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Fenhuangzhen - A case of retrofitting in an heritage site in China

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ABSTRACT

Il patrimonio architettonico mondiale è responsabile per il 40% circa delle emissioni dei gas effetto serra, il 28% di questo totale rappresenta le emissioni dovute a tutte le operazioni necessarie per il funzionamento dell'edificio (riscaldamento, raffrescamento, produzione di acqua calda sanitaria, illuminazione ed elettrodomestici), mentre la produzione dei materiali (energia grigia) e la costruzione degli edifici sono imputabili per un'ulteriore 12%.
Senza una diffusione a larga scala di operazioni di decarbonizzazione per gli edifici esistenti non sarà possibile raggiungere il tetto massimo di 1.5 °C di innalzamento delle temperature definito durante l'accordo di Parigi ed il recente COP26.

Per ridurre le emissioni da parte degli edifici esistente, è necessario intervenire su diversi fronti, in modo da accelerare il tasso di miglioramenti energetici, ad es. l'aumento dell'efficienza energetica, l'eliminazione dell'utilizzo di combustibili fossili e favorire la produzione e/o il consumo di energia proveniente da fonti rinnovabili.

L'obiettivo di questo elaborato di tesi è quindi l'esplorazione e lo studio delle possibilità di ridurre le emissioni di Gas effetto serra da parte del tessuto urbano di Fenhuang, città cinese dichiarata come Patrimonio Culturale.

Lo studio effettuato dall'autore si comporrà da diverse fasi:
- L'analisi della città, dove l'autore, studierà il tessuto urbano, le sue peculiarità e le caratteristiche delle diverse tipologie presenti
- La definizione di un set di regole, basate sull'importanza storica dei diversi manufatti presenti sul suolo della città, cercando di regolare i futuri interventi, fornendo protezione alle più importanti caratteristiche urbane e architettoniche della città.
- Il progetto di un Centro Culturale, in modo

The building sector is accountable for the 40% of global annual GHG (Green House Gas) emissions. Of those total emissions, building operations (related to heating, cooling, DHW and lighting and appliances) are responsible for 28% annually, while building materials and construction (related to embodied energy) are responsible for an additional 12% annually. Without widespread existing building decarbonization across the globe, it is not possible to achieve the Paris Agreement and recent COP26 accord of 1.5°C target.

Achieving zero emissions from the existing building stock will require leveraging building intervention points to accelerate the rate of energy upgrades e.g. increasing energy efficiency, eliminating on-site fossil fuels, and generating and/or procuring 100% renewable energy.

In order to increase the energy efficiency, it is mandatory to find new active or passive solutions capable of: reducing the energy consumption, reducing the energy cost of the materials, selecting whenever possible, local natural materials - or suitably compatible and optimization of the heating and cooling supply solutions.

The main objective of the present thesis is to explore and study the possibilities to reduce the GHG emissions in Fenhuang Town, that has been declared as a Cultural Heritage Site by the Chinese Government. The methodology used for this purpose is based on 'Integrated Design Procedure'.

This study regarding Fenhuang town follows different phases:

- The city analysis consisting of study on the urban fabric, its peculiarities, and the characteristics of the different building typologies.

- The definition of a set of rules based on the heritage values of the different buildings for the

da studiare l'applicazione delle varie tecniche di retrofitting ed i benefici che possono essere apportati in un contesto misto di strutture esistenti e nuove

- Il progetto di una nuova Courtyard che dovrà risultare coerente con il tessuto urbano, pur utilizzando un linguaggio diverso, questo nuovo edificio inoltre servirà come modello per la progettazione di nuovi edifici lungo la strada storica
- L'intervento su un edificio protetto in modo da capire quali sono gli interventi di retrofitting possibili, mantenendo intatti i caratteri importanti di questa tipologia

Per effettuare tutte le simulazioni è fondamentale, progettare e creare un modello parametrico in grado di valutare il comportamento degli edifici nelle diverse condizioni climatiche (estive, invernali e durante le mezze stagioni) che si possono presentare durante l'anno.
Grazie a queste simulazioni, inoltre, è stato possibile valutare l'influenza delle varie operazioni di ottimizzazione delle stratigrafie, della definizione dei diversi setpoint per le temperature interne e successivamente, la progettazione di metodi di produzione di energia a partire da fonti di energia rinnovabili per mantenere le condizioni di comfort all'interno dell'edificio.

Gli interventi sull'involucro dell'edificio e la progettazione di soluzioni ad hoc, rendono possibile ai progettisti di ridurre il consumo di energia e di conseguenza le emissioni dei gas effetto serra del 60%, come dimostrato dal presente elaborato.

regulation of the future interventions, providing protection to the most important characteristics of the town.

- The design of a Cultural Center to study the possible applications of the retrofitting techniques and its benefits on existing structures and new ones.

- The design of a new Courtyard, coherent to the urban fabric, with the subsequent analysis of the building energy consumption.

- The intervention on an existing structure belonging to the heritage protected buildings, to explore the possibilities to create the comfort conditions in this particular typology.

The design and creation of a parametric model is fundamental to evaluate the energy behaviour of the different buildings in the different seasonal conditions (summer, winter, and mid seasons) during the year. With the different simulations, it was possible to evaluate the improvement of the energy demand through envelope improvement, the setpoints optimizations and subsequently, the energy supply through the design of low and energy efficient technologies and renewable energy systems (RES), to maintain the comfort conditions inside the building.

The intervention on the envelope of a building and the creation of tailored solutions allows the designers to reduce the energy consumption, therefore the GHG emissions by 60%, as demonstrated through the present study.

2

INTRODU

2.1 THE ATMOSPHERIC POLLUTION

THE DEFINITION OF ATMOSPHERE

The air, or better said, the atmosphere of Earth, is a heterogeneous mixture of different gases and particles that are retained by Earth's gravity, that surround the whole planet Earth.

Is essential for the existence of life on the planet, since it protects the earth from the ultraviolet solar radiation, warms the Earth's surface through heat retention, mitigates the difference in temperature between day and night and creating pressure allows to water to exists in its liquid form.

Earth's atmosphere composition has changed much since its formation, in the beginning it was composed primarily by hydrogen, but it has changed drastically during time, 2.4 billion years ago, as an example, the levels of oxygen greatly increased to values close to the present day.

The current composition (**Fig. 2.1**) is made by the 78% of Nitrogen, 21% Oxygen, 0.96% Argon and the remaining 0.04% of Carbon Dioxide, with this mixture of gas we can also find, the presence of solid particles in suspension that are called "atmospheric dust" (W. M. Haynes, 2016).

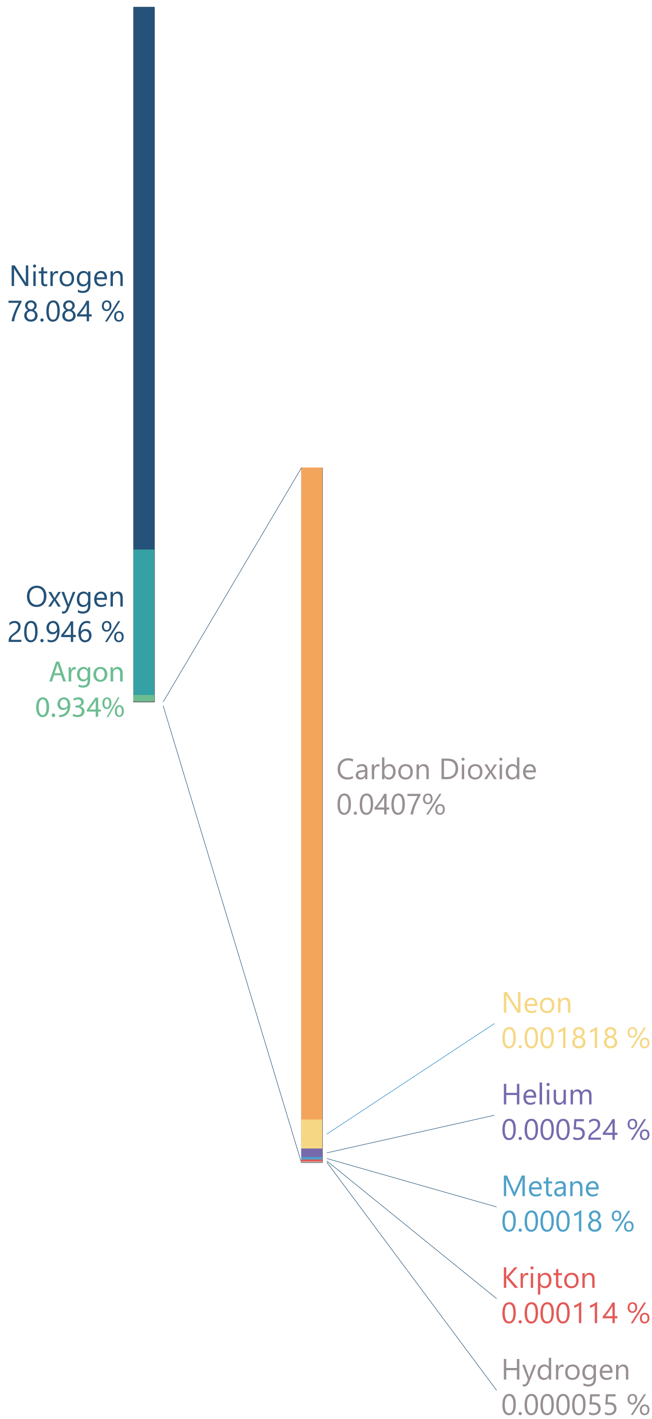


Fig.2.1
Contemporary composition of the Earth's atmosphere

AIR POLLUTION

Air pollution, or atmospheric pollution, can be defined as the presence of substances in the atmosphere, that can harm health of humans and other living beings, or that can cause damage to climate, habitats, materials.

Air pollution is considered as one of the world's worst toxic pollution problems by the Blacksmith Institute, it causes the death of around 7 million people worldwide each year (World Health Organization, 2014).

Productivity losses and degraded quality of life caused by air pollution are estimated to cost the world economy around 5 trillion $ per year (World Bank, Institute for Health Metrics and Evaluation at University of Washington, 2016).

CAUSES

There are two main sources related to air pollution:

- Anthropogenic sources (**Fig 2.2**): the combustion of any kind of fuel (transport, factories, raw materials extraction, controlled burn practices), fumes derived from paint, hairspray, aerosols sprays and other solvents, waste deposition in landfills, military resources, fertilized farmland, intensive animal agriculture.

- Natural sources: Dust from natural sources, methane emitted by the digestion of food by animals, Raddon, wildfires, volcanic activity

In the last 200 years the levels of emissions, coming from natural sources have been stable and constant during the time, but since the industrial revolution, the levels of emissions originated from anthropogenic sources have been increasing drastically.

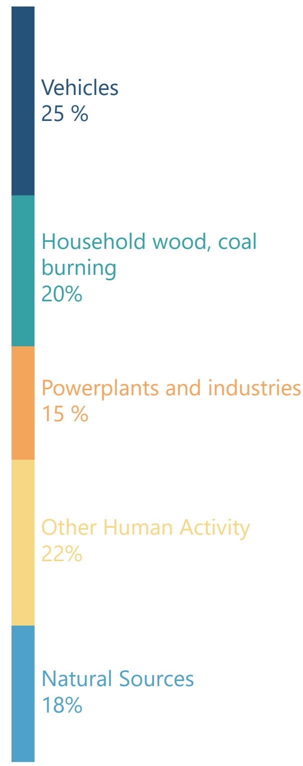


Fig. 2.2
Principal sources of pollution (Vattenfall, 2009)

