. A crack-resistant mortar protection layer and a decorative layer can be added to the surface of the insulation layer, thus forming a complete structure consisting of a decorative layer, a protection layer, an insulation layer, a shaped phase change layer and a wall matrix layer. Because of the addition of phase change material, on the one hand, it concentrates on the role of the phase change layer material in heat storage and temperature regulation, while the shaped phase change material can ensure that no leakage and volume stability problems occur during the recycling process; on the other hand, it can use the insulation material to effectively insulate the heat and fully improve the thermal inertia of the wall. The structure is stable and easy to construct and renovate the old building, playing a role in energy efficiency and environmental protection.

Paraffin wax, which has a low melting point, is a phase change material that is mainly used in the phase change layer of walls. It is usually hot-melted with organic bentonite or expanded perlite in a certain proportion to form a shaped phase change board of 5-10 mm thickness, and the phase change layer is bonded to the back of the insulation by means of a slotted bond in the insulation layer. This new phase change insulation composite wall with a phase change layer can produce a number of beneficial effects:

(1) It can concentrate on the thermal regulating effect of the phase change layer material, which

has a peak-shaving and time-delaying effect on temperature changes in external walls, while the shaped phase change material can ensure that no leakage and volumetric stability problems occur during cyclic use;

(2) The insulation material can be used to effectively insulate the heat and fully improve the thermal inertia of the wall.

(3) The panels are neatly dimensioned and easy to shape, facilitating mechanised production and on-site construction, and facilitating the energy-saving renovation of old buildings;

(4) Eco-friendly, non-toxic, long service life, balanced and stable performance.

3.5 Environmental strategies

The design of contemporary renovation of traditional dwellings needs to respect and retain as much of the original value of the building as possible, but at the same time the living standards and requirements of contemporary dwellings have changed dramatically compared to those of traditional dwellings due to the development of the times and technological updates. Contemporary architecture has introduced a number of standards and requirements in terms of habitat, which makes it necessary to design a renovation strategy for this traditional dwelling that not only restores and preserves the existing values of the building, but also meets and conforms to contemporary architectural occupancy standards. As mentioned and discussed in the previous sections, such a design strategy needs to be based on a green building design basis, taking into account the two main aspects of the building's initiative and economic energy efficiency from an environmental strategy perspective, and covering as many of the design indicators of the Green Building Evaluation System criteria as possible. Figure 3-28 illustrates the overall environmental strategy for this traditional house.

Sunlight provides both natural light and energy. The windows of the original dwelling have been retrofitted with larger glazing and active shading in areas of excessive light intensity; photovoltaic panels have been installed to store, transform and utilise the energy from the sun's rays.

The conservation of water resources is an area of particular concern and research in a world where water resources are in short supply. The traditional house is located in the rainy Jiangnan region of China, a climate that makes the site receive a huge amount of rainfall on average every year, especially during the rainy season. However, with the development of contemporary rainwater harvesting technology, it has become possible to support water harvesting systems for buildings that are able to supply non-potable water to residential properties by collecting and purifying excess rainwater.

Ventilation is a very important aspect of building design and construction, affecting the temperature of the space and determining the quality of the air, which is closely related to the temperature and air quality of the building space environment. The residence is designed for ventilation renewal through modern building technology, using natural heat dissipation and natural ventilation to control the building's indoor temperature to maintain a comfortable range in summer and winter - 26°C in summer and 21° C in winter. This is combined with proactive technical measures to provide a healthy and comfortable air quality inside the building.

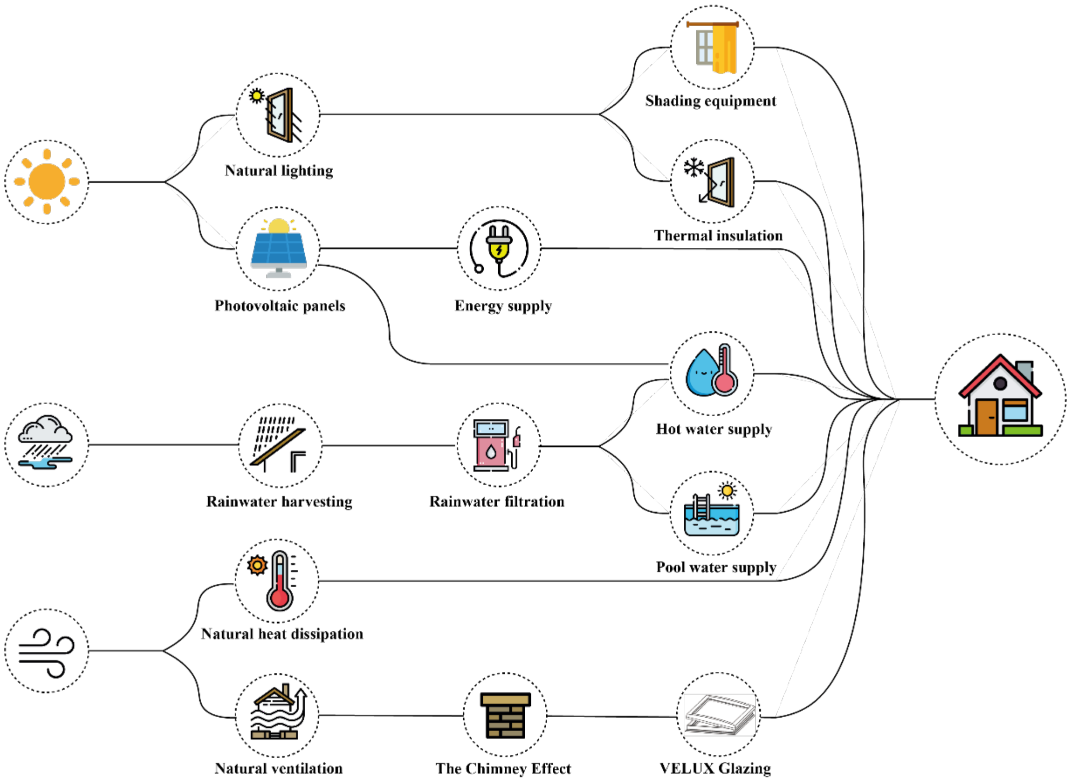


Figure 3-28 Environment Strategies (Self-drawn by author)

3.5.1 Active House Strategies Design

The active performance of the building has been designed to update the sunlight, rainfall, temperature, humidity and air quality affected by ventilation through a combination of active sensing and active regulation to maintain the building in a comfortable and stable state of use all year round. The active sensing technology is made possible by the use of intelligent sensors. Smart sensors are installed in the interior areas of the building and in the main exterior spaces to monitor in real time the C02, temperature and humidity, PM2.5, VOC and illuminance inside the building as well as the temperature and humidity, wind speed and direction, solar radiation intensity, PM2.5 and precipitation intensity outside. These sensors transmit the detected real-time data to a central server for storage and data analysis (Figure 3-29).

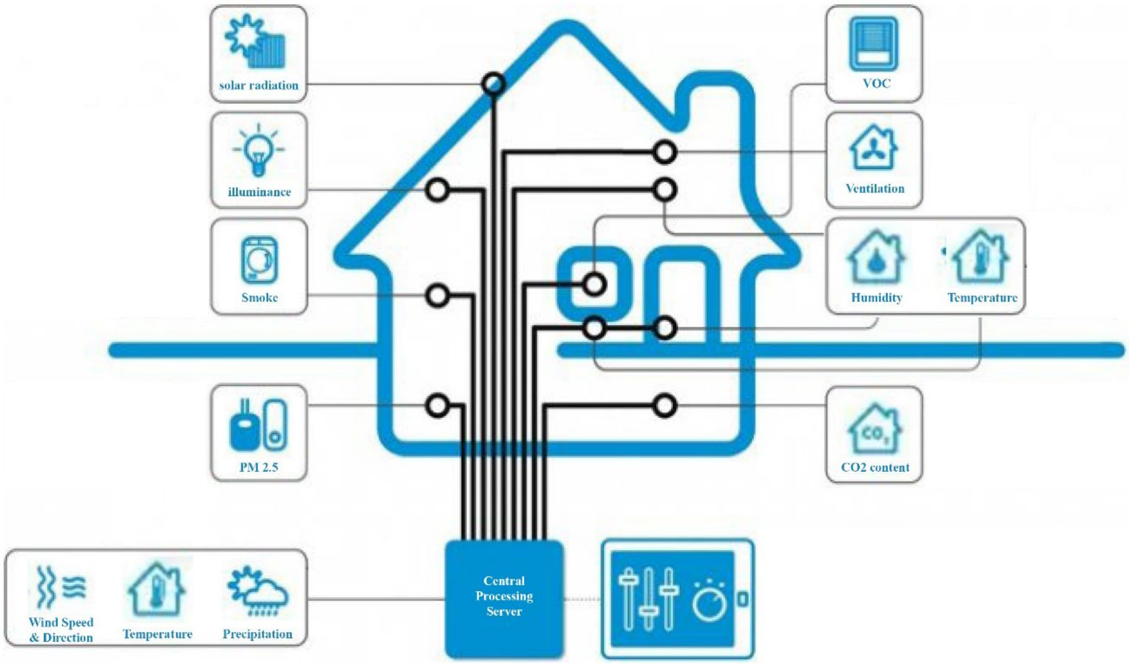


Figure 3-29 Sensors operation mode (Self-drawn by the author)

Once the data has been analysed, the active regulation technology can then be used in accordance with the results of the analysis. The south-facing rooms of the residence are equipped with actively regulated louvres (Figure 3-30), which change the amount of sunlight received in the space according to the solar radiation and the ambient room temperature. The skylights on the roof are also actively regulated by solar energy, adjusting the temperature, light and air quality of the room according to the results of the data analysis in the central server, thus achieving suitable living conditions in the building.

Figure 3-30 Actively adjustable blinds and skylights (http://www.velux.com.cn/content/details198_2092.html)

3.5.2 Design of an energy efficient renewal strategy for economic retrofit

Solar radiation, rainwater and geothermal heat are the environmental resources that are most often used by buildings as a source of energy saving in the design of building renovation. Thanks to the location of the house, the building receives plenty of light and precipitation throughout the year, which ensures that the design of the renovation can be utilised.

The retrofit scheme takes into account the natural elevation of the site and the sloping roof to design a large energy system with active performance to utilise solar radiation and geothermal energy (Figure 3-31). A large number of solar photovoltaic panels and solar collector panels are installed on the sunny roof of the building on the south side of the building to receive the heat generated by the sun's light and radiation and to supply the building with electricity and heat for indoor use. In the new 'L' shaped cafeteria space, a Thermally Active Building System (TABS) is installed in the concrete floor, which works in conjunction with the thermal storage capacity of the concrete structure to achieve a heating or cooling effect, enabling the indoor space to be controlled and adjusted. The TABS is used to control and adjust the ambient temperature of the room to maintain a stable and comfortable range. For the temperature control of other existing building spaces, the ground source heat pump is used in combination with a piping system around the building, using the heat pump principle, and the heat exchange between the building interior and the ambient soil through the supply of electricity collected by photovoltaic panels.

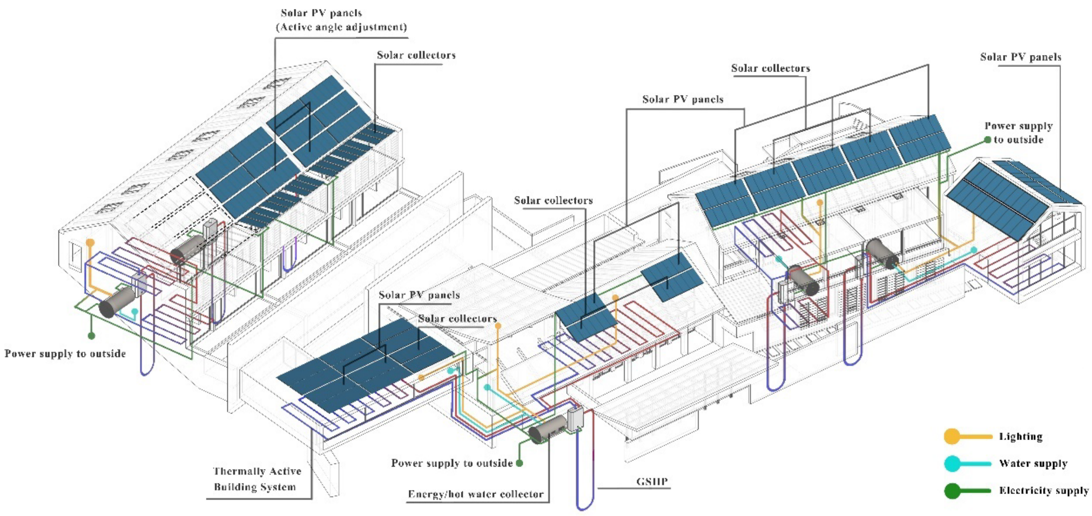


Figure 3-31 Energy System Design (Self-drawn by the author)

4 Life Cycle Assessment (LCA) of The Design

According to the statistics, the total global carbon emission in 2019 is 34.169 billion tons, of which China's carbon emission is 9.826 billion tons, accounting for about 29%. And in 2020, China's carbon dioxide emissions will be about 10.3 billion tonnes, with a per capita carbon emission of 7.4 tonnes. The scale of China's building area ranks first in the world, while China's building carbon emissions are much higher than those of the transportation and production manufacturing industries, with each square metre of house built generating about 0.8 tonnes of carbon according to the current level of technology. The "China Building Energy Consumption Research Report (2020)" released by the China Building Energy Conservation Association shows that in 2018, the total energy consumption of the whole building process in China was bit 2.147 billion tons of standard coal equivalent, accounting for 46.5% of the country's total energy consumption; the total carbon dioxide emissions were 4.93 billion tons, accounting for 51% of the country's total carbon dioxide emissions and 15% of the world's total carbon dioxide emissions. Therefore, energy saving and emission reduction in the construction industry is particularly important, and promoting the construction of ultra-low energy or even zero energy and positive energy buildings through the application of green technologies, new materials and new models in the built environment is an important way to achieve energy saving and emission reduction.