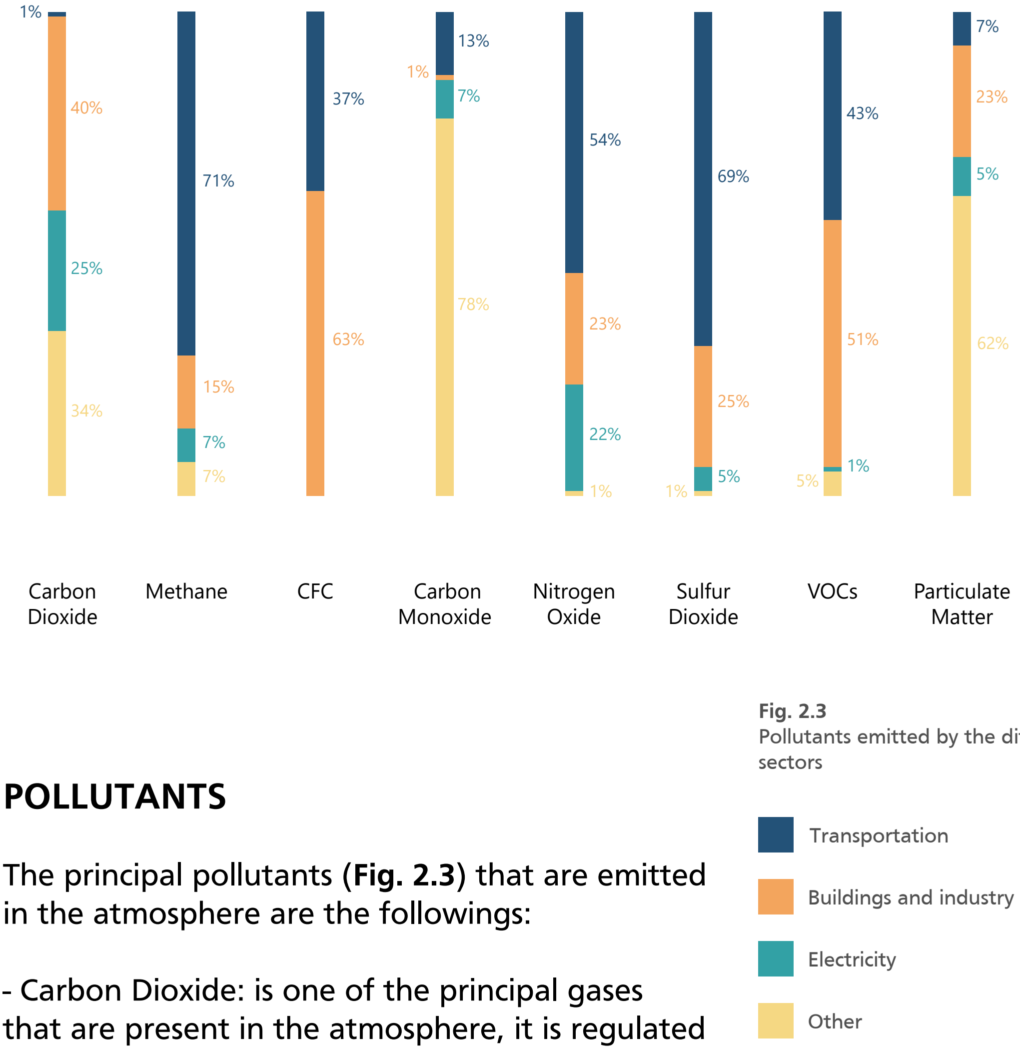


Fig. 2.3
Pollutants emitted by the different sectors

POLLUTANTS

The principal pollutants (**Fig. 2.3**) that are emitted in the atmosphere are the followings:

- Carbon Dioxide: is one of the principal gases that are present in the atmosphere, it is regulated by the "carbon cycle" and can be re-absorbed from vegetation and water. This cycle can be destabilized by the emission of excessive amounts of Carbon Dioxide, that can't be absorbed, the excess remains in the atmosphere causing the Green House Effect.

- Methane: This gas is often present in nature; it has his origins in the decomposition of vegetation.

- CFC: They consist in chemical products derived entirely from human activity.
- Ozone: This gas is not produced from human activity but is generated as a product of a chemical reaction

- Carbon Monoxide: It is created when the carbon inside the fossil fuels is not completely combusted.
- Nitrogen Oxides: these pollutants are generated with the combustion of fossil fuels, the generation of electricity, the heating of buildings and industrial processes

- Sulfur Dioxide: it is created during the combustion of coal and oil

- Particulate matter: this is the most frequent pollutant in the urban areas, these are tiny particles of solid or liquid suspended in a gas. Some of them occur naturally, as dust storms, volcanoes particles, fires, and sea sprays. Also, human activities can generate them burning fossil fuels in vehicles, power plants and various industrial processes.

-VOC: These gases have an important contribution in the greenhouse effect since they prolong the life of methane in the atmosphere and create ozone.

EFFECTS

All the substances that were mentioned, have serious impact over the environment and on the health of every living being:

- Greenhouse Effect: it is defined as the overheating of the inferior layers of the atmosphere, the greenhouse effect gases block inside these layers the infrared radiation, that warms up the Earth's surface. Global warming (**Fig. 2.4**), through its impact on ecology, rainfall, temperature, and weather systems, directly affect the whole world.

It is well known that the average temperature is raising around 0.2 °C each decade, and that since the beginning of the industrial era it has increased

Fig. 2.4
Effects of global warming as described by IPCC, 2007

by 0.7 °C. The threshold, before catastrophic consequences, is calculated to be 2°C. In order to stabilize the greenhouse gas levels, annual emissions have to be reduced by more than 80%.
- Acid rain: The presence of CO_2, Sulfur Dioxide SO_2 and various Nitrogen Oxides, create Sulfuric Acid H_2SO_4, that causes an acidification of the precipitations. This acid rain has different effects on the environment. It can corrode the surfaces influenced by the precipitations, it can damage the vegetation and the leaves, creating problem to the Photosynthesis and it could kill the bacteria that are necessary to the decomposition of the organic substances with the consequent deposit of toxic matter on the seabed

- Ozone depletion: It’s defined as the reduction of the Ozone Stratospheric Layer, that reduces the filter effect from Ultraviolet Radiation of the Ozonosphere hence the increase of the radiation that reaches the Earth’s surface. These radiations are harmful to the living beings

2.2 BUILDINGS, ENERGY CONSUMPTION AND EMISSIONS

The building construction sector and architecture, as expressed by the Global Alliance for Building and Construction, is responsible for the 35% of global total final energy consumption and for the 38% of energy-related CO_2 emissions into the atmosphere. (Global Alliance for Buildings and Construction, 2020)

Buildings have a long-life time, for this reason the building sector is an enormous issue in terms of sustainability.
During the whole lifecycle of a building energy is consumed for different purposes. (**Fig. 2.5**)
In the beginning, the used construction material has embodied energy since it is necessary to extract and manufacture raw materials.
In a second phase, energy is consumed during the construction of the building as all the equipment (heavy machineries, pumps, crane) need energy for their operation. Then the operational energy needed for different energy uses (e.g. space heating, cooling, DHW production, artificial lightning and appliances). In the end, when the lifecycle is finished energy is going to be needed for the demolition and the remotion of the debris.
According to IPCC report, the building sector has the largest potential for reducing the GHG emissions, around 30% in 2030.

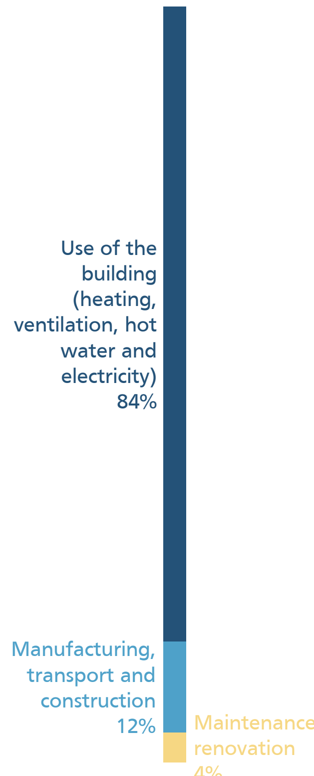


Fig. 2.5
Life cycle energy distribution of a building project (World Business Council for Sustainable Development, 2010)

Fig. 2.6
Inputs and Outputs of a building project

EMBODIED ENERGY

Building sector has been a part of the booming industries in the last century. In the developed countries, the biggest part of the energy is used in the maintenance of the existing building, whereas in the developing countries more energy is spent in construction and development.
At the base of the modern building construction sector, we can find materials such as steel, cement, and glass. These materials have a high embodied energy, equal to the sum of all the energy inputs during all stages of their life cycle. (**Fig. 2.7**)
Steel has an embodied energy that is 24 times higher than wood, while the energy embodied in aluminum is still higher, reaching enormously about 124 times.
Architecture and the building sector are responsible for the consumption of the 50% of the extracted materials in the world. (Krausmann et al, 2018)

Wood	640 kWh/ton
Brick	4x Wood kWh/ton
Concrete	5x Wood kWh/ton
Plastic	6x Wood kWh/ton
Glass	14x Wood kWh/ton
Steel	24x Wood kWh/ton
Aluminum	124x Wood kWh/ton

Fig. 2.7
Energy embodied into construction materials (values referred to wood) (UNHABITAT, 2016)

OPERATIONAL ENERGY

During the lifespan of a building, energy is consumed for different end uses. The residential and commercial sectors alone, account for the 40% of the total energy use worldwide. (Global Alliance for Building and Construction, 2020)

The International Energy Agency estimates that energy demand in building will be stimulating half of energy supply investments in 2030, in developed countries. (IEA 2006)

The biggest quantity of energy is used either for cooling or heating of spaces. In 2005, 67% of the domestic energy consumption in EU was for heating purposes, while it was the 40% in China's urban areas. (UNHabitat, Sustainable Urban Energy: A sourcebook for Asia, 2016)

2.3 ENERGY EFFICIENT SOLUTIONS FOR THE BUILDING SECTOR

The IPCC (2007) report, sustains that, among various sectors, the buildings sector has the largest potential to reduce the GHG emissions, up to 30% by 2030.

There are different ways to improve energy efficiency of existing and new buildings. For existing buildings, energy retrofitting, opaque and transparent envelope components with high efficiency models can provide a significant reduce in energy consumption.
While for the new constructions, it is possible to design them differently, considering the energy saving possibilities since the early design phase (low energy materials, passive solutions for heating and cooling etc.), then the use of smart and energy efficient appliances, waste-heat recovery system, renewable energy installations, energy efficient lightning technologies.

The cost of implementing energy efficient technologies is estimated to be 3-5 higher than conventional buildings (UNHabitat, Sustainable Urban Energy: A sourcebook for Asia, 2016), but the reduction in energy consumption, carbon emissions and financial savings can be substantial. The buildings can be designed to become centers of prosumption, where the energy produced continuously exchanged with the national or local grids. In these buildings it could be possible to integrate solutions to harvest rainwater, for the conversion of bio-degradable waste into biogas or organic compost, it could be possible also to introduce the production of a small percentage of the food demand as one the project themes.

PASSIVE SOLUTIONS

Efficient energy solutions can start in the early design phase of a building, thereby adapting its shapes, construction materials to the climatic conditions of the building site

The selection of the materials is crucial, since the only construction of the buildings is responsible for the 11% of the global emissions of CO_2. The development of efficient technologies for the envelope can reduce noticeably the final energy consumption, since it represents the barriers that allow the internal ambient to maintain comfortable conditions for living, since it reduces the energy dispersion, hence the necessity of active heating or cooling.
Following bioclimatic principles is possible to reduce the energy consumption, thereby analyzing and evaluating the sun movement, wind direction and speed and all the other climatic parameters to improve natural ventilation and lighting. Also, the vegetation could be a strong ally in passive shadowing.

ACTIVE SOLUTIONS

Active solutions can be used, as well, for the energy consumption reduction, using efficient heating and cooling technologies, mechanical ventilation systems with heat recovery, low energy technologies like geothermal heat pumps and photovoltaic systems for electricity generation. Equally important is the usage of low energy appliances, as fridges, kitchens, and all sort of electro domestics, since it can potentially reduce the electricity consumption up to 76% during the year (G energetic class is rated over 781 kWh/year while A++ is rated to consume less than 188 kWh/year)

RETROFITTING

The term of retrofitting describes an action of *modification* over a system, that was created in the past, to modify its elements or insert new ones to obtain a *new version* capable to respond to the necessities of the present.

The term in architecture identifies a series of regenerative interventions of the existing urban fabric, one of the first goals is the sustainability both economic and energetic.

The retrofitting operations are applied to the key elements of the buildings, such as walls, roofs, doors, windows, floors, lighting, AC design, renewable energy system, water heating and conservations and electricity management.

All these processes must be balanced, since each intervention could affect another element:

Fox example an excessive sealed building can be a cause of condensation problems, the insulation of a roof without proper ventilation can cause the deterioration of the timber structure.

3.1 GIATLA HOUSE

The Giatla house (**Fig. 3.2**) is a 300-years old farmhouse, in Innervillgraten, Austria, it has been neglected over the years and the conditions of the whole house were terrible.
The structure of the building was failing, it was at risk to slide down the slope where is located.

The house is a located in the middle of a complex of 8 houses. It was built in 1682, but then expanded in the 1865.

In order to proceed with the renovation, it was necessary to understand, which elements should have been protected and preserved, in this case, the building proportions, the roof with clapboards, and the original windows and glazing.

During the retrofitting project it was decided to strengthen and stabilize the foundation slabs, other than that there was an intervention on the existing envelope to improve the thermal quality, before the application of the new systems for heating and cooling.

ENVELOPE

The original envelope, consisted in a single layer of 120 mm of wood, with a thermal transmittance of 1.20 W/m^2K. This kind of layers was not suitable for a sustainable restoration, so to solve the problem, the external material was maintained and a "second wall" was built inside the building, lowering the U-value to 0.35 W/m^2K. (**Fig. 3.1**)

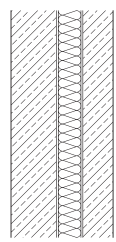


Fig. 3.1
Wall stratigraphy layers (from the outermost to the innermost)

1. Original wood block (120 mm)
2. Wind barrier
3. Natural Sheep Wool insulation (60 mm)
4. Vapor barrier
5. Wood block (80 mm)

Fig. 3.2
Photo of the Giatla House after the restoration

Natural sheep wool was used as insulation material, while a new wood, facade was built and used as interior finish (80 mm).
With this kind of intervention is possible to maintain and blend the original structure to the new one.

GROUND FLOOR

The existing ground floor was composed by a wood structure, that was just raised from the ground with studs.
To create a structure that allowed to the floor heating to be fully utilized, a new ground floor was laid, bringing the U-value from 2.8 to 0.17 W/ m^2K. (**Fig. 3.3**)

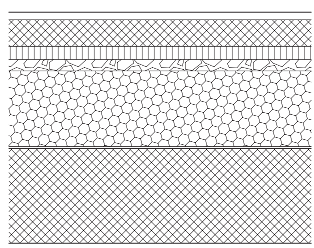


Fig. 3.3
Ground Floor stratigraphy layers (from the outermost to the inner-most)

1. Concrete slab (250 mm)
2. Bitominous sheat (4 mm)
3. EPS insulation (200 mm)
4. Perlite (30 mm)
5. Anti-impact insulator (35 mm)
6. Lightweight screed (70 mm)
7. Wood finish (20 mm)

ROOF

It was not possible to maintain the original roof, it was built from scratch in the traditional method, with the insertion of layers of insulating material whenever a heated space was below it.
The original U-value of the roof was 2.8 W/m^{2}K, while after the restoration it reached the value of 0.11 W/m^{2}K. (**Fig. 3.4**)

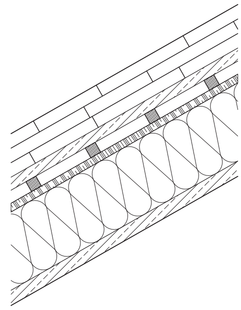


Fig. 3.4
Roof stratigraphy
(From the outermost to innermost)

1. Triple layer of wood shingles (100 mm)
2. Wood planks (30 mm)
3. Wood studs (30 mm)
4. OSB board (20 mm)
5. Natural Sheep wool insulation (180 mm)
6. Wood finish (35 mm)

TRANSPARENT GLAZING

To maintain the original windows, new windows were installed behind the originals (**Fig. 3.5** and **Fig. 3.6**). The existing windows frame had a U-value of 2.2 W/m^{2}K compared to the new frame with a 1.55 W/m^{2}K value.

The single pane glass had a U-value of 5.0 W/m^{2}K, the new value is 1.6 W/m^{2}K.

Fig. 3.5
(On the previous page)
Interior photo of the retrofitted house

Fig. 3.6
(On the left)
Photo of the second wall and window system

HVAC

In the original state the house was only partially heated by a wood fueled stove.

After the renovation, the heat is distributed to the room via floor heating, and the ventilation has a recovery heat system.
The domestic hot water is produced by a wood pellets boiler.

3.2 RESIDENTIAL AND COMMERCIAL BUILDING - BASEL

This residential and commercial building, was built around the 1850, is in Feldbergstrasse, in Basel, in a context of high traffic roads.
The goal of the intervention was to obtain a building that was able to self-produce the quantity of energy necessary for the production domestic hot water (DHW), heating the different locals, ventilation, and auxiliary energy.
With the insertion of new insulation layers, replacement of windows and installation of a system with photovoltaic panels it was possible to reach the proposed goal.

ENVELOPE

The facade was formally changed, this intervention was discussed with the City Commission.
The original state was composed by a single layer of brick masonry covered with plaster on the exterior. The original U-value was 1.4 W/m^2K whilst after the intervention this value was lowered to 0.16 W/m^2K. (**Fig. 3.7**)

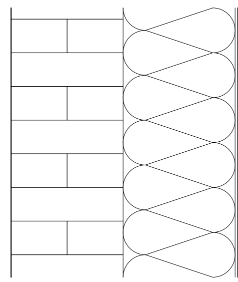


Fig. 3.7
Wall stratigraphy
(From the outermost to innermost)
1. Original brick masonry (400 mm)
2. Mineral Wood (400 mm)
3. Plaster (10 mm)

GROUND FLOOR

The floor that divides the apartments from the unheated basement locals was insulated. Its value was modified from 2.4 W/m^2K to a lower value of 0.15 W/m^2K. (**Fig. 3.8**)

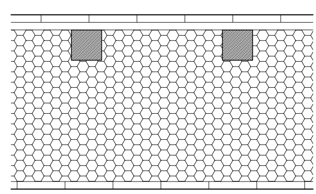


Fig. 3.8
Ground floor stratigraphy
(From the outermost to innermost)
1. Wood board (20 mm)
2. Wood studs and insulation (400 mm)
3. Wood parquet (15 mm)

Fig. 3.9
On the left photo of the south facade of the building. The whole facade has been changed from the original state, a photovoltaic system has been implemented on the roof

ROOF

The roof was considered the most important part of the intervention since it has the necessity to host the installation of the photovoltaic system. The south portion of the roof was protected, since it faces the road, whilst the north portion was modified in order to be covered by solar panels. **(Fig. 3.9)**
Afterwards, the roof was insulated with 50 mm of wood fiber insulation.
Its value went from 2 W/m^{2}K to 0.10 W/m^{2}K. **(Fig. 3.10)**

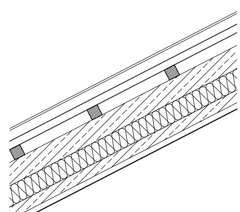


Fig. 3.10
Roof stratigraphy
(From the outermost to innermost)
1. Sun collector (50 mm)
2. Wood roof Structure (85 mm)
3. Wood fiber board (50 mm)
4. Wood planks (30 mm)
5. Plasterboard (15 mm)

TRANSPARENT GLAZING

The facade on the street has been formally changed. Although the windows have been replaced, their dimensions were maintained as the originals, due to the necessity to respect the alignments with the neighbor buildings.
The existing double pane windows were substituted with triple pane, low-e windows. The values went from 2.0 to 1.4 W/m²K for the frame, and from 2.5 to 1.6 W/m²K for the glass.

HVAC SYSTEM AND RENEWVABLE ENERGY SYSTEM

On the roof solar thermal panels were disposed, covering a surface of around 35 m², with these solar panels is possible to heat a storage tank of 40.000L, with integrated heat-exchanger.
The remaining of the roof surface was covered with photovoltaic panels, for a surface that reaches 65 m² (**Fig. 3.11**) and it produces a total of 9000 kWh during the year.

Fig. 3.11
Photo of the roof photovoltaic system, the two smaller pitches are used to produce hot water.

3.3 VILLA CAPODIVACCA

Fig. 3.12
Photo of the main facade of the Villa

The restoration and energy refurbishment of Villa Capodivacca (**Fig. 3.12**) in Saccolongo, Padua can be considered as a “low impact” restoration.
A wise combination of new functions and technical solutions were used, allowing the historical characteristics and the original atmosphere of the building to be maintained, preserving the identity of the building.

The villa was built before the 1600, and is classified as a protected building, therefore all the finishes and the architectural characteristics of the Villa had to be maintained.

ENVELOPE

The whole villa was affected by material degradation (**Fig. 3.13**), and the internal conditions were far away from those that are considered comfortable.
To maintain the original characteristic, the external plaster was restored, and the brick masonry was consolidated.
The committee required that all the insulation interventions were reversible, so the use of dry-laid calcium-silicate panels was the best choice, then covered with a new layer of plaster.
From the thermal point of view the original envelope had a U-value of 1.72, lowered to 0.39 W/m²K after the restoration. (**Fig. 3.15**)

ROOF

The roof retrofitting was crucial to the project since it was necessary to maintain and recover the old shingles that composed the roof mantle. Afterwards also the wood structure was decided to be maintained, so a consolidation work was necessary. The principal beams were damaged so steel blades were used to restore the solidity and the structural purposes.
For the insulation, wood fiber panels were chosen, but the thickness is variable, adapting it to the original profile of the roof.
The thermal performance of the roof modified from 2.38 to 0.22 W/m²K. (**Fig. 3.16**)

TRANSPARENT GLAZING

The new windows have a similar shape and dimension of the existing ones, the frames were replaced with new lamellar larch wood ones. The original single pane glass was replaced with a double pane argon filled glass.
The original frames were discarded since they were not the original ones, since they were replaced in the 70's, in this case, the low historical value and the poor thermal performances were the motives for the decision.
The existing glass had a value of 3.0 W/m²K that was lowered to 1.1 W/m²K with the new configuration, the frame went from 1.9 to 1.7 with the replacement.

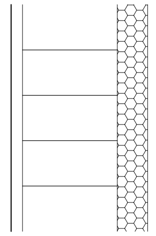


Fig. 3.15
Exterior wall stratigraphy
(From the outermost to innermost)
1. Consolidated plaster (30 mm)
2. Brick masonry (250 mm)
3. Calcium silicate panels (80 mm)
4. Internal plaster (30 mm)

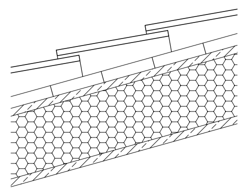


Fig. 3.16
Roof stratigraphy
(from the outermost to innermost)
1. Recovered shingles (80 mm)
2. Wood structure (50 mm)
3. Wood fiber insulation (160 mm)
4. Plasterboard (15 mm)

Fig. 3.13
(On the last page, on top)
Photo of the facade of Villa Capodivacca, the material degradation is noticeable.

Fig. 3.14
(On the last page, on the bottom)
Photo of the interior of the Villa after the restoration.

HVAC SYSTEM

Since the Villa was divided in two different areas, the two floors have different needs and, therefore, different systems. On the ground floor the original stoves were replaced with radiant terminals with better performance. Since the first floor must accommodate a family of residents, wall radiant panels (**Fig. 3.17**) were used, these are useful to heat and cool the room during the year.
 The thermal power station is composed by a boiler and a heat pump that produced hot and cold water.
Also, a dehumidifying system was installed.

Fig. 3.17
Photo of the wall mounted radiant system

3.4 VILLA CASTELLI

Fig. 3.18
Photo of the main facade of the Villa

Villa Castelli (**Fig. 3.18**) is a listed as a protected building, it was built at the end of the 19th century on the riverside of Como Lake.
For this restoration, the owners decided to transform the building into Zero Energy Building, while maintaining the original functions and the external appearance of the Villa.
The form that was present before the renovation was the result of an expansion and rebuilt operation that took place in 1925.

ENVELOPE

The exterior walls of the building were constructed with natural stone masonry with lime mortar on both sides.
The preservation of the exterior appearance of the building was a constriction from the conservative point of view, so the only feasible solution for the insulation was the interior insulation. It was possible with the use of a 20 cm Perlite layer on top of the existing interior plaster, followed with a new lime plaster.
This solution helped to improve the thermal performances of the envelope that changed its U-value from 1.33 to 0.19 W/m²K. (**Fig. 3.19**)
Since, due to geometric characteristics of the building it was not possible to apply the 20 cm of perlite insulation everywhere, it was necessary to develop new solutions for the different cases:

- For the internal insulation of the staircase concrete wall and the veranda pillars, in these cases the original concrete wall was insulated with an 8 cm layer of aerogel. (0.18 W/m²K). (**Fig. 3.20**)

On the other parts of exterior walls, those in brick masonry, 20 cm of perlite were used as insulation (total U-value 0.19 W/m²K.). (**Fig. 3.21**)

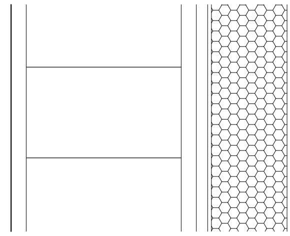


Fig. 3.19
Wall stratigraphy
(From the outermost to innermost)
1. Original external plaster (40 mm)
2. Stone masonry (400 mm)
3. Original interior plaster (40 mm)
4. Level-layer plaster (35 mm)
5. Glue (10 mm)
6. Perlite insulation (200 mm)
7. Interior new finish (10 mm)

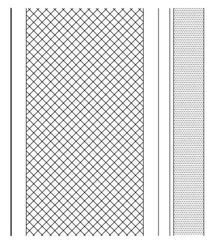


Fig. 3.20
Wall stratigraphy of the concrete stairs
(From the outermost to innermost)
1. Original external plaster (40 mm)
2. Concrete wall (300 mm)
3. Original interior plaster (40 mm)
4. Level-layer plaster (35 mm)
5. Glue (10 mm)
6. Aerogel insulation (80 mm)
7. Interior new finish (10 mm)

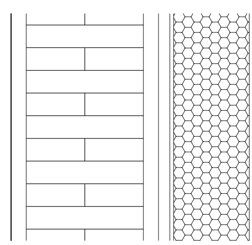


Fig. 3.21
Wall stratigraphy with brick masonry
(From the outermost to innermost)
1. Original external plaster (40 mm)
2. Brick masonry (300 mm)
3. Original interior plaster (40 mm)
4. Level-layer plaster (35 mm)
5. Glue (10 mm)
6. Perlite insulation (200 mm)
7. Interior new finish (10 mm)

ROOF

The roof was not protected by the conservation constraints, so it was decided to replace the existing one with a totally new structure, in laminated wood, with insulation, and as final exterior finish an aluminum roof was chosen. (**Fig. 3.23**)
The thermal performance of the new roof is noticeable better than the original, its U-value was reduced from 2.23 to 0.13 W/m²K. (**Fig. 3.22**)

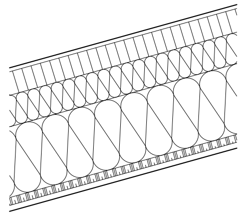


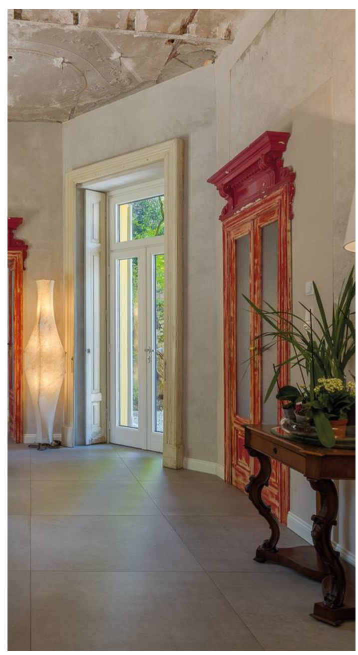
Fig. 3.22
Roof stratigraphy
(From the outermost to innermost)
1. Aluminum roof (10 mm)
2. Rock wool insulation (60 mm)
3. Wood fiber insulation (80 mm)
4. Wood fiber insulation (160 mm)
5. OSB panel (20 mm)
6. Plaster board (15 mm)

Fig. 3.23(on the left)
Photovoltaic system of the roof of the Villa

Fig. 3.24
(below)
Photo of the concrete floor and the interior after the restoration

GROUND FLOOR

The existing ground floor wasn't insulated, so on top of the existing lean concrete structure of the ground floor a 20 cm XPS layer was seated. Followed by the floor heating system and a finish of wood parquet or decorative concrete (**Fig. 3.24**), depending on the different rooms.
The thermal performance of the ground floor was drastically improved modifying from 1.49 to 0.15 W/m²K. (**Fig. 3.25**)



TRANSPARENT GLAZING

The windows did not represent a heritage value form the conservator’s point of view, so, to maximize the energy reduction, were replaced with new triple glazed windows with wood-aluminum frame. (**Fig. 3.26**)
The dimensions and the partitions of the original windows was respected. Particular attention was paid to the craftmanship of the windows.
The initial U-value of the glass in the existing windows was of 4.6 W/m²K but it has been lowered to 0.62 W/m²K with the new system.