This chapter starts with a study of the concept of green buildings, and through the statistical and analytical use of big data, combined with theoretical research, it concludes that the development of green buildings has a great positive impact on the improvement of the global environment and energy saving. Based on the theoretical basis of green buildings, the achievements of green buildings in the world today are analysed in detail and systematically, as well as the different evaluation criteria systems proposed and implemented for green buildings, in which the indicators and scoring criteria contained in the evaluation systems are introduced with the examples of BREEAM in the UK, LEED in the US and CASBEE in Japan, and compared with the Chinese green building evaluation criteria system. The similarities and differences are also compared with the Chinese green building evaluation standard system.

Afterwards, based on the lack of new technical indicators for active buildings in the existing green evaluation standard system, the importance of the active building evaluation standard system is pointed out, and the establishment and development of this system is elaborated. It then describes the establishment of China's active building evaluation standard system and the differences in the content of evaluation indicators with foreign systems, and concludes that the system still needs to be improved and modified in China.

This chapter elaborates on the study of LCA, which plays an important role in the implementation of green buildings, explaining in detail what it consists of and its development history, and introduces the current development status of LCA in China in its infancy by searching and collecting data, and proposes a future direction for LCA and green buildings in China to continue to explore.

Finally, based on the design proposals for the renovation of this thesis project in Chapter 3, this chapter provides a comprehensive comparative assessment of the optimisation results that can be achieved in terms of LCA. Three detailed explanations are given in terms of the comparison of the building structure insulation parameters, the analysis of the energy consumption calculation of the building energy system, the comparison of the lighting of the main interior spaces, and the scoring of the active building evaluation criteria for this project.

4.1 Development of green buildings under China's 'double carbon policy'

Sustainable urban development cannot be achieved without a green and intelligent development concept. China's building energy efficiency originated in the 1980s and the concept of green building was introduced to China in 2005. In recent years, China's green buildings have developed rapidly, but there is still a gap compared to developed countries. To this end, China has set a target to reduce energy consumption and CO_2 emissions per unit of GDP by 13.5% and 18% respectively during the 14th Five-Year Plan period. By 2030, CO_2 emissions per unit of GDP will be reduced by more than 65% compared to 2005. Therefore, the 14th Five-Year Plan period is a critical and window period for reaching the carbon peak. Achieving carbon neutrality has become a top-level design at the national level, and is a necessary condition for the long-term healthy and sustainable development of the national economy. "The 14th Five-Year Plan proposes to develop smart construction, promote green building materials, assembled buildings and steel structure houses, and build low-carbon cities. The development of green buildings that reduce emissions and energy consumption, the adoption of innovative design concepts and new environmentally friendly building materials throughout the construction industry, the reduction of carbon dioxide emissions from buildings, and the improvement of energy performance throughout the life cycle of buildings are important measures to reduce carbon in urban development as a whole. At present, China's zero-carbon building market has huge potential, with over 10 million square metres of ultra-low energy and near-zero energy buildings, and an industry scale of ten billion yuan; it is expected that in the next ten years, low-carbon and zero-carbon buildings will drive a trillion-yuan market; the medium and long-term building energy efficiency improvement targets for 2025, 2035 and 2050 are ultra-low energy, near-zero energy and zero energy respectively, boosting China's zero-carbon building accelerated development. The development of active green buildings can reduce energy consumption by 90% compared to traditional buildings, and by more than 75% compared to new buildings. The application and promotion of active green buildings can bring great development to the low and zero carbon built environment, and thus the new active green building evaluation system needs to be developed in a new way.

Achieving carbon peaking and carbon neutrality is a long-term and profound economic and ecological change and development. In the medium to long term, a fundamental shift is needed in China's future economic growth momentum and ecological environment improvement, to move away from the status quo of high consumption, high pollution, high CO2 emissions and low productivity to low consumption, low pollution and low carbon emissions, to thoroughly restructure the industry, to truly improve total factor productivity (TFP), to use national economic policy as the primary tool to achieve carbon neutral, to achieve sustainable development and solve energy and environmental problems. At present, China's zero-carbon building market has huge potential, with ultra-low and near-zero energy consumption building areas exceeding 10 million square metres and the industry scale reaching tens of billions of yuan; it is expected that in the next ten years, low-carbon and zero-carbon buildings will drive a trillion-yuan market; the medium- and long-term building energy efficiency improvement targets for 2025, 2035 and 2050 are ultra-low, near-zero and zero energy consumption respectively, boosting China's zero-carbon building accelerated development. The development of active green buildings can reduce energy consumption by 90% compared to traditional buildings, and by more than 75% compared to new buildings. The application and promotion of active green buildings can lead to great developments in the low and zero carbon built environment, therefore, the building industry must accelerate decarbonisation to support the net zero goal, while the evaluation system for green buildings also needs to be newly developed.

4.2 Development of a green building based evaluation standard system

With the global attention and development of green building, the green building standard evaluation system for new and renovated buildings has also been promoted and developed by countries around the world. In this regard, some of the developed countries with an early start in green building development have already established some mature green building evaluation standard systems that are recognised worldwide, while China's green building evaluation standard system is also being developed and improved gradually with the increasingly rapid development of green buildings over the years, and is striving to gain worldwide recognition. Although the evaluation standard system for green buildings is now enriched and developed around the world, and has been widely used in the development of green buildings around the world, the rapid development and enrichment of technologies and concepts has exposed the lack of regulations and judgments of the established evaluation standard system for different development directions and technology stages. For example, there is still a lack of clarity in the international definition of zero-carbon buildings, while there are no clear regulations on the boundary and definition of carbon emission calculation for zero-carbon buildings in China; the emergence and development of active buildings also require the development of new evaluation standards for assessment. Therefore, expanding the content of green buildings, standardising and improving the development of standards and establishing a sound assessment system are still goals that countries around the world are working towards.

4.2.1 Mature green building evaluation standard systems in countries around the world

As one of the first countries to develop green buildings, the UK introduced the first green building assessment method, the Building Research Establishment Environmental Assessment Method (BREEAM), which evaluates new buildings, community buildings, operational buildings, old building renovations, ecology and sustainability. New buildings include courthouses, data centres, education, nursing homes, industrial, residential communities, offices, prisons, retail, etc. The BREEAM evaluation method uses the whole life cycle approach and is calculated as $F = Fi / Fgi \times K$, (F is the total building evaluation score, Fi is the score value of each evaluation indicator, Fgi is the highest score of each indicator, i is the BREEAM evaluation indicator, K is the (F is the total building evaluation score, Fi is the score of each evaluation indicator, Fgi is the highest score of each indicator, i is the BREEAM evaluation indicator, K is the weight ratio of the indicator to the total score). The scores are calculated based on the above rating methods and are used to classify green buildings into five levels, with 85 and above being outstanding, 70-85 being excellent, 55-70 being very good, 45-55 being good and 30 and above being passable. Currently, over 270,000 buildings worldwide have completed certification.

The US LEED rating system, which is also a highly authoritative green building rating standard, has been revised and improved in several versions since its introduction, with LEED V4.0 rating indicators and the weighting of each component being 16% for site selection and transportation, 10% for sustainable sites, 11% for water efficiency, 33% for energy and atmosphere, 13% for materials and resources, and 16% for indoor environmental quality. In this evaluation criteria system, integrated design is used as a prerequisite, while design innovation is a plus. the LEED BD+C evaluation method uses a cumulative index score, $E=E1+E2+E3+E4+E5+E6+E7+E8$, (E is the total building evaluation score, E1~E8 are the scores of each evaluation index). According to the evaluation score the building is divided into 4 levels, with 80 points or more being platinum; 60~80 being gold; 50~59 being silver;

and 40~49 being certified.

Japan has established CASBEE evaluation standards evaluation objects are mainly residential buildings, including new buildings, existing buildings, renovated buildings, commercial interiors, markets, temporary buildings, heat islands, urban development plans, cities, independent dwellings and residential units. the CASBEE evaluation method is to divide the building into two parts: environmental quality Q and environmental load W, where environmental quality Q is calculated by the indoor environment, the Environmental quality Q is calculated by summing the scores and weights of three evaluation indicators: indoor environment, service quality and outdoor environment in the area; environmental load W is calculated by weighting the scores and weights of three evaluation indicators: energy, resources and materials, and off-site environment. BEE ≥ 3 and Q ≥ 50 are considered outstanding (S), 1.5≤BEE<3 and Q<50 are considered very good (A), 1.0≤BEE<1.5 are considered good, 0.5≤BEE<1 are considered poor, and BEE<0.5 are considered poor.

4.2.2 The Establishment and Development of China's Green Building Evaluation Standard System

In 2006, China formed a green building certification system, the Green Building Evaluation Standard, and officially launched the evaluation of the logo in 2008. In recent years, China's green buildings have developed from scratch, from local to national, on a large scale. According to statistics, by the end of 2020, China's new green buildings accounted for 77% of new civil buildings in cities and towns, with a total of 24,700,000 green building label projects and a building area of over 2,569 million square metres, and the growth of assembled buildings has also been achieved. 2019 China revised and improved the implementation of the Green Building Evaluation Standard (GB/T50378-2019), which stipulates that the evaluation The target is all types of civil buildings, including public buildings and residential buildings. The evaluation content mainly consists of three parts, including the control item (Wo), the scoring item (Wi) and the improvement item (Wt). The evaluation indicators of the scoring items include safety and durability (W1), health and comfort (W2), convenience of living (W3), resource conservation (W4) and environmental livability (W5). The evaluation is based on the cumulative calculation of the scores of the green building evaluation indicators, which is calculated as (Wo+W1+W2+W3+W4+W5+Wt)/10, and is divided into four levels according to the scores. A score of 85 or more is considered a three-star rating, 70 to 85 is a two-star rating, 60 to 70 is a one-star rating, and meeting all the basic requirements of the control items but scoring 60 or less is a basic level. The detailed classification criteria and requirements are shown in Figure 4-1:

Figure 1-1 Classification of Green Building Assessment Levels

Rating	Evaluation scores	Control items	Thermal performance of the envelope or AHU	Heat transfer coefficients for external windows in harsh and cold areas	Efficiency of water use in water-saving appliances	Concentration of indoor pollutants	Acoustic insulation of residential buildings
3-star rating	> 85	Meet all requirements	20% envelope upgrade or 15% load reduction	20% load reduction	Level 2	20%	Meets the limits of the National Standard High Requirements Criteria
2-star rating	70~85	Meet all requirements	10% envelope upgrade or 10% load reduction	10% load reduction	Level 2	20%	Meets the average values of the National Standard High and Low Requirements Criteria
1-star rating	60~70	Meet all requirements	5% envelope upgrade or 5% load reduction	5% load reduction	Level 3	10%	—
Basic rating	—	Meet all requirements	—	—	—	—	—

Figure 4-1 Classification of Green Building Assessment Levels (Redrawn by the author from references)

A study comparing domestic and international green building evaluation standards shows that although BREEAM in the UK attaches great importance to green building energy consumption and carbon dioxide emissions, it does not form a clear carbon emission indicator. The US LEED and Japan's CASBEE, on the other hand, do not involve indicators on carbon dioxide emissions of green buildings. China's green building evaluation standards basically cover the mandatory options of the evaluation indicators recommended by the International Organisation for Standardisation ISO. However, there is no clear control and description of the pollution indicators recommended by ISO in them. In the 2019 edition of the Green Building Evaluation Criteria, although it is mentioned that a building carbon emission analysis is conducted, the provisions mentioned in the criteria are all voluntary, as the indicator is grouped under the improvement and innovation indicators, and there are no mandatory provisions stipulating the range within which the carbon emissions of green buildings should be controlled. This makes it easy for green buildings that have been awarded a star rating to be less energy efficient and reduce emissions.

Based on the rapid development of green buildings around the world, especially the emergence of active building concepts and technologies that can further improve the indoor environmental quality of buildings, energy efficiency and resource conservation, the world's green building evaluation standards are beginning to take active building technologies into account, and China is no exception. Building Evaluation Standard", which came into effect in December 2020. This evaluation standard is an expanded and additional evaluation standard system based on the green building evaluation standard system, and thus the evaluation is applicable to the performance of active buildings in all types of new, renovated and expanded civil buildings.

4.2.3 Active House Evaluation Criteria System

The evaluation system for active buildings is based on the three main principles of Comfort, Energy and Environment. Comfort includes Thermal Environment, Indoor Air Quality, Daylight and

Acoustic Quality; Energy focuses on Energy Demand, Energy Supply and Primary Energy Performance; Environment includes Freshwater Consumption and Sustainable Construction. Energy focuses on Energy Demand, Energy Supply and Primary Energy Performance; Environment includes Freshwater Consumption and Sustainable Construction. Each sub-category is scored and an objective and comprehensive evaluation and conclusion is drawn. The Active House Radar is used to reflect the results of the evaluation criteria in order to provide a clearer and more intuitive representation of the building's active score.

The Active House Radar shows the level of ambition of each of the three main Active House principles, containing four criteria for Comfort, three for Energy, and two for Environment. The integration of each principle describes the level of ambition of how 'active' the building has become. For a building to be considered as an Active House, the level of ambition can be quantified into four levels, where 1 is the highest level and 4 is the lowest passing level. The ambitious requirement for Active House includes all nine criteria and recommends the lowest level for each of them. As long as a criterion is better or equal to the lowest level of ambition, it is an Active House feature within that specific criterion. The figure 4-2 shows how all criteria within each principle are balanced against each other. It also shows that the Active House criteria depend on active choice and prioritization within each principle.

The Active House Radar is a great tool for displaying the ambition reached for the building with the calculated values. When the building is inhabited and the criteria are calculated based on measurements, the Radar can also be a useful tool for monitoring, evaluating and improving the building. As a communication tool, it provides a clarity as to why the integration of criteria is important for creating Active Houses.