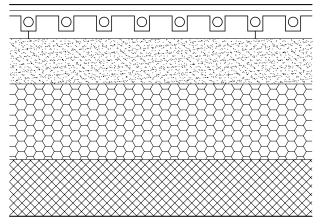


Fig. 3.25
Ground floor stratigraphy
(From the outermost to innermost)
1. Concrete (150 mm)
2. XPS insulation (200 mm)
3. Lightweight screed (120 mm)
4. Heating system (75 mm)
5. Parquet (15 mm)

Fig. 3.26
View of the interior

HVAC SYSTEM

The energy for heating and cooling and hot water is supplied by a heat pump with geothermal plants. Therefore, the heating is distributed through a radiant floor system. The ventilation is guaranteed by a mechanical system with heat recovery. This system guarantees pollen-free air and a healthy indoor environment. Paired with CO2 sensors for the automated ventilation, is possible to reduced furthermore the energy consumption for heating and cooling of the locals.

RENEWABLE SYSTEM

The remaining of the energy demand of the building is supplied by the photovoltaic system installed on the top of the roof, and it is not visible from the outside. The system is composed by monocrystalline modules with a peak power of 11 kWp. It was fundamental to pay attention to the panels layout to obtain the heritage office approvement.

On the roof also microturbines were installed, to create a small amount of energy, recovered from the winds.

Geothermal probes, going to 80 m depth, were used to feed the heat pump.

4 METHOD

4.1 THE INTEGRATED PROCESS FOR ENERGY EFFICIENT BUILDING DEVELOPMENT

The design process is crucial to the development of a project where, sustainability is a great concern. In the past the design path has always been a linear path, where the architectural design phase is followed by the design of the heating and cooling system, followed by the construction of the project.
This process is incompatible with the creation of low energy, high comfort buildings, is necessary to integrate an energy evaluation phase that allows the architect to evaluate and base his decisions on climatic basis.
Is fundamental to integrate this information since the beginning of the process, since the most critical decisions are made in this phase.
The design process (**Fig. 4.1**) should integrate the role of an energy expert that analyze the situation, finds new solutions that will be recommended to the architect and the engineer, who are in charge, of the HVAC systems design. (Butera et al, 2014)
This circular design path, is essential to design a zero-energy building.

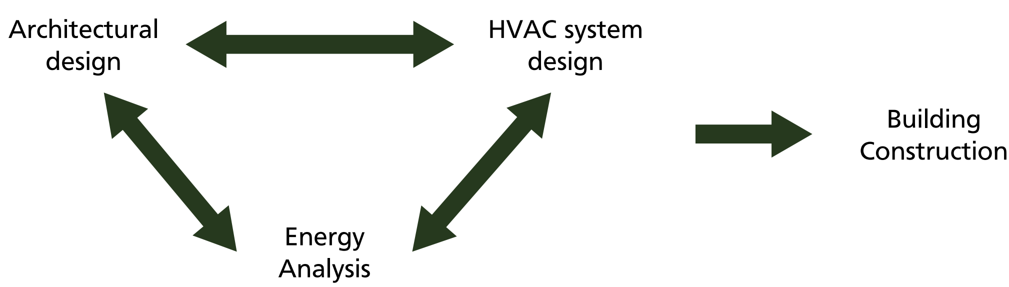


Fig. 4.1
Circular design flow chart

THE ENERGY ANALYSIS

PRELIMINARY OPERATIONS

Before starting with the design process, is essential to analyze and study all the different characteristics of the climate where the building is going to be constructed.
This analysis comprehends climatic parameters as:
- solar radiation
- air temperature
- relative humidity
- wind

SOLAR RADIATION

Solar radiation is the most important climatic parameter since it influences temperature and gives rise to regional winds.
The temperature depends on the angle of incidence of solar rays, the nearer the angle of incidence is to the normal, the more radiation reaches the surface, hence the higher temperature.
It is possible to calculate the sun position (and the angle of incidence), in any time, at any place, with the use of algorithms, but if a certain level of simplification can be accepted, is possible to use Sun Charts (**Fig. 4.2**)

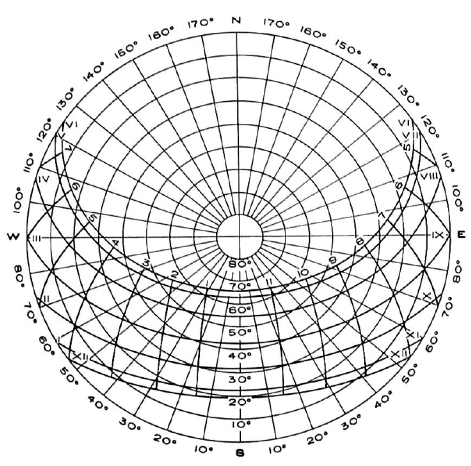


Fig. 4.2
Sun chart

IRRADIATION AND IRRADIANCE

These two parameters indicate the power of the solar radiation on a surface.
Irradiance is the instantaneous solar power incident on a surface, and is measured in W/m², irradiation instead is defined as the cumulative energy captured from a surface in given period and is defined as kWh/m².
Global irradiation consists in three different components, direct, diffuse and reflected irradiation.
The first one depends only by the spatial disposition of the surface; Diffuse radiation is influences by the way the surface "sees the sky"; the reflected irradiation depends on the mutual spatial disposition of the absorbing and the reflective surface.

AIR TEMPERATURE

This parameter is influenced by the context and depends primarily on the geographic position of the project, the topography, the hydrography, the surface texture, solar radiation, wind etc.
Temperature has a cyclical variation during the day and the year, it reaches his minimum value during the dawn, then increases until midday, reaching its

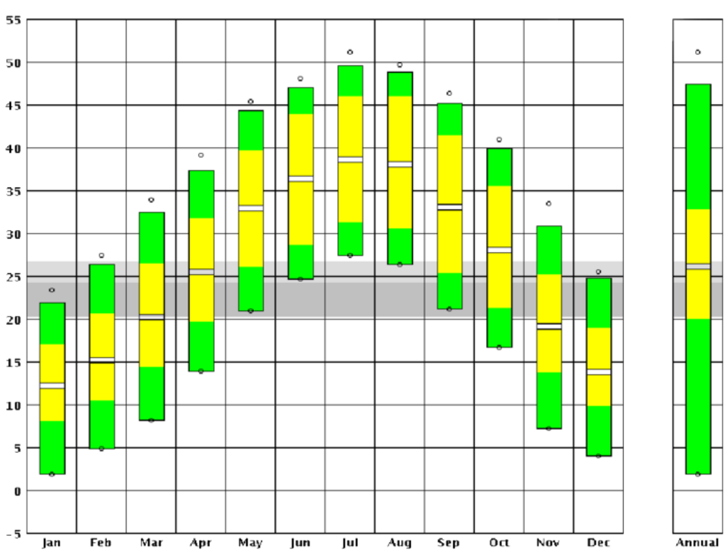
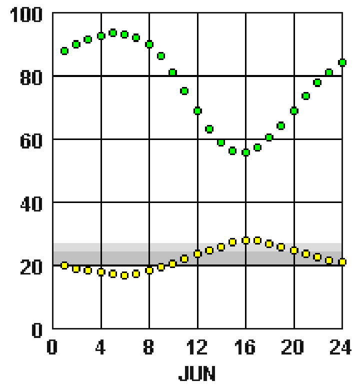


Fig. 4.3
Temperature diagram, the yellow part indicates the range of the average temperature during each month, while the green parts indicate the minimum and maximum temperature ranges. The dots indicate the minimum and the maximum temperatures registered during the period of analysis

maximum value in the early afternoon, decreasing slowly until it reaches his new minimum.
This parameter can be found in databases that records all the temperature variations during the year and are shown into graphs. (**Fig. 4.3**)



● Relative humidity
● Dry Bulb

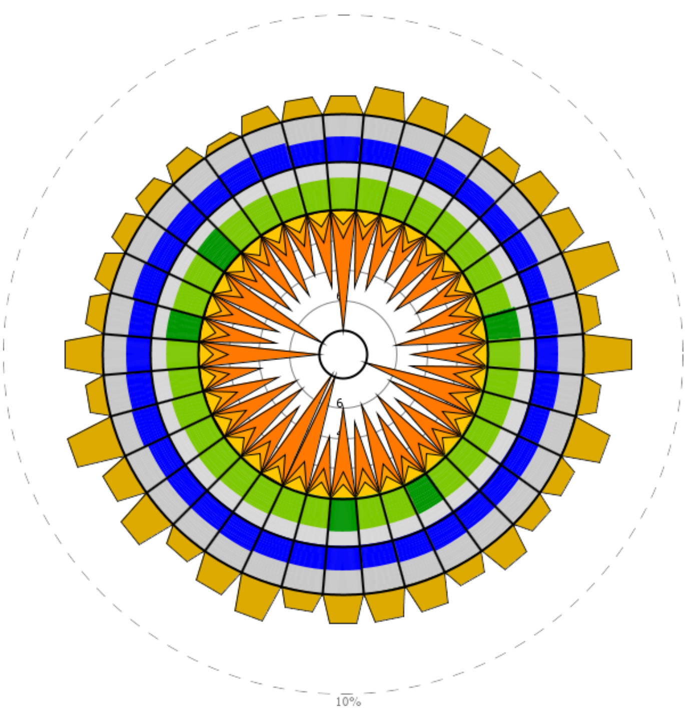
Fig. 4.4
Relative humidity and dry bulb temperature

RELATIVE HUMIDITY

Relative humidity expresses the ratio between the water vapor contained in the air and the maximum amount that can be contained before condensation, is expressed as a percentage.
(**Fig. 4.4**)

WIND

Wind is the movement of air masses, caused by a difference in atmospheric pressure and air temperature.
This parameter is characterized by 3 principal factors: speed, direction, and frequency.
This characteristic can be shown contemporarily on a Windrose. (**Fig. 4.5**)



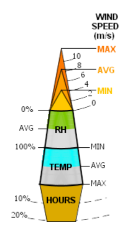


Fig. 4.5
Wind rose diagram

THE DESIGN CONSIDERATIONS AFTER CLIMATIC ANALYSIS

The results of the climatic analysis can be used to make informed decisions about the building shape, its orientation, the materials that must be used for the envelope design, the dimension and position of windows and their components.

BUILDING SHAPE

Since the capability of a building to store or release heat depends on its volume (and to its mass and shape) since losses or gain is related to the contact surface between the exterior envelope and the air. Therefore, the heating or cooling rate of a building depends on the ration between the Surface and volume (S/V)

BUILDING ORIENTATION

Building orientation is crucial since the quantity of radiation receive but the surfaces changes based on its orientation, in the norther hemisphere, South Facing surfaces are the ones more exposed to radiation, while north facing ones receive light only by diffusion a reflection.
As the irradiation of the surface increases, the temperature on the surface increases.

CONSTRUCTION MATERIALS

The 40% of the raw materials and energy worldwide are used in the building sector. Cements is responsible por almost a quarter of the annual worldwide CO_2 emissions from fossil fuels, the iron production generate the 4% of the energy consumption in the world and the related emissions. The choice of construction materials must be made trying to prefer the choice locally available materials and materials that doesn’t require a high quantity of energy to be produced.

ENERGY SIMULATION

In this phase, with the help of computer programs, is possible to generate models that can represent a reliable indication about the behavior of a building in its context.

With these tools is possible to evaluate the energy necessary to maintain the comfort conditions in the building. It possible to measure the electric consumption of the appliances and lighting.

Most importantly can be used to develop strategies that can minimize the energetic needs of the project

GEOMETRY GENERATION

Obviously, all the simulations would need a geometric input, to create one, is necessary to simplify the geometries, to have only primitive solids such as cylinders, prism, cones etc.
Another important detail is to consider outer limit of the buildings as the perimeter of the energy model volumes.
In the model, it is also important to define all the openings of the project, such as windows, skylights, doors etc.