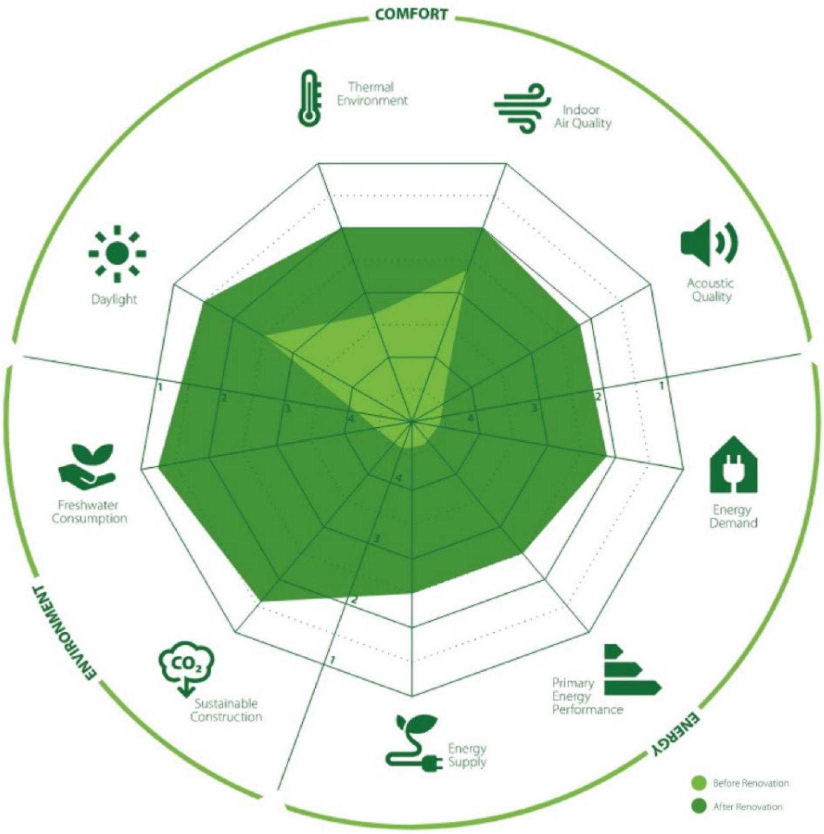


Figure 4-2 Active House Radar (The Active House Specifications - 3rd Edition)

Although the Chinese active building evaluation indexes are also nine sub-criteria, there are some differences between the classification of the evaluation indexes and the foreign evaluation indexes. The evaluation index system for Chinese active buildings has deleted the two criteria of Acoustic Quality and Primary Energy Performance from the three main principles of Comfort, Energy and Environment, and has changed the two criteria in the Environment principle to Environmental. The two criteria in the Environment principle have been modified and replaced by Environmental Loads and Water Conservation. The principle of activity has also been added, containing the two criteria of active sensibility and active reaction ability. For a building to be considered, the level of ambition can be a major factor. For a building to be considered, the level of ambition can be quantified into five levels, where 5 is the highest level and 1 is the lowest passing level. The figure shows the Active House Radar of China. The design projects in this paper were also assessed for the Active House score.

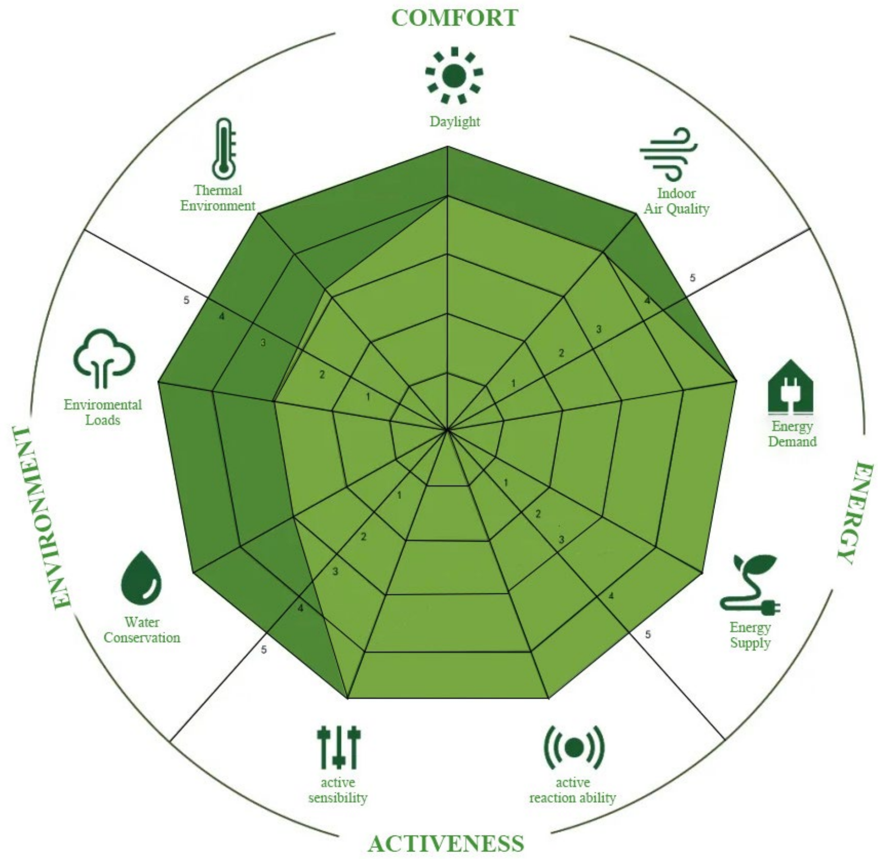


Figure 4-3 Active House Radar China (Assessment Standard for Active House)

4.3 Research on green building design based on whole life cycle evaluation

Life cycle assessment (LCA) is an internationally recognised and standardised tool that systematically analyses the consumption of resources and potential environmental impacts during the life cycle of a target, including raw material extraction, processing, manufacture. LCA has proven to be a valuable approach to environmental management and preventive environmental protection. This approach is now part of the decision-making process regarding sustainability.

Statistics show that the total energy consumption of China's buildings accounts for nearly 50% of the country's total energy consumption and carbon emissions, so reducing energy consumption and carbon emissions requires consideration and control of energy consumption throughout the entire process of building design, construction, operation and maintenance. This requires the role of whole life management of green buildings, from transformative design, building materials, construction, operation and maintenance, and building demolition.

This chapter aims to present the latest research developments of LCA, as well as the current status and development direction of China's exploration in LCA.

4.3.1 The development and standard of LCA

The development of life cycle assessment (LCA) began in the 1990s in the United States and Northern Europe. The first methods were primarily intended to assess the use of raw materials and energy and the production of solid waste, the main concern of the United States, where landfills were the main waste disposal method. It is interesting to note that over the years the environmental impacts considered were governed by public concern: solid waste production, air pollution, water pollution, energy use. In addition to a substantial difference in the presentation of the results and impact categories, initially there was also a significant difference in the data collection methodologies for the inventories. Only since the early 2000s, the concern about the incorrect use of the LCA, led the International Standards Organization (ISO) to develop a series of standards (series 14000: 1997-2002) whose update in 2006 is still the one currently in use. The framework of a life cycle assessment (LCA) is including, according to standard EN ISO 14040:2006:

- Goal and scope definition;
- Life Cycle Inventory phase (LCI);
- Life Cycle Impact Assessment phase (LCIA);
- Life Cycle Interpretation;
- Report and Critical Review;
- Limitations of the LCA;
- Relationship between the LCA phases;
- Conditions for use of value choices and optional elements.

The purpose of these standards is to describe the principles and phases of a life cycle assessment, to provide data quality requirements and to describe the mandatory or optional elements for a comprehensive assessment. These standards can be used as guidelines for the construction of a life cycle assessment, considering that the standard explicitly states the requirements of the calculation methodologies, but the methodology itself is a choice to be made in accordance with the objective and scope of the study.

In 2011 the European Commission's Institute for Environment and Sustainability published a handbook entitled "Recommendations for Life Cycle Impact Assessment in the European context". This publication details methods and calculation models for impact assessment, providing advice and suggestions, as well as comparing the different methods with each other. The aim of this publication is to be an addition to the ISO standard to assess in detail the aspects left generic in ISO 14000 and to homogenize the choice of methodology as much as possible in order to compare more easily the results of the studies.

EN 15987:2011 provides information about the methodology for carrying out a life cycle assessment of buildings. The standard also specifies that for a complete study, not only the environmental aspects should be considered, but also try to integrate the economic and social side of the project.

Figure 4-4 shows in a schematic way the concept of sustainability assessment of a building. In the standard it is also intended to highlight the importance of technical and functional requirements. At the basis of a complete assessment, the life cycle of a building must be considered: in this regard, the standard also proposes and analyses the stages that have been identified for the life of a building.

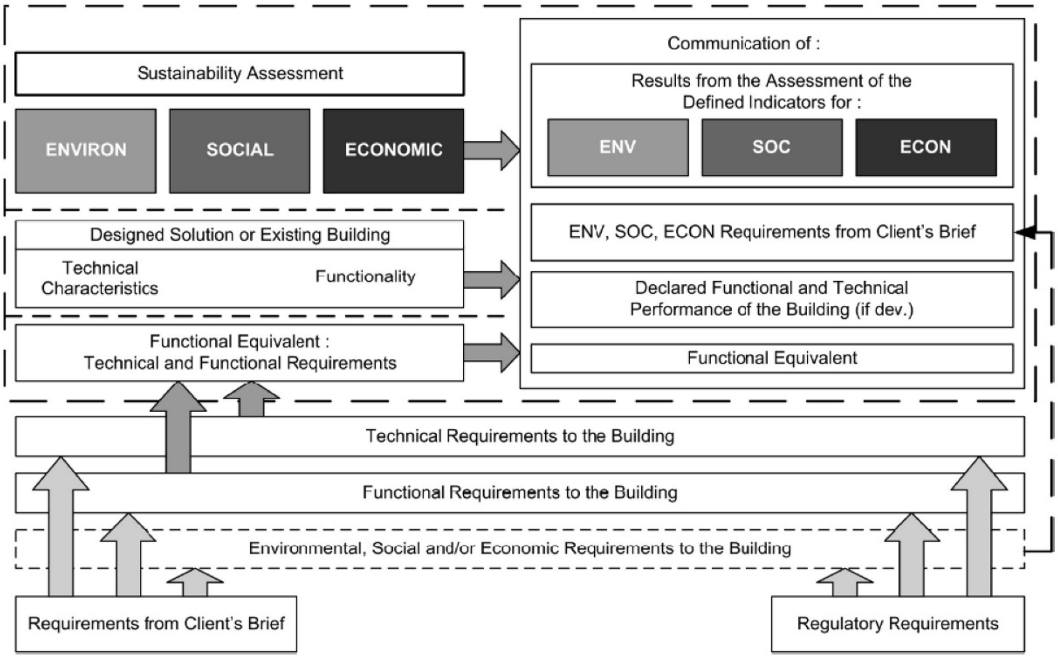


Figure 4-4 Concept of sustainability assessment of buildings (EN 15978:2011)

4.3.2 Current status and development potential of China's exploration in LCA

In 2006, China began to explore a life-cycle assessment method for buildings that is suitable for the Chinese context. The five phases of a building's life-cycle were analysed and studied, pointing out that the majority of energy and capital consumption and environmental pollution are allocated to two phases: the production of materials and the operation of the building. A framework for life cycle assessment of buildings is proposed(Figure 4-5).

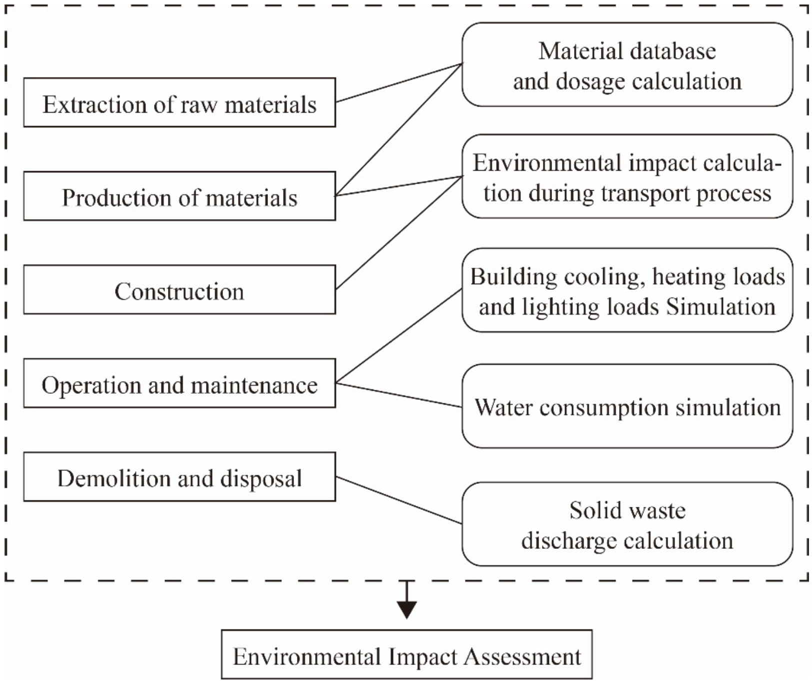


Figure 4-5 The framework for environmental impact assessment of LCA of buildings

(Redrawn from: Life cycle assessment for China building environment impacts)

Although China is actively exploring the application and development of LCA, the concept of green and ecological buildings in China has started late compared to the development of green buildings in developed countries in Europe and the United States, and because of the pressure of economic and social development, the construction of the LCA evaluation system in China is still in the early stages of exploration and still needs to be revised and improved. This includes three main aspects: optimising the evaluation process, improving incentives and implementing the responsibilities of the main body.