THERMAL ZONES DEFINITION

The following step is to understand and define a division of the building in different thermal zones, each thermal zone is a part of the building that has a different requirement for heating and cooling temperatures, humidity, ventilation (a Gallery has different requirements compared to a restroom).
In this way, it is possible to regulate the amount of energy that is distributed in the whole building, reducing the energy demand.

This also helps, to understand in an easier way the results of each simulation, giving the opportunity to find better solutions for each zone.

STRATIGRAPHY OPTIMIZATION

Since the choice of the exterior and the interior materials derive from the architectural project, with the energy simulations it is possible to understand how to optimize the interior layers of the whole envelope.
It is possible to run several simulations with different levels of insulation, different order of the layers, to collect different results and take decisions based on the cost optimal solutions.

An important consideration should be made when talking about stratigraphy and construction systems, since this operation has to be adapted to each case, budget and situation.

In the case of a new building, it is possible to adapt the stratigraphy according to the budget of the building, trying to reach the most suitable solution by evaluating the costs and the reduction of energy consumption.

When intervening on an existing building, is necessary to understand if it is possible to improve the conditions of the whole building or if it is possible to intervene on a single living unit.
The solutions are going to be different and less effective when working on a single unit (thermal bridges are going to be a great problem, as well as the reduction of internal space due to the obvious impossibility to utilize a retrofitting operation on the exterior of the building.

In the case of protected building, it will be necessary to always study the current conditions and perform a study on the conservation status of the building.

The operations of retrofitting will have to consider the set of rules that are applied to the building. Also, it is important to evaluate the identity of the building maintaining, when is possible, the integrity of the original structures and all the elements that have an historical value.

SETPOINTS OPTIMIZATION

Another important point in the process is to understand the *schedules* of the different thermal zones, in this way is possible to have different thermal setpoint during the day, depending on the usage of the different locals.
During the night for example, if a local is not used, it is possible to reduce the amount of heating or cooling.

Setpoint will vary in any case on the function of a building, in some buildings, it is necessary to maintain the same temperature for the whole day or is necessary to have a higher air volume exchange during the day etc.

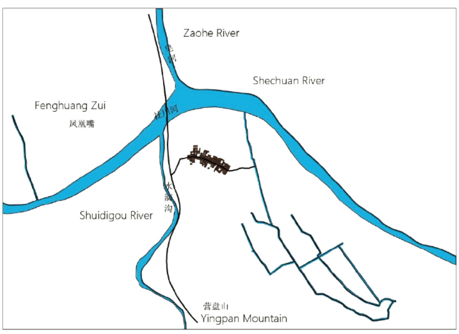
5.1 FENHUANGZHEN

The province of Shaanxi territory is enclosed on the north by the Qinling Mountains and on the south by the Data Mountain while the Han River runs through the area from west to east.
The city of Shangluo is located in the southeastern part of Shaanxi, 129 km far from the best-known city of Xi'An; it is characterized by the presence of different features that belong to the Qin (ancient state dated during the Zhou dynasty, 897 B.C) and the Chu (ancient state dated during the Zhou dynasty, early 8th century B.C.E).
Shangluo has a strategic geographical location, it represents the shortest way to get to Jingchu, region in the eastern part of China. In fact, the Shangluo Road has always been an important channel for economic and cultural exchanges in Jinchu and Guanzhong (region in the south-east of China). Shangluo was also an important wharf and a material distribution center for the Dancing River, especially during the Ming (1368-1644) and Qing (1636-1912) dynasties.

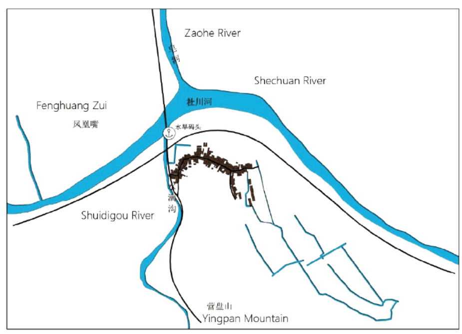
Fenghuanzhen is a village located in the Shaanxi province, where Shangluo is the prefecture city. (**Fig. 5.1**) The Shaanxi provide cover an area of 205,000 km; it is landlocked in Northwest China with a population of 37 million people. Xi'An is the capital and largest city in the provide and Xianyang, which served as the Qin dynasty capital, is located nearby.

Despite the various data about the province of Shaanxi and its capital, having accurate information about the city of Fenghuang is not easy, in fact most of them refer to Fenghuang ancient town.

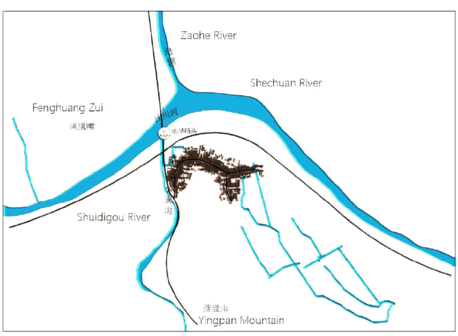
Fig. 5.1
Fenghuang town location



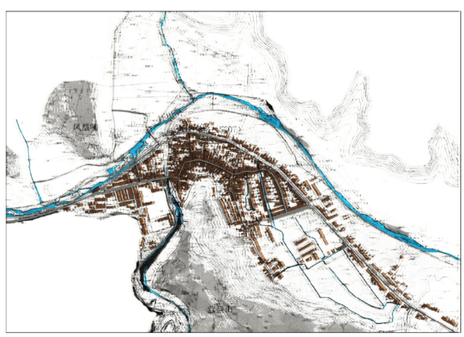
Tang dynasty - Sanchane Kou



Ming & Qind Dynasty - Fenhuang Zui



Republic of China - Fenhuang Town



State of the Art - Fenhuang Town

Fig. 5.2
Fenghuang town ancient maps

Fenghuangzhen is located at the south of Qinling mountains, at the intersection between the Shechuan River, the Zaohe river and the Shuitangou river. It has an administrative area of 163 km_2 and the cultivated land is 15400The Mountain located behind the ancient part of the city is called the Yingpan Mountain and, as it is written in the article Analysis on regional characteristics and ecological experience of traditional residential areas in Shangluo area - take the Feng Huang ancient town in Zhashui County, according to the fengshui ideas, it creates “a natural barrier” so that the city can resist to the winter cold winds. (**Fig. 5.3**)

The city was founded during 8th year of Wude of the Tang Dynasty (625 AC) and flourished in the Ming and Qing dynasties. (**Fig. 5.2**)
At the foundation the city was formed by 53 families that came from Wu, Chu and from other surrounding cities. It was called Sanchahe Kou. The strategic position of the city allowed it to flourish, thanks to its commercial connections, the three rivers and the possibility to be easily crossed with mules and horses. At the end of Qing Dynasty and the beginning of Republic of China, Fenghuang had become a commercial port, with several large business spread across the town, it has become an important trading town connection the Yangtze River system and the Yellow River in the south area of Qinling mountains. More than 200 cargoes crossed these waters during the peak of the commercial importance of the city

The position of the city had an important role to the merging of the culture of the people that migrated here from the south and from the northern areas of Hondong, Shanxi.
This merging granted to this city a unique folk culture

Fig. 5.3
Drone view of the city, is easily noticeable the particular shape of the city, modelled around the mountain.
The ancient road and the vertical road remind the shape of a Phoenix.

THE IMPORTANCE OF FENHUANG TOWN

Fenghuang Town value is not only in its geographical location, immersed in the mountains and bathe by the rivers that allow its inhabitants to be able to live on agriculture, but also on its ancient street and the historical value of its historical constructions. In fact, many of these constructions, which are houses with a commercial front, belong to the Ming and Qing dynasties. According to Gas Lin and Wang Jin in "Preservation of Fenghuang ancient town in Zhanshui city and its development, there are 12 buildings belonging to the Qing dynasty, while there's not a precise count over the Ming dynasty buildings.
These buildings, that we can categorize in "Remaining buildings of the old city" have an historical value because of their architectural structure, material, and ornaments.
Furthermore, another value of the city is in its importance of being a business and trade town: it connects the Yangtze River and the Yellow River systems. Nonetheless the folk culture that was developed must be preserved, as well as the traditional crafts techniques.

We can still see the workshops that collect chines herbal medicine and raise the tussah (wild silk), spinning workshops and blacksmith workshops.

THE IMPACT OF TOURISM

Since 2010 Fenghuang has been listed in the "Fifth batch of China Historically and Culturally Famous Towns" (CHCFT), and soon the Fenghuang old town shows a touristic and commercial development. In the article "Preservation of Fenghuang ancient town in Zhashui city and its development", the authors tell us about some problematics that the city of Fenghuanzhen has to

face with the development of the local tourism. These problems concern both the inhabitant's relationship (internal pressures) with the historical context and the local tourism (external pressures). Firstly, it is important to mention that in 2006 the Government promulgated measures for the protection of the ancient town formulating a plan "Plan Protection and Utilization Plan of Fenghuang Ancient Town in Zhashui County".
The plan was needed not only as a guideline for architects but also because, according to the authors, the inhabitants do not have a sense of protection for the city. The plan mainly focused on the protection of the courtyard houses, and on the fact that the new buildings should follow the local architectural style.
However, even though the city is under the protection of this plan, it is still facing internal and external pressures. The internal pressure, as mentioned before, is due to inhabitant's lack of sense of protection for the ancient buildings: "For example, some residents have removed old wooden partitions to use larger areas. Some residents include the original corridor area to expand their living area. The most common scenario is that some residents would have to change their original wood carving windows with glass windows to facilitate lighting. Local villagers believe that these are just ordinary houses and they do not realize their value. Many local villagers have demolished the wooden components of ancient buildings in the village and sold them to make money. Another situation is to simply remove the old house and build a new brick house on the original basis.
The main reason is the expansion of the village population.
With the absence of additional space, the house developed upwards, some with white tiles on the outside, and some with brick walls directly exposed. Colors and materials appear to be very incongruous in ancient buildings."

The outside pressures are caused by local tourism, benefited from the construction of the urban road and the highway in 2018. According to the Zhanshui government website, already in 2006 the city of Fenghuang received more than 1200 tourists per day and 2000 people on weekends (those numbers reported in the article are not sure 'according to people who visited the city. The numbers seem to be augmented in the article). Of course, tourism has brought both negative and positive aspects. The negative effects are for example: traffic, long queues, increase in commercial outlets placed in the front of the residential buildings that ruin the image of the ancient town, destruction of the agricultural fields, between 2015 and 2019, placed in the north near the river to build the urban road (the agricultural fields were partially rebuilt starting from 2018). The positive factor is that tourism brings economic benefits to the local activities. The majority of buildings in the town are privately owned so of course tourism will influence a lot the inhabitants life. This information is quite general but they represent the only source specifically related to the Fenghuang context that we have. But, what it is possible to learn from literature is that the development of a tourism destination may have social/cultural, economic, and environmental effects upon the local community: they are defined as tourism impacts. China passes three important tourism phases: pure politics, politics plus economics and economics over politics. The first phase covered the period from 1949 to 1978, where tourism sought no economic benefits for the country; the second phase came during the early stages of China's economic reform (1978-85), when the country started to consider tourism as both a component of foreign affairs and economic activity. However, the government still placed politics, an example was the discriminatory pricing policy that let overseas Chinese and compatriot residents from Hong Kong, Macao, and Taiwan pay much less that non-Chinese foreign tourists,

for the same services; in 1986, China turned into its third phase when the government declared tourism to be a comprehensive economic activity. Chinese government, since 1986, has repeatedly stressed the importance of tourism as an essential service that requires less investment, but produces faster profits, better efficiency, lager employment potentials.
The three phases of tourism development have brought China tremendous economic benefits (“The impact of tourism in China on local communities, Yiping Li, The University of Hong Kong)
Foreign and domestic tourist arrivals reached 38 million in 1992, representing a 14,3 per cent increase over the previous year. The growth continued since China became a leading tourism destination.
The city of Shenzhen is an example to observe the impact of tourism in China, it was a small village that with the economic growth due to tourism started its expansion. The information of Shenzhen tourism impacts that we have found are based on data collected via face-to-face interview survey and information on newspapers and other media reports (information that we cannot have for the city of Fenghuang). The inhabitants saw the benefits of tourism mainly in economic or economy-related social/cultural terms: attracting foreign capital investment, creating job opportunities, improving living standards and enhancing community life by offering better consumer goods and services.
The negative effects are visible on the social aspect: the inflow of outside visitors brought economic benefits but also let to social and cultural changes. The inhabitants reported social problem such as social instability, prostitution, family crisis and conflict between local residents and outsiders. Furthermore, the rapid growth and change in Shenzhen had attracted not only tourists but also thousands of migrant workers who dreamed of making a better living in the city.

Inhabitants were concerned that some migrant workers might become beggars or turn to crime when their dreams are not realized, creating a crime and violent scenario in the city. The increase in the crime rate is not the only price Shenzhen had to pay for its rapid growth and change: prostitution, especially, now is quite common.
On the environmental point of view, tourism brought both benefits as leading to the greening of the city, preserving, or revitalizing heritage sites, and promoting environmental awareness, and negative environmental effects as the modification of landscape destructing the wildlife habitats. An example of the negative effect on environment is the threat posed by Shenzhen's cultural theme parks to the Natural Reserve of Mangrove Tree nearby. The theme parks built in that area had a lot of success on the touristic point of view, but it also brought to the construction of a new highway, which was constructed on reclaimed land.
The highway represents a threat for the natural wildlife habitat, and with the parks, it changed the natural environment, and it was considered a disaster by the people interviewed.
In conclusion, the opening to the outside has transformed China, and it has led to significant changes in its economic structure and in society and culture. Tourism has an important role in This change bringing both positive and negative aspects, respectively on the economic point of view and on the social point of view. The economic growth was, and is today, essential to led China to modernization, but the negative effects upon its people should be minimized.

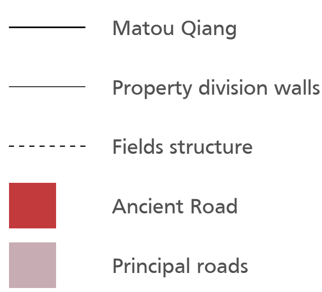
5.2 CITY LAYOUT

The layout of the city is characterized firstly by the presence of some important roads: some of those can be considered as “vertical” (north south direction) and others, among them the historic road are “horizontal” (west-east direction).

The city is also characterized by the radial arrangement of the residential units, starting from the historic road going towards the river in the north and towards the terraces in the south. **(Fig. 5.4)**
The rhythm is set by the courtyard building dimensions and by the Matou Qiang, the adorned wall placed between each courtyard. This wall emphasizes the rhythm on the historical road, in fact, the head of the wall is always visible when walking around the principal road.

The Matou Qiang, creates the division between the singular residential units, these are divided in “functional stripes”:
the front of the courtyard building is dedicated to commercial services, behind it, we can find the rooms of the house around the court, on the back of the court we usually find two rooms dedicated to important events.

Fig. 5.4
Diagram of the structure of the city.

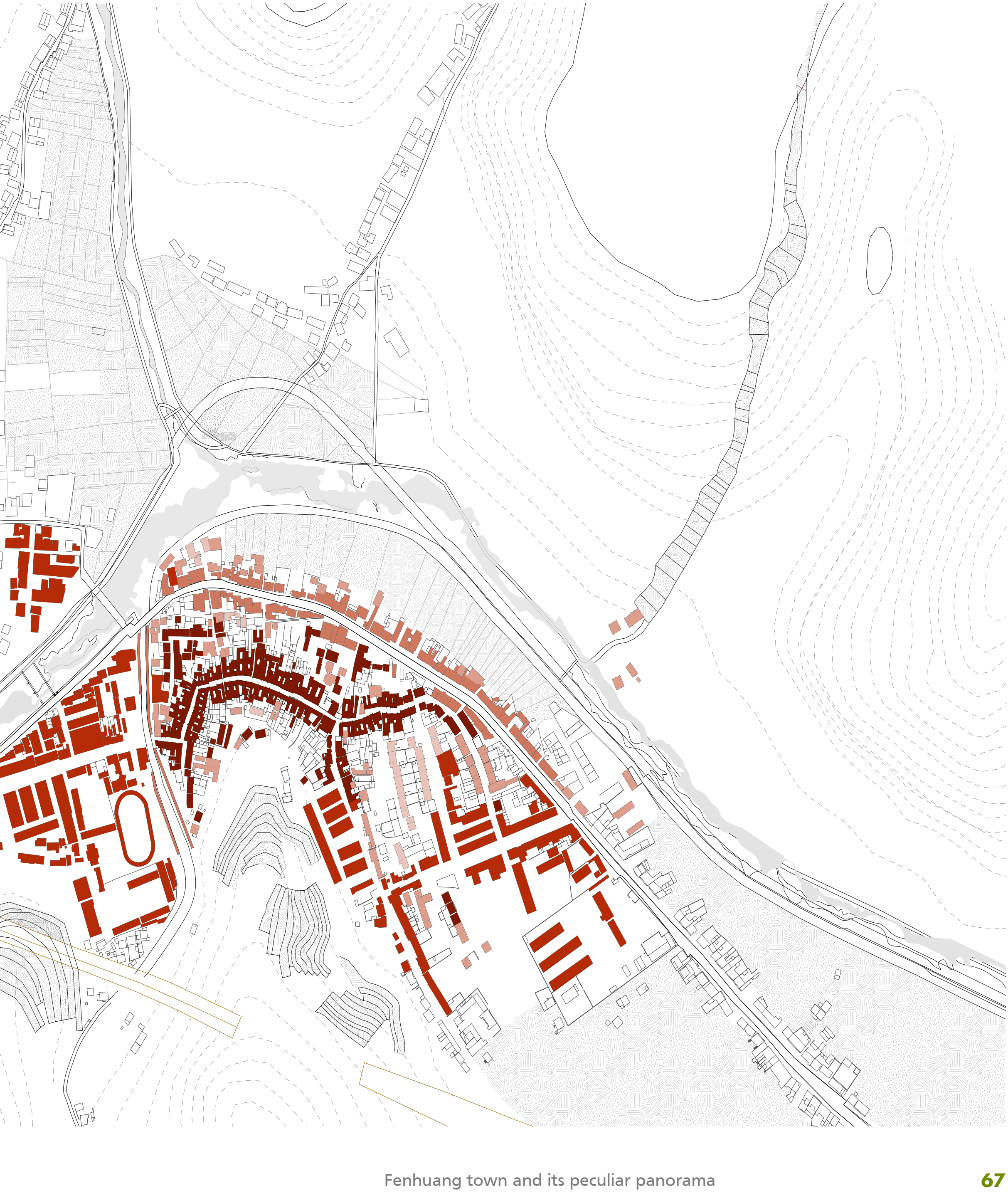


5.1 THE 5 BUILDINGS CATEGORIES

The city of Fenghuan is characterized by a variety of built spaces, one different from the other. The following classification take into consideration five different building typologies: remaining buildings of the old city, new construction with ancient techniques, new constructions with modern techniques, contemporary buildings, contemporary buildings in style. (**Fig. 5.5**)

Fig. 5.5
Map of the 5 categories distribution in Fenhuang Town

- Remainings of the old city
- New constructions with ancient techniques
- New constructions with modern techniques
- Contemporary buildings
- Contemporary buildings in style



REMAINING OF THE OLD CITY

This typological building (**Fig. 5.6**) derives from the Zhai yuan type of Guanzhong with, original additions imported by migration.

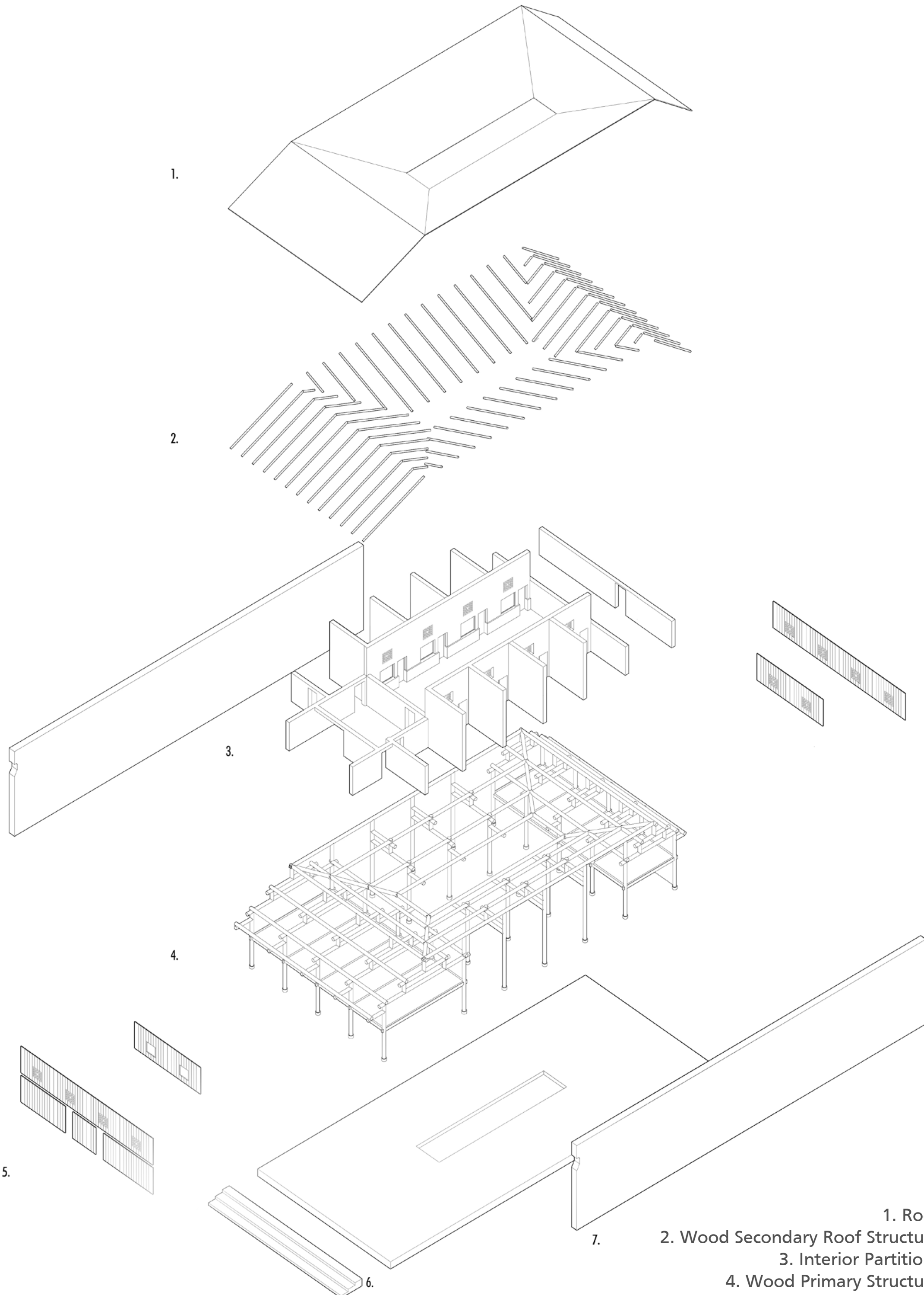
The courtyard is composed by a front that’s raised on a stepped basement, usually this has commercial purposes, this is followed by a really narrow courtyard, that has both lightning purposes and “symbological” meaning, since acts as an impluvium collecting water from the roof’s eaves in a tank that’s paved in cobblestone.

The courtyard is covered by 4 roofs that overhang from the surrounding walls. (**Fig. 5.8**) The wings usually are devoted to warehouses, they also include mezzanines that can be used in some cases also as rooms, the second floor is accessible only by ladders.

On the back of the courtyard, we can find the main residential area, next to the “important room” used usually in the case of important meetings.

This typology is characterized by the use of a load bearing timber frame between a frame made by the Matou Qiang, a firewall built in rammed earth, decorated with a “horse head” on the top in correspondence of the ancient road. (**Fig. 5.9**)

Fig. 5.6
Exploded axonometry of the traditional courtyard building in Fenhuang Town



1. Roof
2. Wood Secondary Roof Structure
3. Interior Partitions
4. Wood Primary Structure
5. Wood Facade
6. Basement
7. Matou Qiang

Fig. 5.7
Photo of the ancient road, in this image is possible to notice how the front of each courtyard has commercial purposes, they usually use the stepped basement to position tables to show goods.

Fig. 5.8
Photo of a double courtyard is noticeable the impluvium that's present in the center of all the buildings that belongs to this category.

Fig. 5.9
Photo of the ancient street, the presence of the Matou Qiang creates a continues rhythm in the road, another important detail is the facade of the buildings with the visible structure

Fig. 5.10
A restored ancient building, the Matou Qiang has been covered with white plaster and the facades has been built with a natural finish wood.

NEW CONSTRUCTION WITH ANCIENT TECHNIQUES

This typological building (**Fig. 5.11**) derives directly from the courtyard type, they were built during the Cultural Revolution.

The building is raised on a stepped basement, and the single units are divided with walls that recall the Matou Qiang.

The construction techniques used are the traditional ones with wooden structure and compressed earth walls.

This is the first typological discontinuity with the courtyard type.
From the functional point of view, these buildings host only residential purposes that are usually distributed on more levels.