In terms of optimising the evaluation process, it is necessary to combine the characteristics of each phase, design the process of whole life cycle evaluation, clarify the detailed requirements of the evaluation process, implement the details of the green building construction process, allocate the weights of various indicators and calculate the green, economic and geographical benefits of green buildings. In terms of improving incentives, reasonable and sufficient policy support and help subsidies should be provided for the development of green building projects that meet the standards, so as to stimulate the whole society's awareness of green buildings and the LCA evaluation system. In addition, as the whole life cycle evaluation system of green buildings involves many relevant responsible subjects in many stages, the responsibilities of each subject should be clearly defined in construction, management and evaluation to ensure the quality and accuracy of the evaluation system results.

We will vigorously develop assembly-type buildings, green buildings and ultra-low energy consumption buildings, carry out pilot projects for the construction of "no-cost cities", promote "fourth-generation housing" and other three-dimensional garden building projects, improve the ecological environment for human habitation, and give full play to the comprehensive carbon sink capacity of three-dimensional garden buildings. The application of passive, active and renewable energy technologies will help to achieve lower energy consumption, lower carbon emissions and a better living experience. Strengthen the innovation of general contracting mode, develop enterprise organisations based on whole life cycle engineering design, consultation and services, and cultivate the whole process engineering consultation market, etc. Promote the synergistic development of the whole construction industry chain with wisdom as the technical means, industrialisation as the production method and green building materials as the material basis.

4.4 Evaluation of Design Project

4.4.1 Comparison of thermal insulation performance - External walls

Thermal Transmittance, or U-value, is a parameter used to assess the thermal conductivity of a material. The smaller the Thermal Transmittance, or U-value, of a building, the less heat is lost through the wall and the better the thermal insulation of the building wall. Based on this, the project proposal evaluates the thermal insulation performance of the external walls and compares the results with the U-value of the original walls of the project building to analyse the optimisation of the design solution for the thermal insulation performance of the building.

By searching the article, the important parameters of each layer of the facade construction were obtained, and the following tables were compiled to obtain Table 4-1:

Table 4-1 Characteristics of each layer of External Wall (Self-drawn by the author)

Layer	Thickness [mm]	Thermal Conductivity λ [W/mK]	Thermal Resistance R [m^2K/W]
Plasterboard	12.5	0.21	0.0595
Cork	70	0.038	1.842
Plasterboard	12.5	0.21	0.0595
Waterproof	0.5	0.2	0.0025
SIPs	180	0.21	0.857

Vapour barrier	**0.5**	**0.17**	**0.0029**
Fibre Gypsum board	**12.5**	**0.2**	**0.0625**
Gypsum board	**12.5**	**0.2**	**0.0625**

The above table lists the main parameters of the façade construction for the project design scheme, from which the Total Thermal Resistance of the façade can be calculated, and in turn the values of the parameters in the following table 4-2 can be calculated:

Table 4-2 Characteristics of External Wall (Self-drawn by the author)

Characteristic	**Value**
Thickness[mm]	300
Thermal Transmittance U-value [W/m^{2}K]	0.339
Interstitial Condensation Check	OK

This table shows that the U-value of the new façade is 0.339 W/m^{2}K, whereas the original façade is a brick wall, which is usually 2 W/m^{2}K. This means that the new wall construction has better thermal insulation properties than the brickwork, providing a more comfortable and stable environment for the internal spaces of the building.

4.4.2 Analysis of energy consumption calculations for building energy systems

A total of 275.7 m^2 of solar photovoltaic panels and 99.5 m^2 of solar collector panels are installed on the south side of the house to receive the sun's light and radiant energy for use. The photovoltaic panels are made of P-type crystalline silicon doped with phosphorus to produce N-type silicon, forming a P-N structure. When light strikes the panels, some of the photons are absorbed and the energy is transferred to the silicon atoms, causing electrons to migrate and become free electrons that collect on both sides of the P-N junction to form a potential difference, which, when the circuit is switched on, generates a certain output power through the flow of current. The absorber absorbs most of the solar radiation energy and transforms it into heat energy, which is then transferred and utilised.

The Thermally Active Building System (TABS) designed for the new cafeteria volume works on the basis of the thermal storage capacity of the structural concrete parts of the building, where the concrete floor and ceiling are used as 'energy panels' for heating and cooling the building. ". The "active" nature of the combined heating and cooling application is achieved by means of embedded ductwork in the structural concrete slab. The thermal activation of the building structure is an extremely clever technology; not only does it provide a constant, comfortable room temperature but it is also environmentally friendly and cost effective to run. TABS achieves constant room temperature control primarily through heat conduction and heat radiation rather than heat convection. Heating and cooling are achieved by circulating hot or cold water in the TABS modules (water temperature 15-20°C for cooling and 25-35°C for heating), which, in contrast to other heating and cooling systems, does not produce airflow fluctuations due to the very low convection velocity in heat transfer and makes environmentally friendly use of naturally available energy. The TABS system operates close to the ambient temperature, thus making more efficient use of ambient heat and cold sources and renewable energy sources to achieve ultra-low energy consumption, making it ideal for systems that use low temperature heat sources and natural cooling energy.

Ground-Source Heat Pump (GSHP) is a technology that takes advantage of the relative stability of the soil and groundwater by using the heat pump principle to transfer low and high heat energy to and from the building by means of a small electrical input. In winter the heat is "removed" from the soil, warmed up and supplied to the indoor heating, and in summer the indoor heat is "removed" and released into the soil, so that the underground temperature can be balanced all year round. Due to the conditions of the project site and the distribution of the buildings, it is more appropriate to use Ground-Coupled Heat Pumps (GCHP), which use the soil as a heat source/sink and consist of a heat pump unit with a buried heat exchanger, usually a high-density polyethylene or polybutylene tube, which is fed through The flow of circulating fluid (water or antifreeze) in the enclosed underground buried pipe achieves heat transfer between the system and the earth. In the operation of a buried pipe ground source heat pump system, the dynamic changes in the building load and the underground soil heat exchange are closely related and coupled to each other. The buried pipe method of GCHP is divided into two types: horizontal and vertical. The solution chose the more common vertical buried pipe approach, which is slightly more costly in terms of initial investment, but because the temperature of the deep soil is more stable throughout the year, it can make the operation of the heat pump system more stable as well.

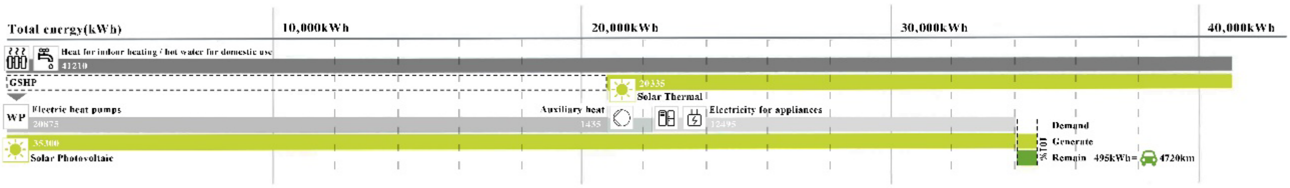


Figure 4-6 Energy System Energy consumption calculation (Self-drawn by the author)

Based on the operational design of the complete energy system, the results of the simulation of the production and consumption of thermal and electrical energy for the whole building are reflected in Figure 4-6. The solar heat collected from the solar collector panels is about 20335 kWh, while the remaining half of the energy demand is about 20875 kWh, which needs to be supplied by the ground source heat pump (GSHP). The total amount of electricity required for the building is 34,805 kWh per year, which means that the solar photovoltaic panels in the building energy system can generate a total of 35,300 kWh per year, which is equivalent to the surplus of 495 kWh when the building's annual electricity demand is fully covered. This is equivalent to driving a purely electric car for 4,720 km, which can be used as an external power supply for the small-scale electricity consumption of the town.

Figure 4-7 shows that the energy system can be used to solve the building's own energy demand by using sunlight, geothermal, fresh air and at the same time supplying additional energy to the external State Grid. Grid.

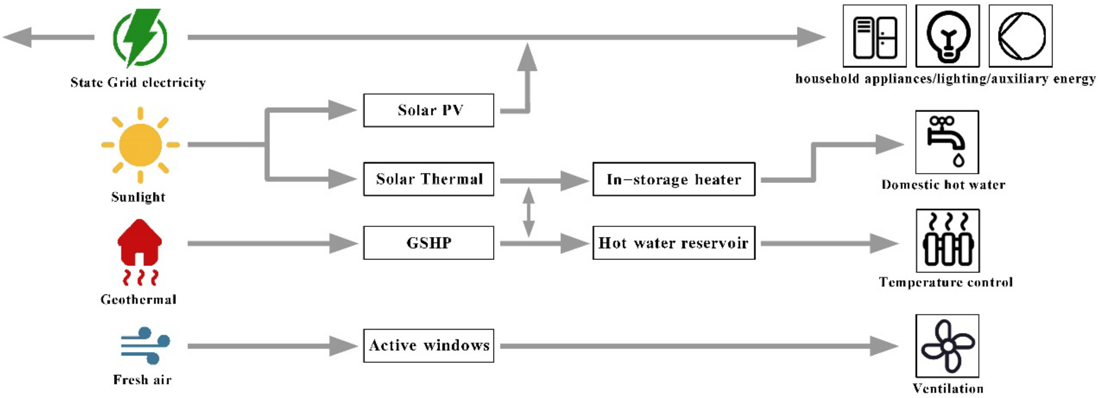


Figure 4-7 Energy System final design result (Self-drawn by the author)

4.4.3 Design optimisation of the architectural light environment

Three typical rooms in the three main building volumes of the project were selected and modelled by simulation software for both the original and the renovated rooms, and the simulation test conditions were adjusted to June in summer, when direct sunlight is more abundant, and the time was set at noon(Figure 4-9). Under the same simulation parameters, different window openings were simulated for the old and new rooms to obtain the indoor light distribution for each control room. The simulation results are compared and analysed to visualise the effect of the design on the building's light environment.

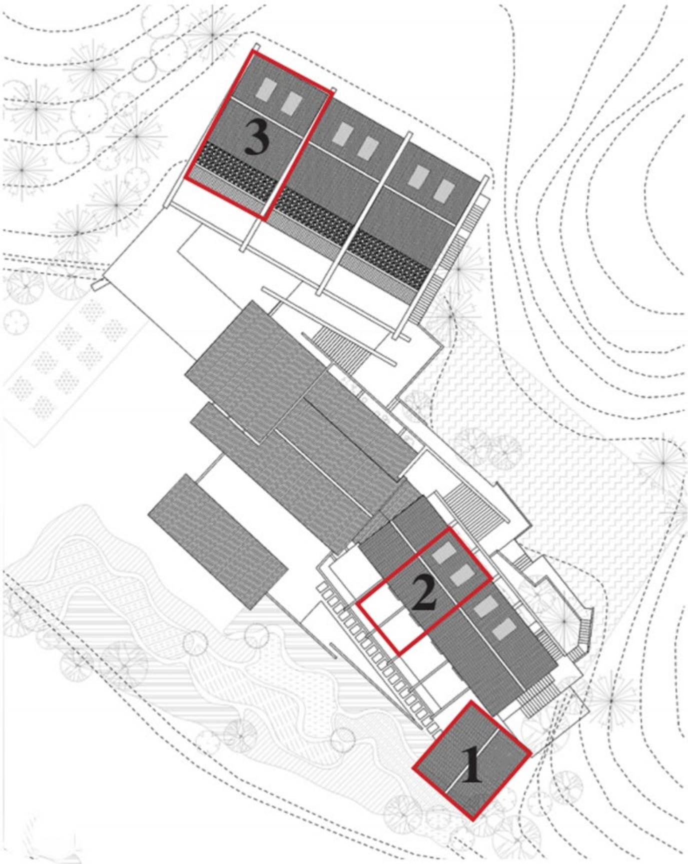
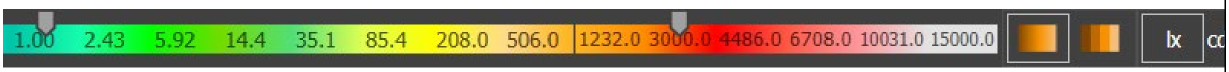
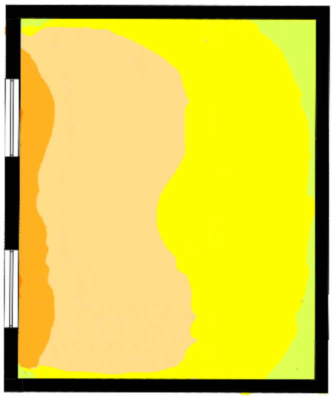
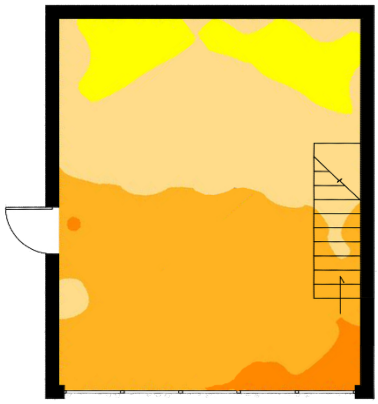
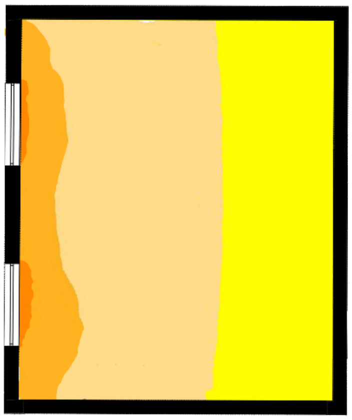
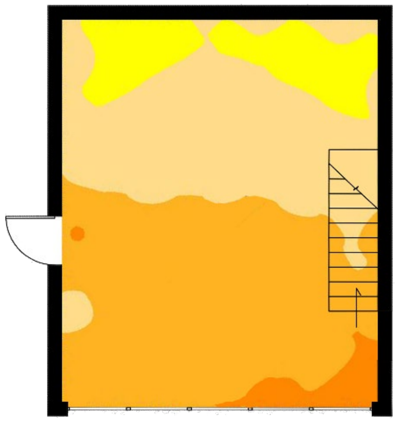
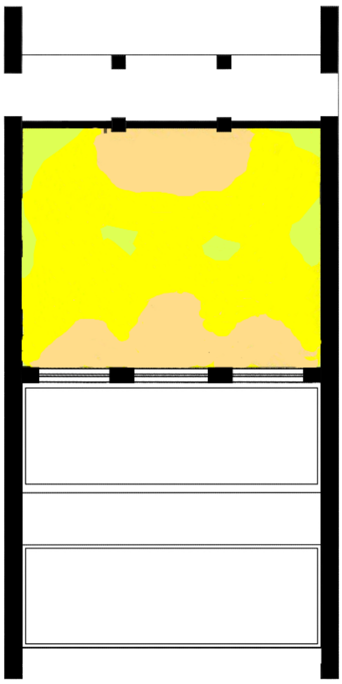
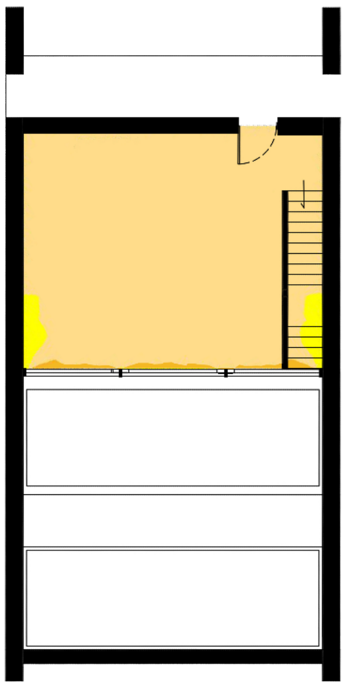