The backyard still presents a vegetable garden and fields

Fig. 5.11
Exploded axonometry of a modern building that utilize ancient construction techniques

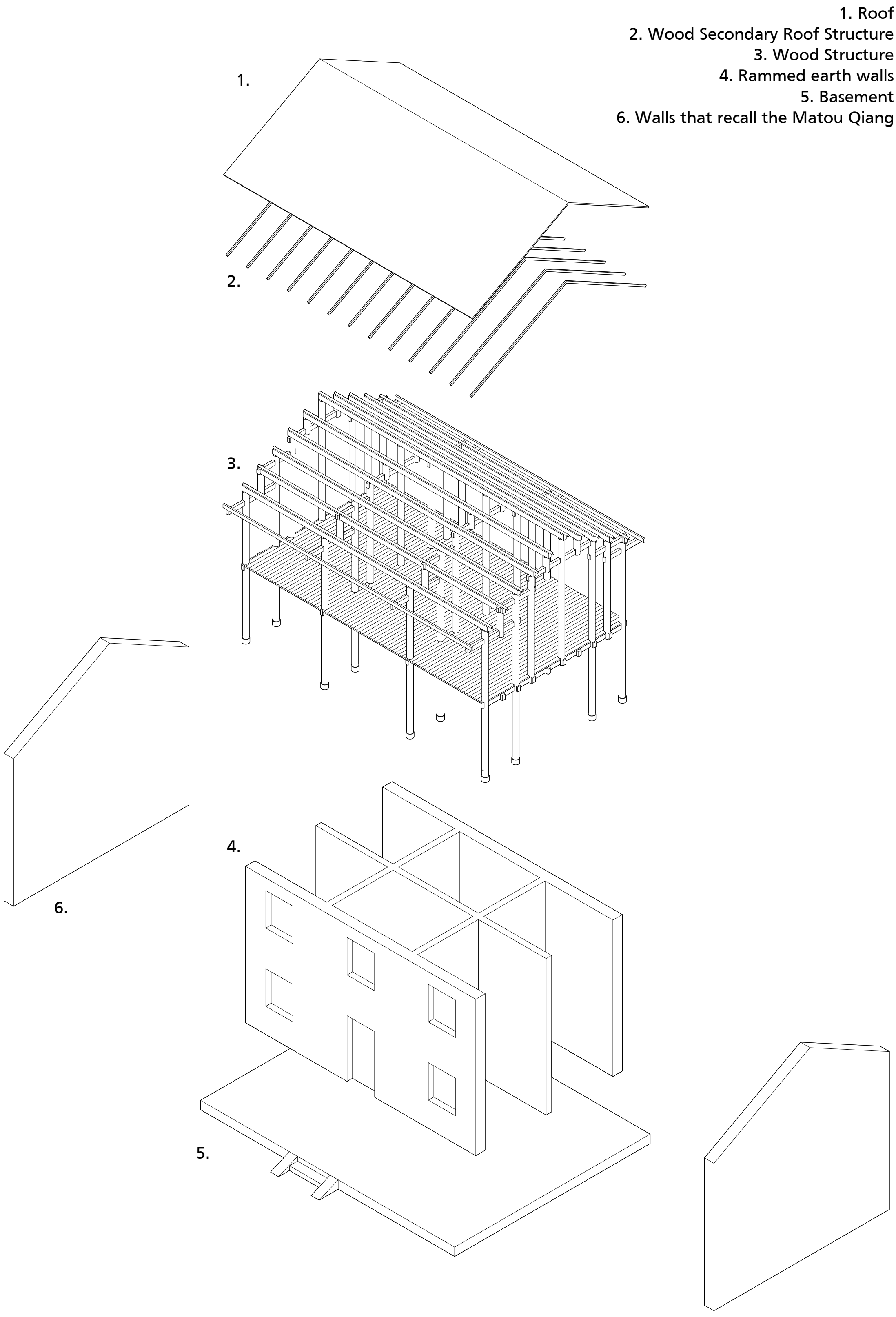

1. Roof
2. Wood Secondary Roof Structure
3. Wood Structure
4. Rammed earth walls
5. Basement
6. Walls that recall the Matou Qiang
1.
2.
3.
4.
5.
6.

Fig. 5.12
Photo of a series of new buildings built with the ancient construction techniques, is possible to notice the Matou Qiang interpretation

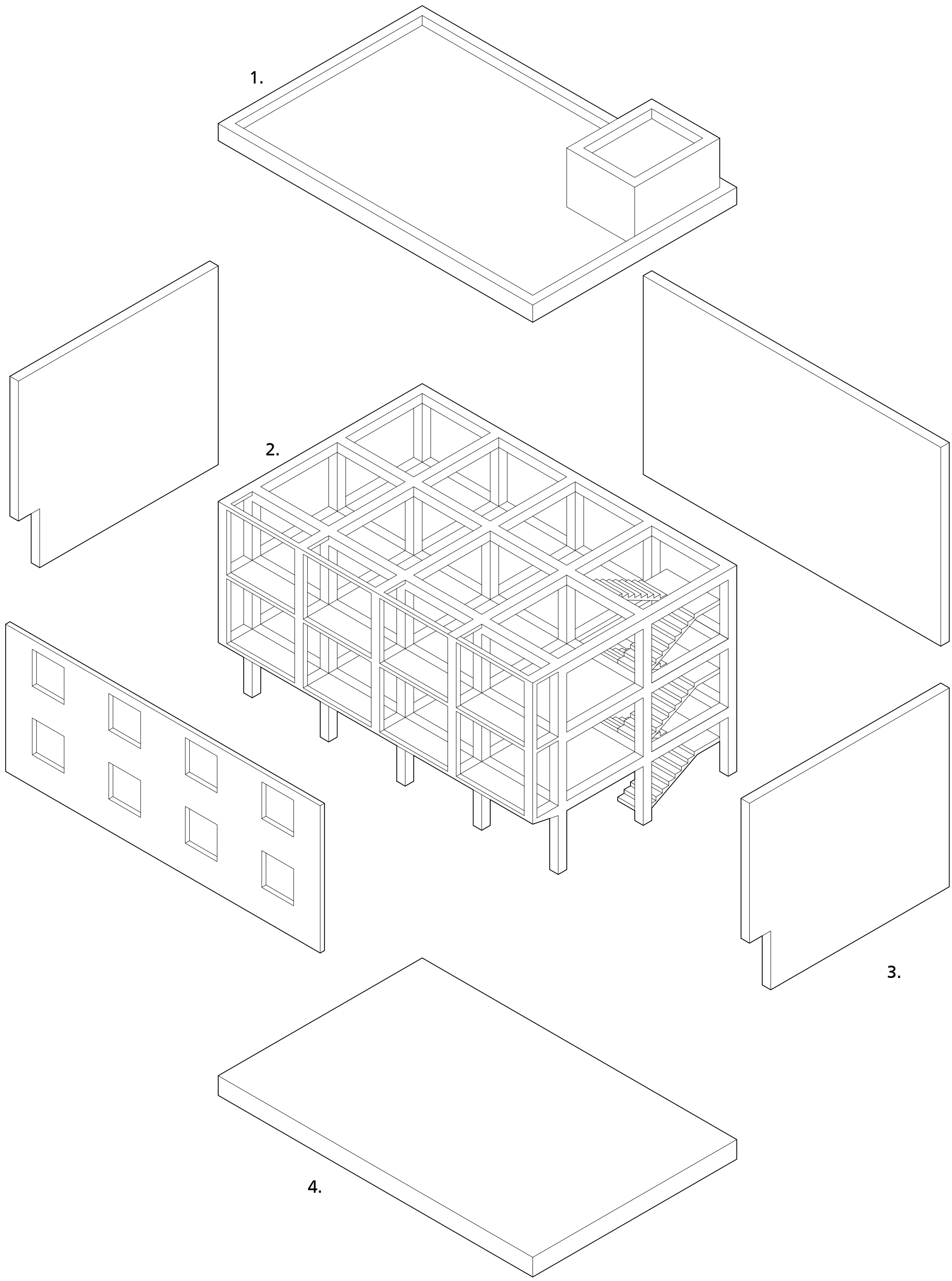
Fig. 5.13
Photo of new buildings in the west side of the town.

NEW CONSTRUCTION WITH MODERN TECHNIQUES

This category (**Fig. 5.14**) comprehends all those buildings that were built after the cultural revolution, they use modern techniques as concrete or modern bricks wall.

The structural system is composed by concrete columns and beams, usually there's an overhang in the superior floors. (**Fig. 5.15**)
These buildings usually are 3 or 4 stories high, and they host only residential functions.

Fig. 5.14
Exploded axonometry of a modern building



1. Flat roof
2. Concrete Structure
3. Brick uninsulated wall
4. Basement

Fig. 5.15
Photo of modern buildings with a concrete structure

Fig. 5.16
Photo of modern buildings with a concrete structure

CONTEMPORARY BUILDINGS

This category comprehends all those buildings that were built between the 80's and the present. The construction techniques were the same that characterized the "modern buildings". (**Fig 5.17**)

Fig. 5.17
Photo of the contemporary buildings, this complex is built around the only plaza present in the Town

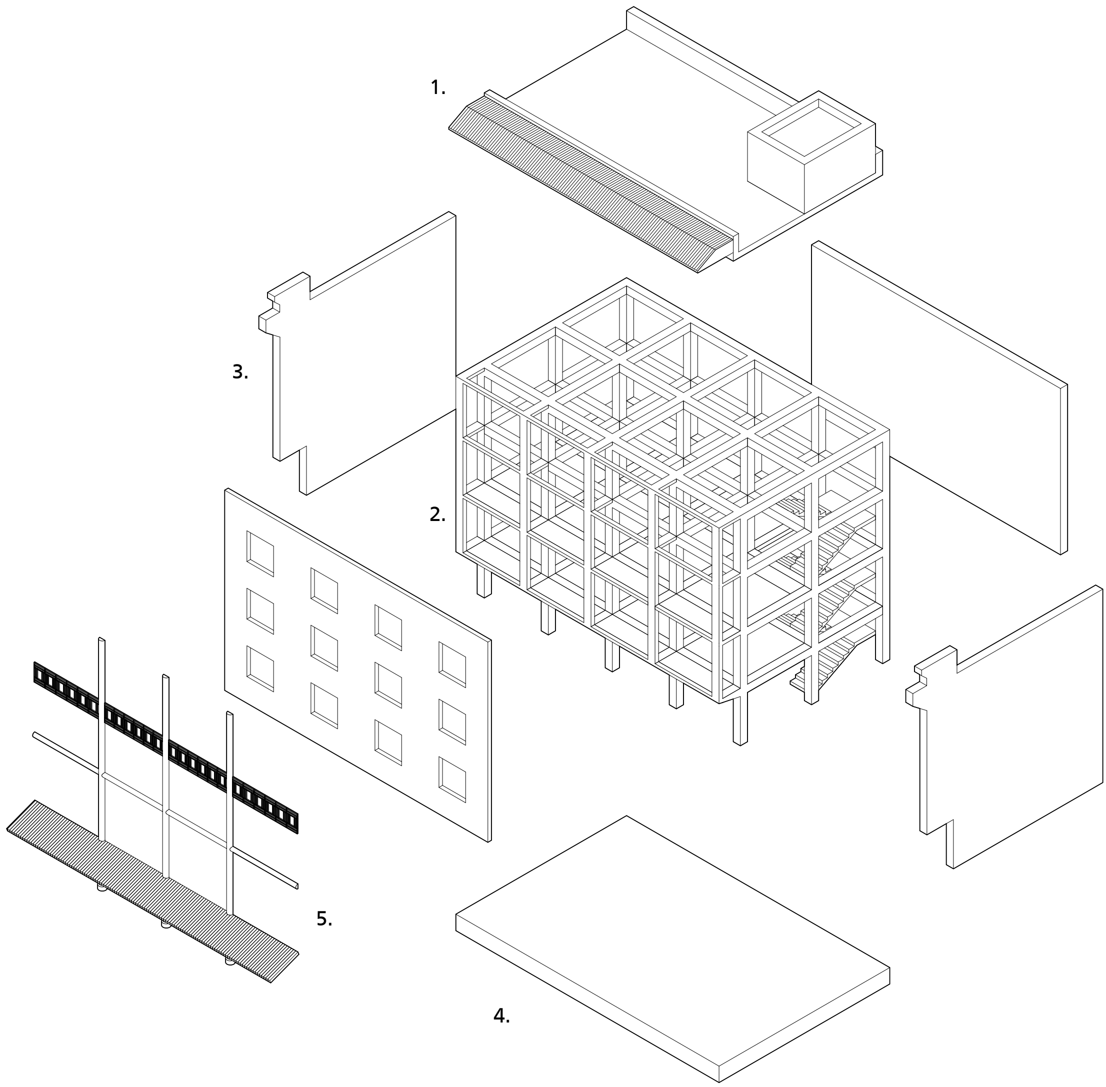
CONTEMPORAY BUILDINGS IN STYLE

This category of buildings (**Fig. 5.18**) includes buildings that were built between the 80' and the present, but, since they were built on the principal road of Fenghuan Town, their architectural characteristics, imitate, the traditional ones.

The wooden structure has been changed with a punctual concrete structure, the envelope is composed by brick walls, covered with plaster. On the facade the windows imitate the traditional ones and often, there's a decorative wood structure. (**Fig. 5.19**)

Also, the Matou Qiang is still present.

Fig. 5.18
Exploded axonometry of a contemporary building in style, the decorations try to imitate the ancient buildings.



1. Flat roof
2. Concrete Structure
3. Brick uninsulated wall
4. Basement
5. Decorations

Fig. 5.19
Photo of contemporary buildings on the new secondary road, as is possible to see, the buildings have decorations that reminds of the traditional buildings

Fig. 5.20
Contemporary building on the new road

Fig. 5.21
Photo a bridge that was built on the river, imitating the ancient techniques, this solution creates false historic buildings

5.1 GUIDELINES FOR THE FENHUANG TOWN PRESERVATION

The analysis of the different typologies and the different schemes with their position, allowed to identify three different levels of protection of the city, that has to be respected in order to preserve its identity, even when modifications are necessary to improve the quality of life of its inhabitants.