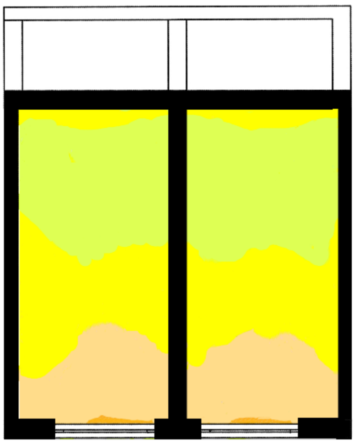
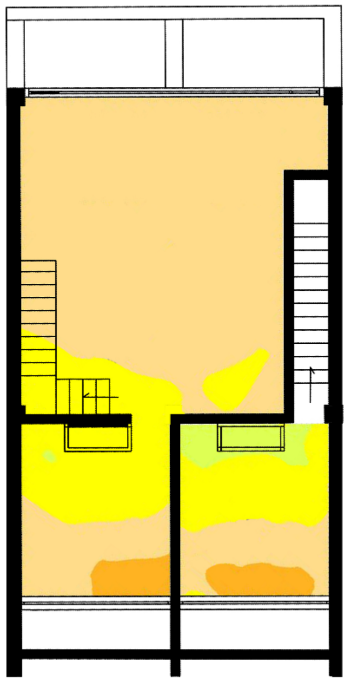
Figure 4-8 Three typical rooms selection (Self-drawn by author)

Three typical rooms in the three main building volumes of the project were selected and modelled by simulation software for both the original and the renovated rooms, and the simulation test conditions were adjusted to June in summer, when direct sunlight is more abundant, and the time was set at noon(Figure 4-8). Under the same simulation parameters, different window openings were simulated for the old and new rooms to obtain the indoor light distribution for each control room. The simulation results are compared and analysed to visualise the effect of the design on the building's light environment.

Table 4-3 Comparison of light environment simulations (Self-drawn by the author)

		
Room Selection	**Original Room**	**Renew Room**

Room 1 **Floor 1**		
	50 – 800 lux	100 – 3000 lux
Room 1 **Floor 2**		
	90 – 1000 lux	100 – 3000 lux
Room 2 **Floor 1**		
	50 – 550 lux	100 – 1000 lux

Room 3 **Floor 1**		
	50 – 750 lux	80 – 1500 lux
 		

The results of the data from the Table 4-3 legends can be summarised as follows:

Firstly, as stated in the previous sections on the existing lighting deficiencies of the project, it can be seen through the illustrated data that the illuminance of the interior light in the main spaces of the original building is mainly concentrated in the range of 50-500 lux (cd/m2), and in most areas around 300 lux. This is mainly due to the choice and scale of window openings in traditional Chinese vernacular residential architecture. In the case of this project, the standard window openings in the original building are mainly on the south side of the brick wall. Due to the limitations of the old construction techniques and the structural strength of the building, it is difficult to achieve large scale and free window openings, so the window openings on the south side are basically 900mm wide x 1200mm high. The window openings on the south side of the building are 900mm wide x 1200mm high. This size of window openings has a significant impact on the amount of natural light coming in from the south side. On the north side of the building, a high window of 500mm in height has been built into the north wall for ventilation purposes only. This makes it difficult for the interior of the building itself to receive a certain amount of light from the reflected light of the north-facing sun.

Thanks to the updated design of the project, which includes a timber structure with a pierced bucket and structural insulated panels, the new building has a more liberal choice of window positions and scales. As a result of this freedom of window opening, the scheme makes extensive use of full, large floor-to-ceiling windows on the south side of the building to increase the light penetration on the south side of the building and thus receive more direct sunlight. At the same time, larger standard window openings have been added to the north wall of the building to allow for greater diffuse solar reflection into the back side of the building. In addition, the use of VELUX skylights in the sloping roof on the backlit side of the building allows a certain amount of direct solar light to reach the interior spaces on the north side of the building, which do not receive direct solar light. As can be seen from the graphical data of the updated light simulation of the building's interior spaces, the updated design of the building's window openings has improved the ventilation of the building itself, while optimising the light environment of the building's interior spaces. For example, Room 1, which is the open space of the multi-purpose hall, has more than doubled the light intensity on both floors, reaching a maximum of 3000lux, while Room 2 and Room 3 also have nearly doubled the light intensity.

By optimising the design of the window openings, the light intensity of most of the interior spaces in this project has reached a reasonable range, meeting the light requirements of the building for daily human activities. It also reduces the use of artificial light sources during the day, especially in daylight conditions, and reduces the consumption of electricity, making the building itself more in line with the requirements of a green and low-carbon building.

4.4.4 Value evaluation of Active House Standards for project proposals

In the previous chapters of this paper, we have described in detail how China's active green building assessment system assesses the technical performance of buildings in four areas: effectiveness, comfort, energy and environment. Each specific rating item has a score of 5 out of 5, and each rating item needs to achieve a score of 20%, i.e. a score of 1 or more, before the rating item can be considered valid. Based on these evaluation criteria, the project's renewal design was assessed for the value of active green building technologies and the score descriptions were summarised as follows:

Activeness

The design solution is based on active sensing, with intelligent sensors in all indoor areas of the building and outdoors. In terms of active sensing, all indoor areas and outdoor areas of the building are equipped with intelligent sensors that detect CO_2, temperature and humidity, PM2.5, VOC and illuminance in real time, as well as outdoor temperature and humidity, wind speed and direction, solar radiation intensity, PM2.5 and precipitation intensity, and upload the data to a central server for storage; in terms of active regulation, the south side of the multi-purpose hall and accommodation rooms are equipped with active regulation blinds, and the roof is equipped with active regulation solar-powered skylights, which adjust the indoor lighting and air indicators according to the data from the server. The roof is equipped with an active solar-powered skylight, which adjusts the indoor lighting and air indicators according to the server data.

Table 4-4 Activeness Evaluation (Self-drawn by the author)

Sensibility parameters		**Score**
Indoor	Temperature, humidity, CO_2 concentration, PM2.5, VOC, illumination, noise	**2**
Outdoor	Temperature, humidity, wind speed, wind direction, solar radiation intensity, precipitation intensity, CO_2 concentration, PM2.5, noise	**1**
Percentage of sensed indoor space	More than 50% of the total floor area of the main functional rooms with sensory functions	**1**
-----	Function to transmit sensed indoor and outdoor environmental data to the server	**0.5**
-----	Server with the ability to store and playback environmental inspection data inside and outside the greenhouse	**0.5**
Regulation parameters		**Score**
Temperature & Humidity	The main functional rooms, which account for more than 50% of the area, are able to regulate the room temperature and humidity	**1**
Illumination	The main functional rooms with more than 50% of the floor area are able to adjust the illumination level in the room	**1**
CO_2 concentration	The main functional rooms with more than 50% of the floor area are able to adjust the CO_2 concentration in the room	**1**
PM2.5	The main functional rooms with more than 50% of the floor area are able to adjust the PM2.5 in the room	**1**
Noise	The main functional rooms with more than 50% of the floor area are able to adjust the noise in the room	**1**

Because of the comprehensive design of the project proposal in terms of active building techniques, the score as listed in Figure 4-11 allows for a perfect score of 5 for both the active sensibility and active reaction ability in the assessment of activeness.

Comfort

The main spaces of the building receive good natural light. Large areas of light glazing and active shading are used on the south side. Automatically controlled skylights provide good light and ventilation regulation. 80% of the occupied spaces have a light factor of approximately 5.5% and a light uniformity of approximately 0.4 to 0.5. The landscape planting around the building complex provides a good microclimate which, together with the natural ventilation of the building, provides a healthy and comfortable air quality inside. The building's indoor temperature is controlled at 26°C in summer and 21°C in winter, and the relative humidity can be maintained at close to 60%.

Table 4-5 Daylight Evaluation (Self-drawn by the author)

Daylight		**Score**
Daylight factor(DF) %	DF⩾5	**2.5**
Natural light uniformity factor(Uc)	0.4⩽ Uc < 0.5	**1.5**
Thermal Environment		**Score**
Temperature(℃)	Summer cooling: 25.5 < To ⩽26 Winter heating: 21⩽ To <22	**0.6+0.8**
Relative Humidity(%)	40%⩽ RH ⩽60%	**2**
Indoor Air Quality		**Score**
ppm	600< C_{CO2} ⩽700	**2**
Annual average PM2.5 concentration(μg/m³)	$C_{PM2.5}$ ⩽35	**2**

The scores in the table show that in terms of comfort, the scheme scores 4, 3.4 and 4 in Daylight, Thermal Environment and Indoor Air Quality respectively.

Energy

The building's new walls are constructed using SIPs with a thermal conductivity of approximately 0.14W/m^{2}K, providing good passive performance. 275.7m^2 of solar photovoltaic panels and 99.5m^2 of solar collector panels provide the building's main electricity consumption and the ground source heat pump system is the main indoor temperature control device. The average energy consumption of the building is 41kWh/m^2-a. The building capacity indicator is achieved at 101%, enabling additional power to be supplied to the external grid or to additional electric vehicles.

Table 4-6 Energy Evaluation (Self-drawn by the author)

Energy		**Score**
Energy Demand	20% below guide value	**5**
Ratio of energy supply & demand Rr(%)	Rr ⩾100%	**5**

As the updated design of the project has been calculated to be fully self-sufficient in terms of energy and can even provide additional surplus energy, the scheme scores a perfect 5 out of 5 in both energy categories.

Environment

The building is made of sustainable materials and the carbon emissions are calculated to meet the national guidelines for full cycle carbon emissions (LCA). Level 2 water conservation features are used, with an annual water saving rate of approximately 45%. The use of building materials with the National Green Building Material Label has enabled the new scheme to be designed to meet the carbon emission targets required for green building assessment. As a result, the project received a pass mark of 3 for both Environment Loads and Water Conservation in the Environment score.

Table 4-7 Environment Evaluation (Self-drawn by the author)

Environment		**Score**
Environmental loads	Achieving advanced values	**3**
Water Conservation R_{WR}(%)	$40\% \leqslant R_{WR} < 50\%$	**3**

The final Active House Radar diagram (Figure 4-9) for this project is obtained by combining the results of the project's design scheme on all four scoring items. The project in this paper has finally passed the value assessment of the Active Green Building Standard in terms of design through a comprehensive and complete renovation scheme, and the rationality and feasibility of the design scheme has been certified by more authority.

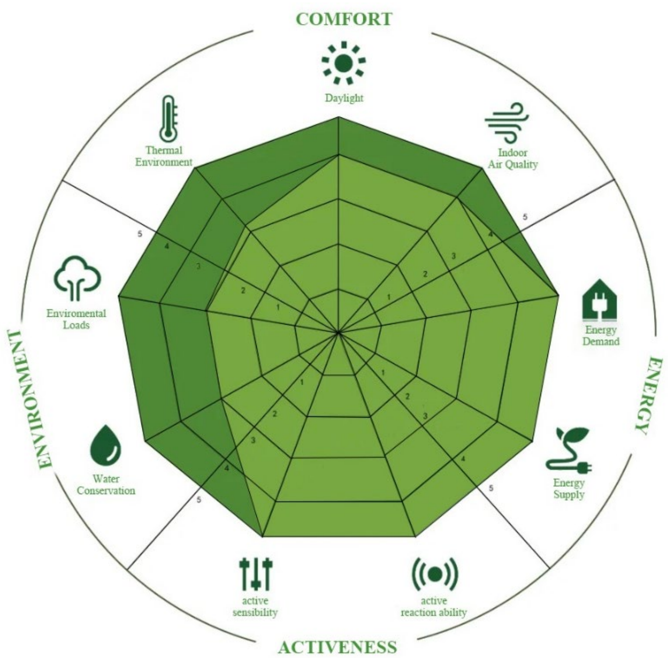


Figure 4-9 Project Active House Radar (Self-drawn by the author)

5 Conclusion

The article discusses in detail the characteristics and problems of contemporary Chinese traditional vernacular architecture in the context of the development of green building technology and from the current situation of sustainable renewal and renovation design of Chinese traditional vernacular architecture. Through analysis and summarisation, the article proposes an operational design strategy.

Using a combination of theory and examples, the article takes a typical timber-framed vernacular house in Quzhou, China, as the object of study, and examines the timber system thoroughly, from the timber material itself to the timber structure system type. structure and the Traverse-bracket frame structure. The article also presents an in-depth study of two typical Chinese traditional timber structures, the Raised-beam frame structure and the Traverse-bracket frame structure.

The article combines the relevant research with the design of a strategy for the renewal and renovation of the studied timber-frame vernacular houses. The proposal redesigned the original timber frame structure as the primary structure of the building, and together with the Structural Insulated Panels as the secondary structure, formed a new load-bearing system for the house. The new load-bearing system of the house was also re-designed with new structural components such as the building envelope, roof, foundation and floor. In the environmental strategies, active building technologies have been incorporated into the design of the house, and the design of the window system, the placement of photovoltaic panels, and the water saving strategies have been carefully considered in terms of lighting, ventilation, energy consumption and water saving.

In the final chapter, the article provides a theoretical assessment of the design strategies for the renovation of traditional vernacular houses in the context of the life cycle assessment and Assessment Standard for Active House. Firstly, the U-value of the building envelope before and after the retrofitting design is compared, and the new envelope is found to be significantly more effective in insulating the building itself. In terms of building energy consumption, the final analysis concluded that the building is theoretically self-sufficient in terms of energy consumption through the collation and calculation of energy consumption-related data. In terms of building ventilation and lighting, the simulated results of the light environment before and after the renovation of the building interior space were compared to clearly visualise the improvement of the building's interior light environment after the renovation design.

The study also presents the Assessment Standard for Active House, which is a value-based assessment of the renovation of traditional Chinese vernacular houses. The results of the theoretical and simulated evaluation prove the rationality and validity of the design strategy, and provide a methodology for future research on the renewal and renovation strategy of a large number of traditional vernacular houses in China.

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7 Acknowledgements

As I write this, my master's studies are coming to an end. I have fantasised countless times about how I would eventually finish this period of study, but at this moment I have suddenly become extraordinarily calm and open.

From the moment I got on the plane to Milan in 2019, I was destined to have an extraordinary study experience. I will always remember swiping my phone on the train back to Milan from the snowfields in early 2020, following the real-time news of the epidemic starting to spread in Italy. After that, like everyone else in the world, I experienced a nightmare of living at home, living in fear and worry every day. Today, as if by some miracle, the epidemic and I are bound together, it has slowly disappeared and I have finally finished my Master's degree.。

I have always felt lucky to have met the right people at the right time in my life. I am sincerely grateful to my supervisor during my final thesis, and also to my mentor at this stage of my life, professor Marco Imperadori. It was his kind and generous hand that pulled me out of the mire of life. I will always remember Professor Marco Imperadori's sincere words of "Forget the past, Shizhe! forward!". Thank you, Professor, for believing in me and for not giving up on me, so that I could have the confidence and courage to come out of the darkness and accomplish my goals.

Thanks to my good friends, PhD. YU Zhongyao and Elizabeth LI, who worked with me on the Active House Project, the time I spent with them on the design and research was my initial knowledge and study of the final thesis topic. It was with their help that I was able to research my project so smoothly and thoroughly.

I am grateful to DouDou for calling me on the phone every night to keep me company, for her encouragement and confidence in my ability to complete the article successfully, and for her constant urging to speed up my progress and improve my efficiency. Without her supervision, I might not have been able to complete the study. I had a celebratory cup of milk tea when I finished.

Thank you to ZZ, MaoMao and QingQing for talking to me when I was stressed out and had nowhere else to go. No matter how late it was, no matter how depressed I was, no matter how busy I was, they never turned me down, they stayed with me in my treatment, they stayed with me to adjust myself, and they stayed with me step by step towards graduation.

Last but not least, I cannot leave Politecnico without mentioning the staff of School Office, Who worked really hard to solve problems as soon as possible for students like me.

8 Appendix

This section contains a section of drawings on the project design scheme that have not been studied in the previous sections of the article and is added as an appendix at the end of the article.

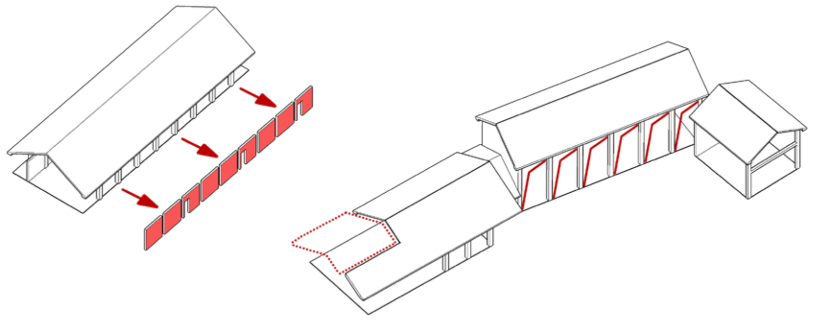
Overall Look of the Project

Supervisor:
Prof. Eng. Marco IMPERADORI

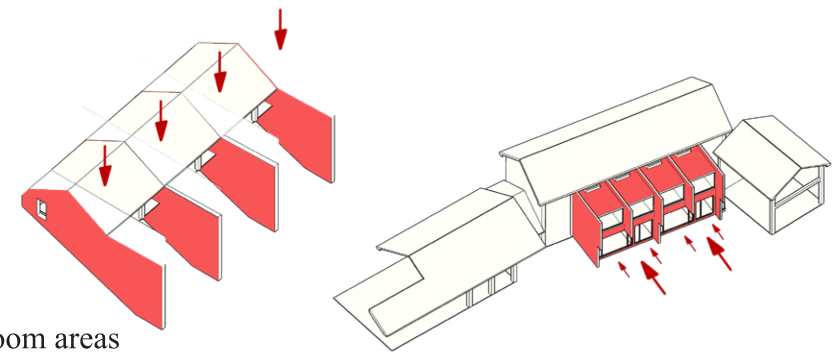
Candidate:
Shizhe LIU

Appendix

Architectural derivation

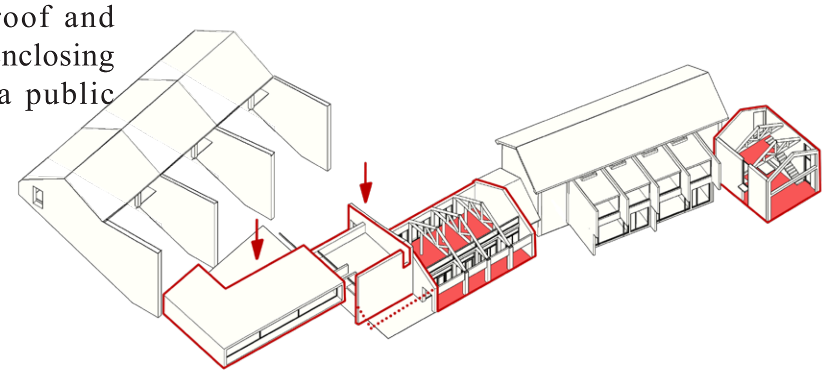


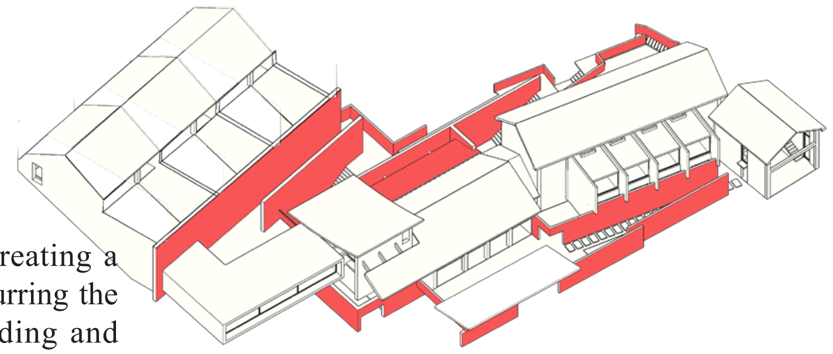
A.Removal of building envelope walls and clearance of collapsed roof



B. Selection of guest room areas and division of house space

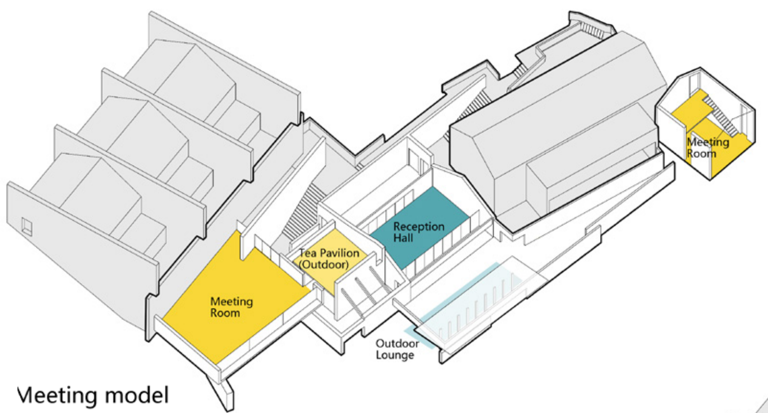
C. Completion of the collapsed roof and insertion of the connecting blocks.Enclosing the remaining building to create a public function





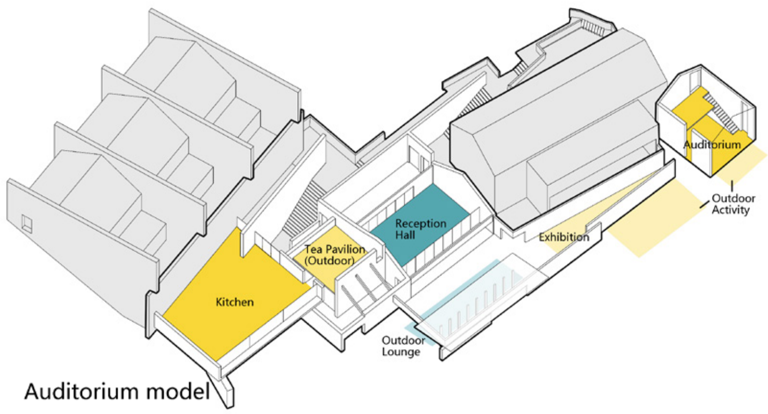
D. Adding outdoor space, creating a multiplicity of places and blurring the transition between the building and its external environment in a gradual manner

Variable space analysis



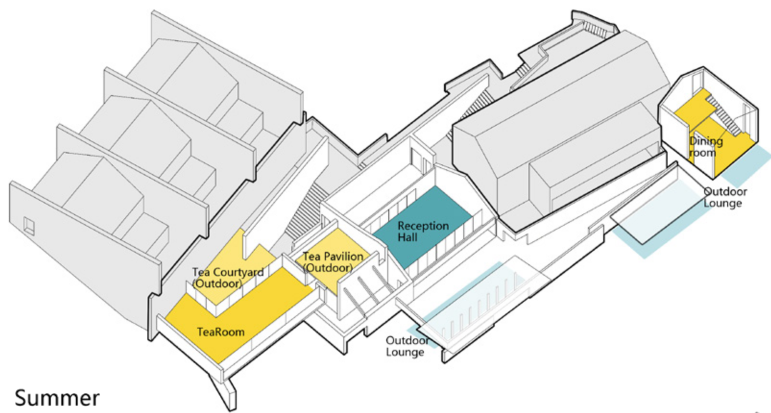
Meeting model

Indoor public spaces can be used as meeting rooms where the meeting mode demands, while outdoor open spaces can also provide a secondary function.



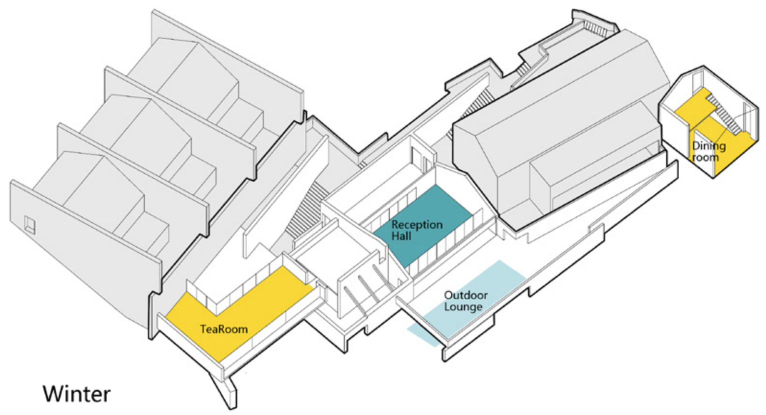
Auditorium model

With the needs of the auditorium model, the indoor public space provides a variety of functions such as a restaurant and auditorium, while providing more space for outdoor activities.



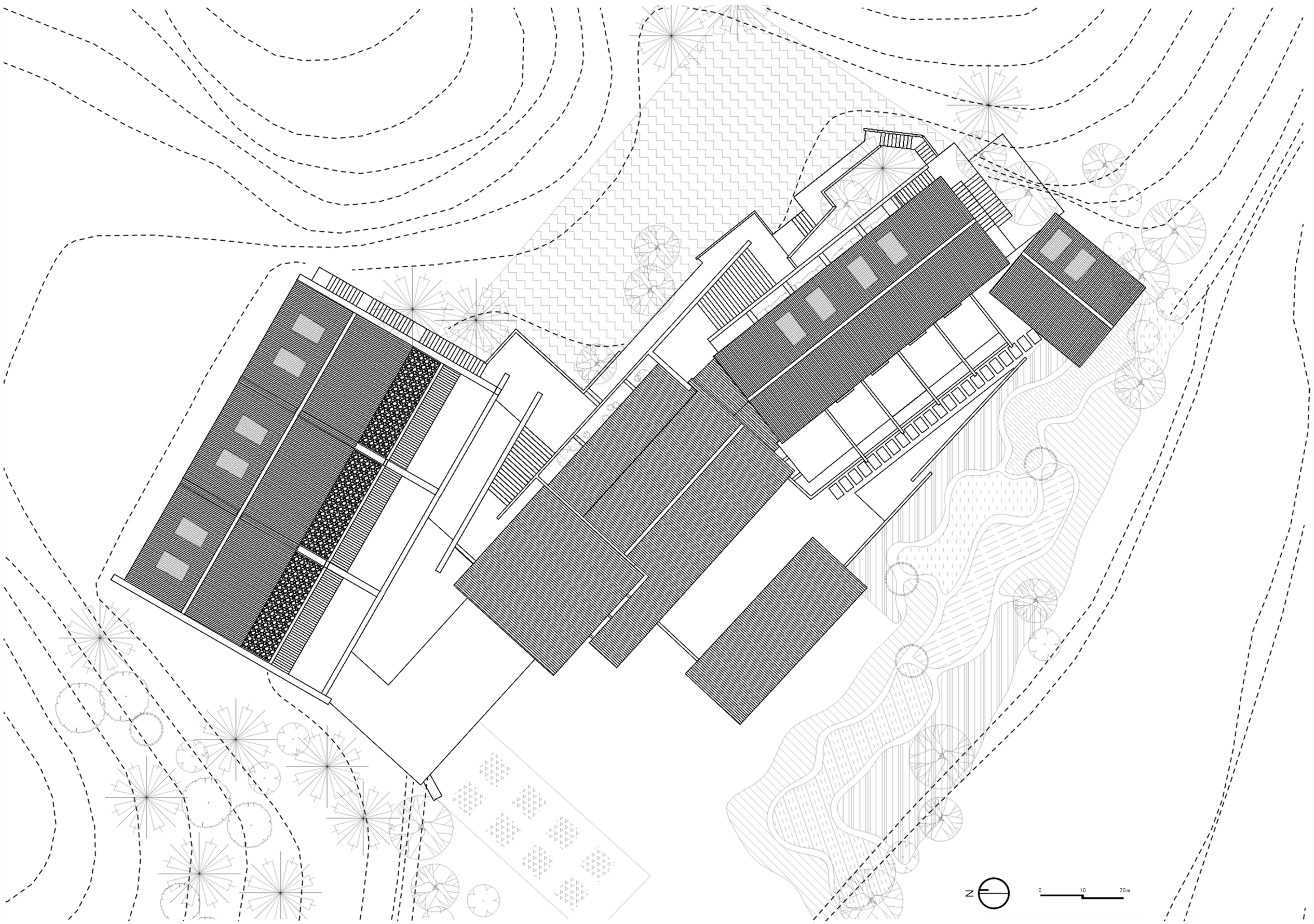
Summer

In summer the main use spaces are extended to the outdoors, adding a richer outdoor activity area.



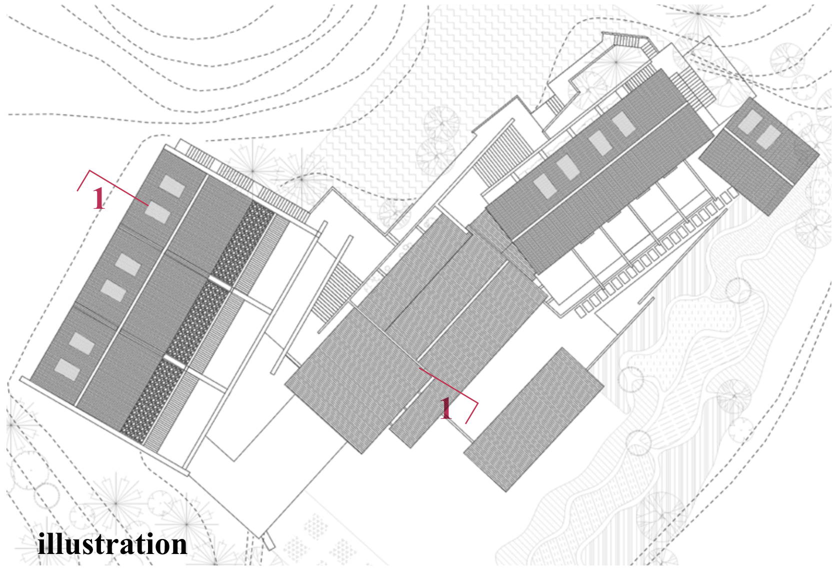
Winter

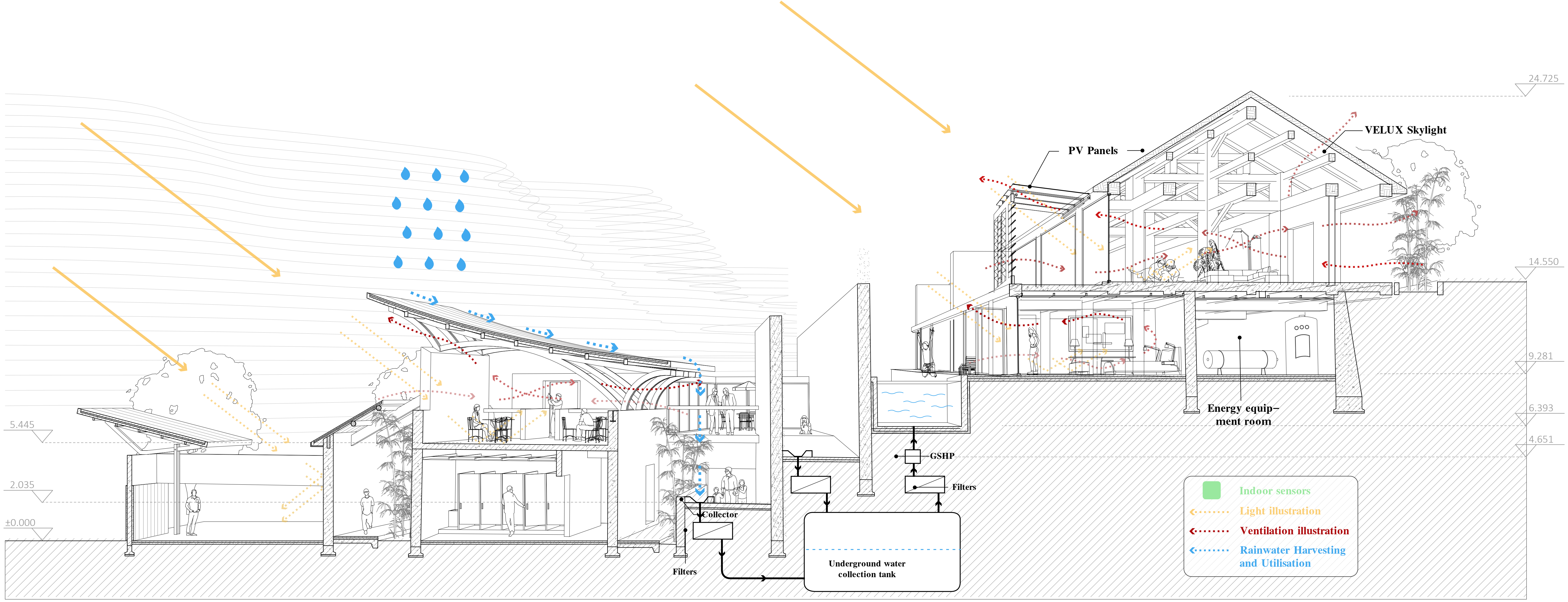
The comfort of using indoor spaces is ensured in winter by reducing the connection between indoor and outdoor spaces.


N
0
10
20m

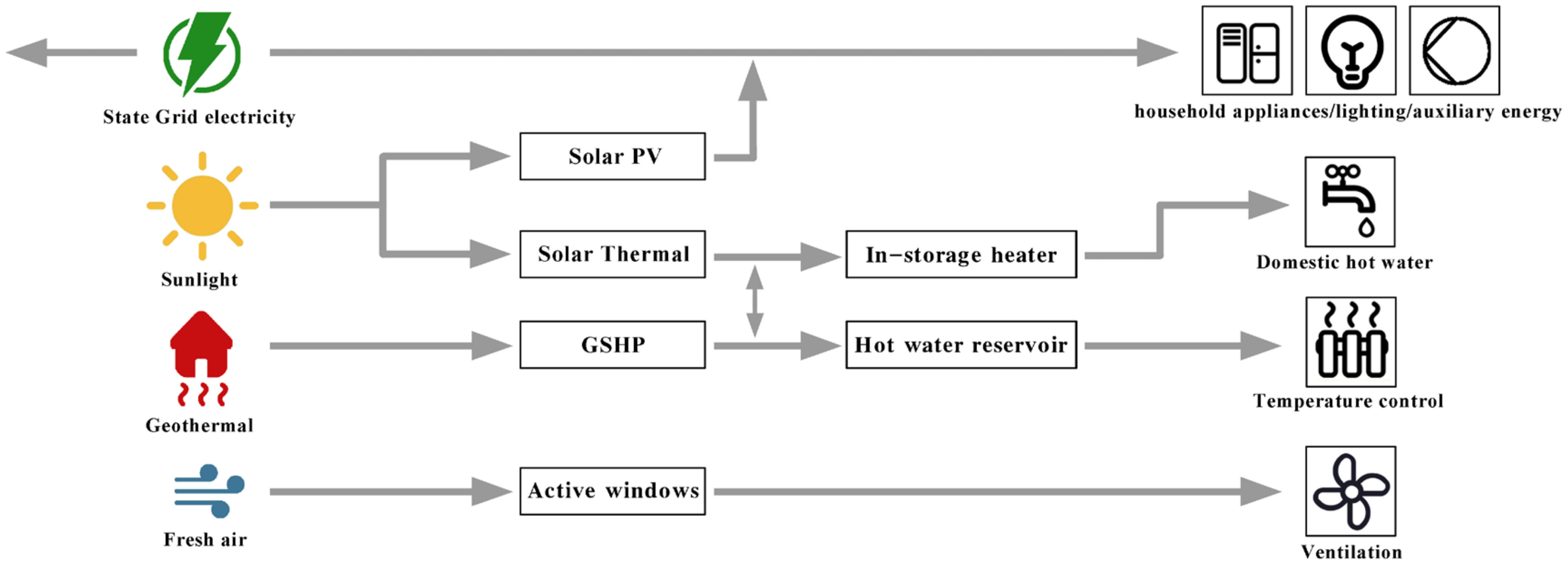

1
2
3
4
5
6
7
1 Front desk office
2 Guest room (room type 1)
3 Guest room (room type 2)
4 Guest room (room type 3)
5 Service room
6 Function room
7 Bathroom
N
0
10
20 m

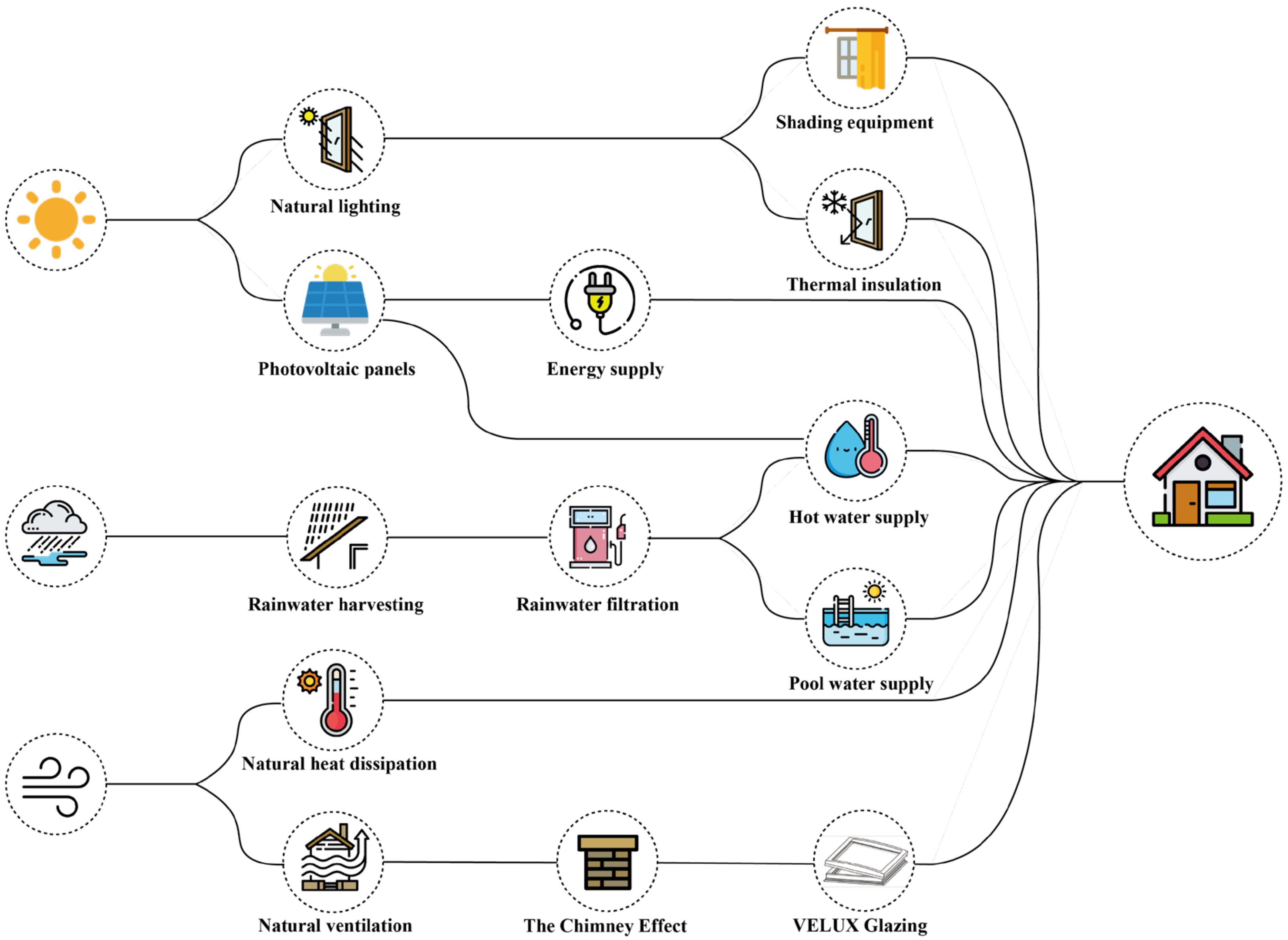

5
6
2
3
9
4
10
8
2 Guest room (room type 1)
3 Guest room (room type 2)
4 Guest room (room type 3)
5 Service room
6 Function room
8 Tea Room Restaurant
9 Outdoor Tea Room Restaurant
10 Relaxation space
N
0
10
20 m

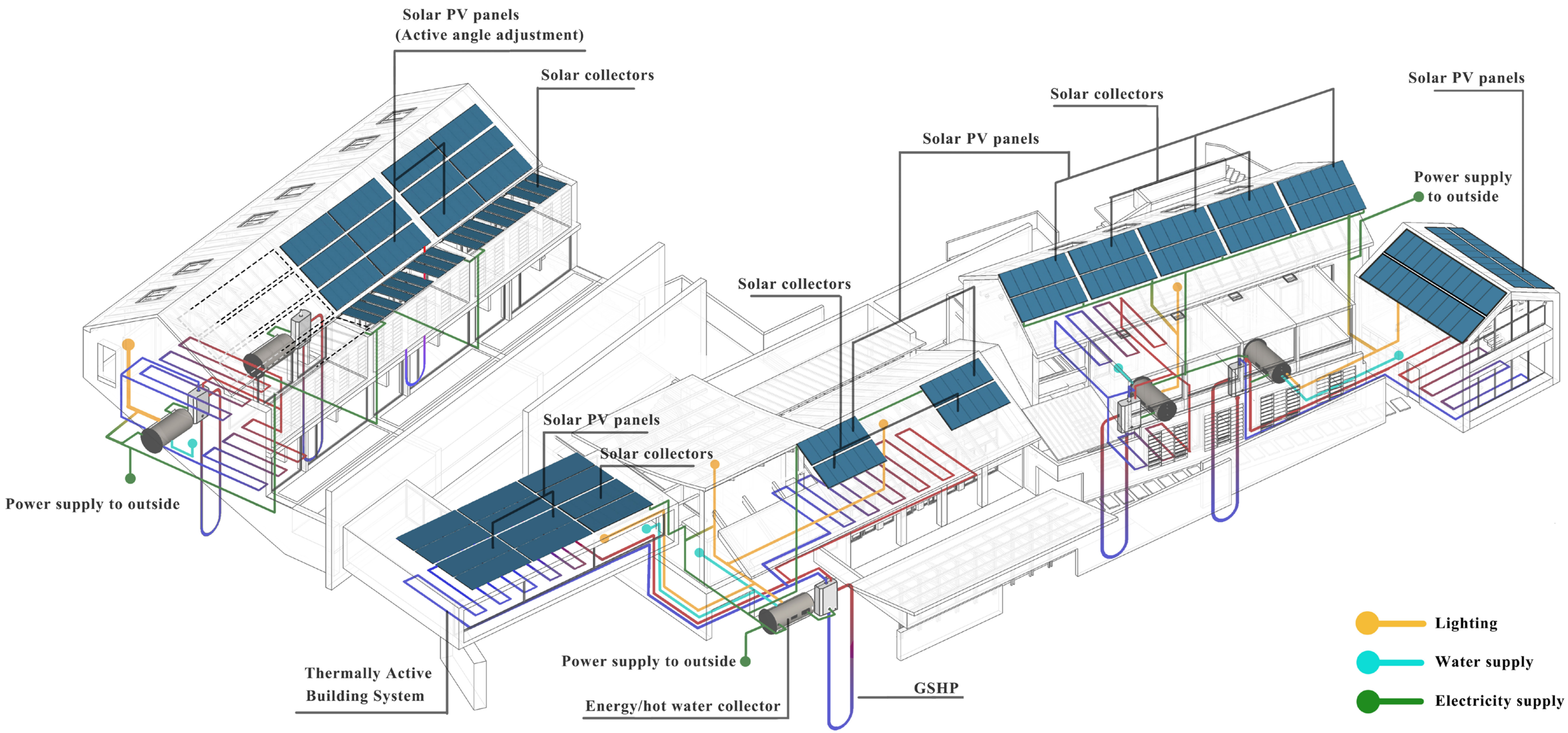

1
1
illustration


24.725
VELUX Skylight
PV Panels
14.550
9.281
6.393
4.651
5.445
2.035
±0.000
Energy equip-
ment room
GSHP
Filters
Collector
Filters
Underground water
collection tank
Indoor sensors
Light illustration
Ventilation illustration
Rainwater Harvesting
and Utilisation

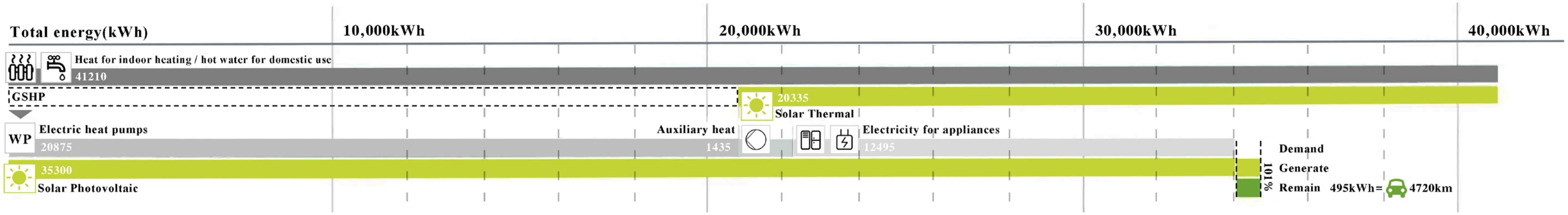
Section 1-1


State Grid electricity
household appliances/lighting/auxiliary energy
Solar PV
Sunlight
Solar Thermal
In−storage heater
Domestic hot water
Geothermal
GSHP
Hot water reservoir
Temperature control
Fresh air
Active windows
Ventilation


Shading equipment
Natural lighting
Thermal insulation
Photovoltaic panels
Energy supply
Hot water supply
Rainwater harvesting
Rainwater filtration
Pool water supply
Natural heat dissipation
Natural ventilation
The Chimney Effect
VELUX Glazing



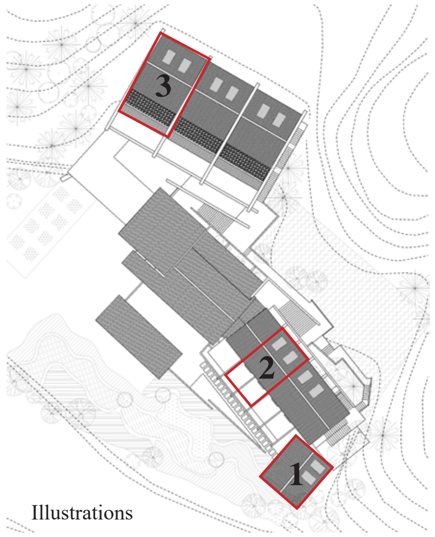
Solar PV panels
(Active angle adjustment)
Solar collectors
Solar collectors
Solar PV panels
Solar PV panels
Power supply
to outside
Solar collectors
Solar PV panels
Solar collectors
Power supply to outside
Thermally Active
Building System
Power supply to outside
Energy/hot water collector
GSHP
Lighting
Water supply
Electricity supply



Total energy(kWh)
10,000kWh
20,000kWh
30,000kWh
40,000kWh
Heat for indoor heating / hot water for domestic use
41210
GSHP
20335
Solar Thermal
WP
Electric heat pumps
20875
Auxiliary heat
1435
Electricity for appliances
12495
35300
Solar Photovoltaic
Demand
Generate
Remain 495kWh= 4720km
101%

Appendix

Natural light simulation of main spaces



Room 1:
The multi-purpose room has large glass windows facing south, so fixed trial shades must be used to reduce direct sunlight. At the same time, to ensure that the interior is evenly and suitably lit, a skylight is opened at the top in the south-east to help light the interior space. The lighting reaches a maximum of 3000lux at the summer solstice and an average of 1000lux at the winter solstice.

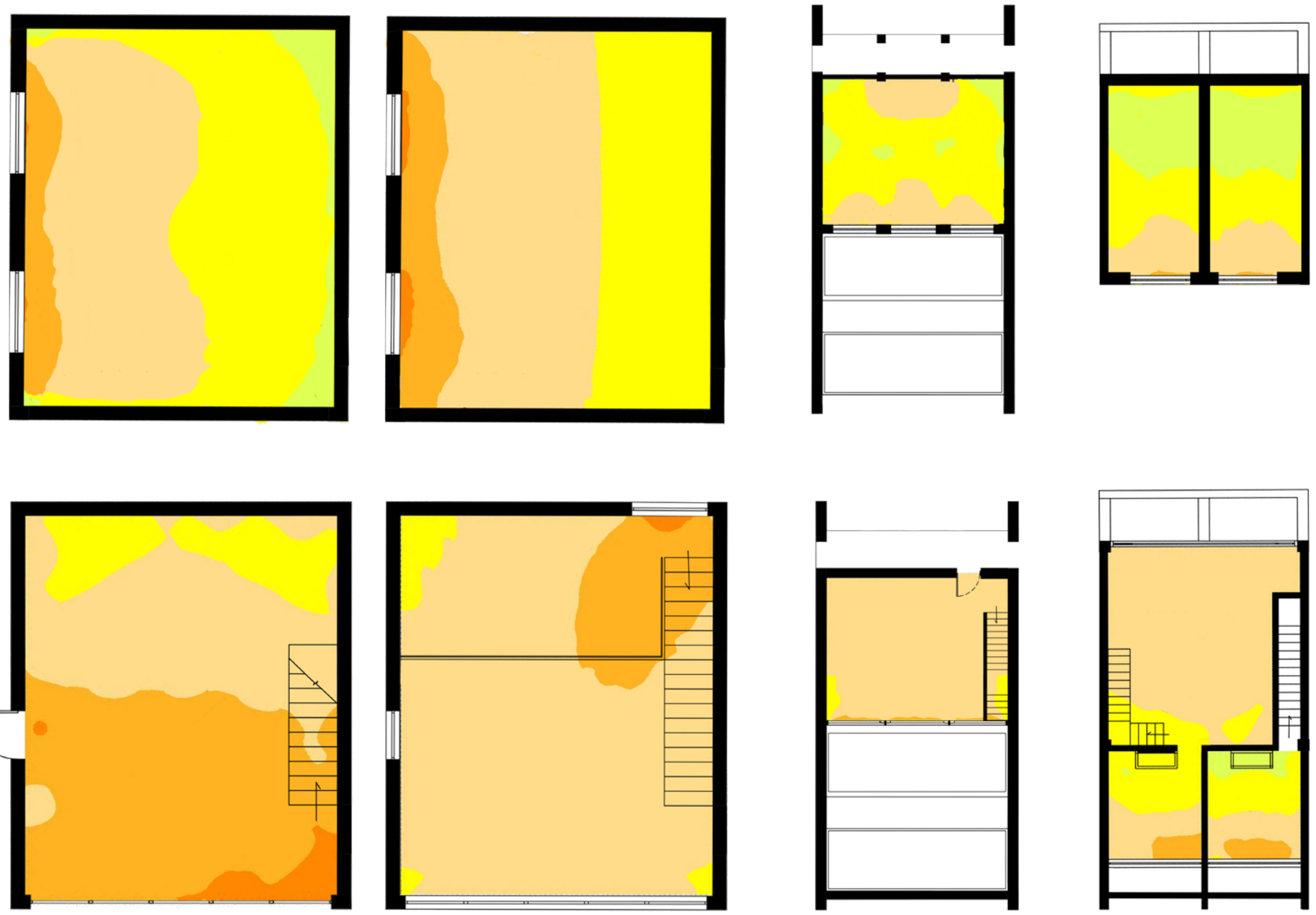
Room 2:
The small B&B, with its grille on the front side enclosure and sunshade curtains, reaches a maximum of 1000lux at summer solstice, with more even light.

Room 3:
The villa B&B rooms are the most evenly lit due to the retaining wall on the front side of the room, and the values are maintained within a reasonable range to meet the needs of people's daily activities.

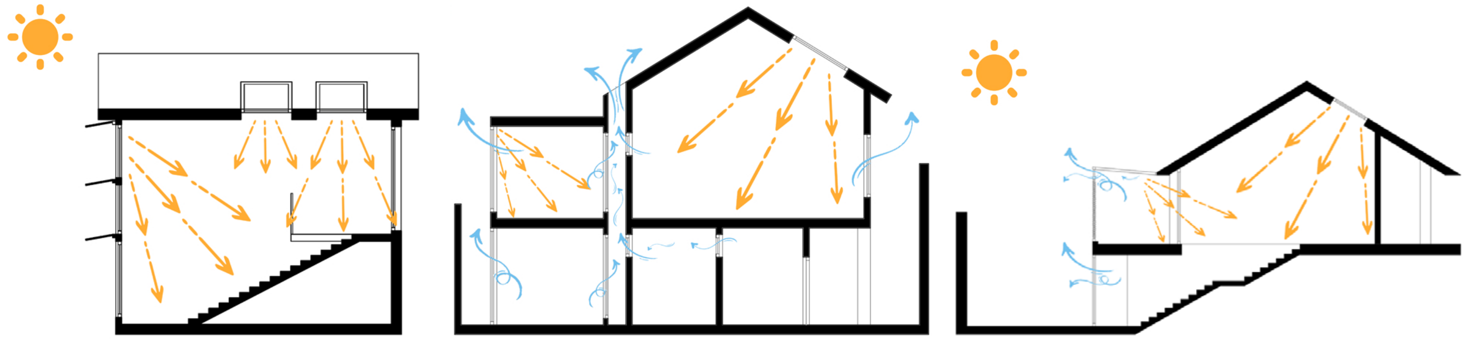
ROOM 1 1F | ROOM1 2F | ROOM 2 | ROOM 3

Before

After



Light & ventilation of main spaces



ROOM 1 2F | ROOM 2 | ROOM 3

Renders of scenes