THE THREE LEVELS OF PROTECTION

The **first level** of protection refers to all those building that are considered “Remaining buildings of the old city”, these buildings are the ones that were built during the Ming (1368-1644) and the Qing (1636-1912) dynasties. They can be considered as the historic value of the town and for this reason, they should be preserved and therefore have a strict list of rules for the interventions.
The **second level** is designed, for those buildings that are classified as “New Construction with ancient techniques”, these buildings has to be protected since they have historic value and they also use the traditional constructive system. But also, their location and their use allow them to have a less restrictive set of rules.
The **third level** is related to all those building that has no historic value and share modern constructive systems, in this category is possible to find those buildings that were built as “false historical buildings”.

In the next paragraph all the rule sets are going to be defined, divided also in the various compatible and incompatible interventions for any constructive element.

FIRST LEVEL OF PROTECTION

Fig. 5.22
Map that individuates the first level of protection that should be applied in Fenhuang Town

GENERAL RULES

- The demolition of any traditional building is prohibited, unless structural problems are present, and they cannot be resolved by interventions of consolidation (they still have to respect the following rules about the possible interventions onto the structural system). The demolitions must be performed with precautions regarding the surrounding buildings
- In case of new constructions or reconstructions of traditional buildings, the new buildings must be reconstructed respecting the architectural characteristics of the ancient road. The height of the new building must respect, the surrounding.
- It is not possible to build any element or space, above the height of the roofs of the traditional buildings
- Addition of new elements, should be avoided, when necessary, they should be easily distinguishable to avoid historic imitations
- The Matou Qiang and therefore the city structure must be respected, and no modifications are allowed

STRUCTURAL INTERVENTIONS

The structural system of the courtyards is based on the use of wood pillars and beams (oak or pine), this system is used to the vertical transfer of the weight. The pillars usually have round shape, with a stoned base, used to prevent the rising of humidity.
These elements can suffer from different type of degradations, such as the deformation of the elements or the breakage ion different points. They can also suffer from rotting phenomena, biological attacks.

COMPATIBLE INTERVENTIONS
- Cleaning of the elements
- Protection of the elements with the use of a coherent and resin-free paint
- Replacement of the broken or deformed parts, with wood elements, that must be distinguishable from the original
- Disinfestation from biological attacks
- Any operation util to the consolidation of the elements that respect the rules above

WALL INTERVENTIONS

There are two main constructive systems used for the construction of the walls. The first one, is based on the use of earth blocks, covered with plaster. The second one is the method used for all the other walls, interiors or exteriors and is composed just by a single layer of wood planks. These two systems are not suitable for a comfortable building since the insulation is not sufficient.
The base of the earth walls is composed with several layers of rocks, this was done to prevent the humidity rise into the wall structure.
The decays phenomena affecting the wall structures can be divided into two big families: lesions and structural instability and deterioration related to materials and surfaces. The lesions, the

Fig. 5.23
Detail of the wooden beam on the facade

Fig. 5.24
Wood column visible in the interior of a local, the interior walls are thinner that the column

Fig. 5.25
A wall with earth-based plaster, subject to plaster peeling phenomena

fractures, the bulges and the collapses belong to the first family and involve the entire masonry box or portions of it. The lesion in correspondence with the cantonal, indicate the tendency of the wall box to open, injuries in correspondence with opening can be caused by a collapse of the foundations; injuries in correspondence with the connections between masonry and roof can denounce punching phenomena by roof elements; the outlines indicate the tendency of the wall to open under the weight of vertical or inclined thrusts. However, for the decays that affect the surfaces of the buildings, two phenomena can be identified. The first one related to the materials used (erosion, scaling, faults, fractures) and the second one related to the presence of biological patinas and attack from weeds.

Fig. 5.26
A earth-bricks Matou Qiang, it's possible to notice the decoration made with roof tiles

COMPATIBLE INTERVENTIONS
- Partial and punctual additions of collapsed or unstable masonry using compatible materials
- Removal of the vegetation on the surfaces and disinfestation by bio-deterioration agents.
- Cleaning of the masonry surfaces
- Reparation and rendering of the paster layers using lime-based or earth-based plasters according to tradition.
- Protection of surfaces exposed to atmospheric agents with breathable and transparent impermeable products.

Fig. 5.27
Stone made Matou Qiang

ROOF INTERVENTIONS

The roof is two pitched and rests on a wooden structure thanks to the use of wooden beam and joists. The ridge of the roof is decorated with tiles or stone elements.
The structure of the roof is composed by wood and it is "insulated" with a layer of rammed earth. The structure of the roof can be affected by the same problems of the ones descripted in the paragraph "Structural interventions", therefore the solutions used for the structural parts can be

Fig. 5.28
Courtyard Roof

considered the same.
Also, the problems related to the wood purlin, that are part of the structure, can be attributable to the marking and breakage of the elements.
The breaking of the roofing tiles can cause infiltrations that damage the wooden elements of the roof structure: the wooden elements of the secondary and main warping may therefore be subject to rotting phenomena favored by infiltration from the roof covering.
The decorations can be subjected to breakage and formation of biological patinas.

Fig. 5.29
Roof wood structure, it is possible to notice the rammed earth layers use to insulate the wood planks and also to offer sustain to the tiles

COMPATIBLE INTERVENTIONS
- For the structural part of the roof, all the considerations made in the "structural interventions" paragraph can be considered valid
- The replacement of the shingles has to be made with elements with the same construction material, and has to be coherent with the existing ones, if possible, a slightly different shade of color is preferable in order to help the distinguish of these elements from the original ones
- Cleaning of shingles
- Replacement of the decoration elements, with one with similar characteristics, with distinguishable materials, to avoid historic false elements
- Any major intervention on the structure must be made with the same structural system, is not possible to build a new slab in concrete or similar materials

Fig. 5.30
Ridge decoration of the roof, in this case both the tiles and the stone decoration are present

INTERIOR SLABS AND PAVEMENTS

The horizontal partitions inside the courtyard typology are built with wood planks seating on top of a wooden structure. The floor on the ground floors are covered with a concrete layer. The forms of decay that interest most the wood elements of the slabs are related to rot phenomena. The decay
phenomena that interest wood are related to

the high level of humidity and infiltration of water that can occur due to a lack of maintenance. The primary and secondary beams that support the slabs, are related to structural decays: localized deformations, fractures, and collapses.

COMPATIBLE INTERVENTIONS

- Disinfestation and disinfection from biological attacks
- Cleansing of wooden elements
- Replacement of individual degraded and not recoverable planks with other similar ones in terms of shape and materials

Fig. 5.31
Interior horizontal division, is possible to notice the presence of paper that was glued to the structure in order to protect it from humidity

OPENINGS

DOORS

The doors in the courtyard typologies can be divided in two categories, the first ones, that relates to the apertures on the ancient road and the second one that contains the doors that connects the interior locals to the courtyard. The first ones are composed by a series of wood planks that can be removed to create a full open facade. The doors of the second category are single or dual doors in wood.

Fig. 5.32
Facade opening, the single wood planks are removable, allowing the resident to adapt the “door” to his needs

WINDOWS

Windows can be divided in two types, fixed windows, with no possibility to be closed and windows with a wood fixed frame and a wood shutter that allows the inhabitants to close them. These two elements may exhibit rotting phenomena, especially in the parts that are most exposed to atmospheric agents. Another problem can be breakage of the components or deformations.

COMPATIBLE INTERVENTIONS

- All the interventions of consolidation must be

made with compatible wooden materials
- The replacement of elements must be made with wooden elements
- The construction of new opening must be made respecting the proportions of the facade, and has to be similar to the existing ones, using traditional materials and techniques.
- Insertion of new protective systems, installation of new shutters
- New frames can be used, only when the recovery of the original ones is not possible.

Fig. 5.33
Opening with no shutter, on the facade of a traditional building

STAIRS

All the historic buildings along the ancient road seat on a higher lever from the road. The connection between these two levels is made possible with the use of a stone stair.
The interior connection between the floors of this typology is made with the use of a wood ladder.
External stairs are particularly expose to atmospheric agents and can be subjected to different decays, such as lesions, breakage, and deformation of the components (due to the temperature change and the use of the stairs)
Another problem could be the growth of vegetation in the cracks of the stone.

COMPATIBLE INTERVENTION
- Periodical cleansing and removal of weed vegetation
- Replacement of the elements with compatible new elements, equal in craftmanship
- In the case of the ladders is possible to replace the single broken element or the whole ladder, when is not possible to recover it.

SECOND LEVEL OF PROTECTION

Fig. 5.34
Map that individuates the position of the building with a second level of protection

GENERAL RULES

- The demolition of any building of this category is prohibited, unless structural problems are present, and they cannot be resolved by interventions of consolidation (they still must to respect the following rules about the possible interventions onto the structural system). The demolitions have to be performed with precautions regarding the surrounding buildings
- In case of new constructions or reconstructions of traditional buildings, the new constructions must respect, the surrounding.
- It is not possible to build any element or space, above the height of the roofs of the existing buildings
- Addition of new elements, should be avoided, when necessary, should be easily distinguishable

STRUCTURAL INTERVENTIONS

The structural system of the buildings in this category is the same of the traditional building. The pillars usually have round shape, with a stoned base, used to prevent the rising of humidity. These elements can suffer from different type of degradations, such as the deformation of the elements or the breakage ion different points. They can also suffer from rotting phenomena, biological attacks.

COMPATIBLE INTERVENTIONS

- Cleansing of the elements
- Protection of the elements with the use of a coherent and resin-free paint
- Replacement of the broken or deformed parts, with wood elements, that must be distinguishable from the original
- Disinfestation from biological attacks
- Any operation util to the consolidation of the elements that respect the rules above

WALL INTERVENTIONS

Fig. 5.35
Exterior walls of the typology, here is possible also to observe the different openings from the previous category and also the presence of a different type of Matou Qiang

Wall are all built with the same construction system, it composed by a structure of earth brick covered with plaster.

The walls can suffer from lesions and structural instability and deterioration related to materials and surfaces. The lesions, the fractures, the bulges, and the collapses belong to the first family and involve the entire masonry box or portions of it. The lesion in correspondence with the cantonal, indicate the tendency of the wall box to open; injuries in correspondence with opening can be caused by a collapse of the foundations; injuries in correspondence with the connections between masonry and roof can denounce punching phenomena by roof elements; the outlines indicate the tendency of the wall to open under the weight of vertical or inclined thrusts. However, for the decays that affect the surfaces of the buildings, two phenomena can be identified. The first one related to the materials used (erosion, scaling, faults, fractures) and the second one related to the presence of biological patinas and attack from weeds.

COMPATIBLE INTERVENTIONS

- Partial and punctual additions of collapsed or unstable masonry using compatible materials
- Removal of the vegetation on the surfaces and disinfestation by bio-deterioration agents.
- Cleaning of the masonry surfaces
- Reparation and rendering of the paster layers using lime-based or earth-based plasters according to tradition.
- Protection of surfaces exposed to atmospheric agents with breathable and transparent impermeable products.

ROOF INTERVENTIONS

The roof is two pitched and rests on a wooden structure thanks to the use of wooden beam and joists.
The structure of the roof is composed by wood, and it is “insulated” with a layer of rammed earth.

The structure of the roof can be affected by the same problems of the ones descripted in the paragraph “Structural interventions”, therefore the solutions used for the structural parts can be considered the same.
Also, the problems related to the wood purlin, that are part of the structure, can be attributable to the marking and breakage of the elements.
The breaking of the roofing tiles can cause infiltrations that damage the wooden elements of the roof structure: the wooden elements of the secondary and main warping may therefore be subject to rotting phenomena favored by

infiltration from the roof covering.
The decorations can be subjected to breakage and formation of biological patinas.

COMPATIBLE INTERVENTIONS

- For the structural part of the roof, all the considerations made in the “structural interventions” paragraph can be considered valid
- The replacement of the shingles must be made with elements with the same construction material, and must be coherent with the existing ones, if possible, a slightly different shade of color is preferable in order to help the distinguish of these elements from the original ones
- Cleaning of shingles
- Replacement of the decoration elements, with one with similar characteristics, with distinguishable materials, to avoid historic false elements
- Any major intervention on the structure must be made with the same structural system, is not possible to build a new slab in concrete or similar materials

INTERIOR SLABS AND PAVEMENTS

The horizontal partitions are built with wood planks seating on top of a wooden structure.
The floor on the ground floor is covered with a concrete layer.
The forms of decay that interest most the wood elements of the slabs are related to rot phenomena. The decay
phenomena that interest wood are related to the high level of humidity and infiltration of water that can occur due to a lack of maintenance. The primary and secondary beams that support the slabs, are related to structural decays: localized deformations, fractures, and collapses.

COMPATIBLE INTERVENTIONS

- Disinfestation and disinfection from biological attacks
- Cleansing of wooden elements
- Replacement of individual degraded and not recoverable planks with other similar ones in terms of shape and materials

OPENINGS

DOORS

The external doors are usually dual doors, in wood, with wood frame. The interior ones are single doors in wood.

WINDOWS

Windows are larger than the ones that we can find in the traditional buildings, they usually have a wood frame with single pane glass.

COMPATIBLE INTERVENTIONS
- All the interventions of consolidation must be made with compatible wooden materials
- The replacement of elements has to be made with wooden elements
- The construction of new opening must be made respecting the proportions of the facade, and has to be similar to the existing ones, using traditional materials and techniques.
- Insertion of new protective systems, installation of new shutters
- New frames can be used, only when the recovery of the original ones is not possible.

STAIRS

There's no information regarding the typology of stairs in this building.

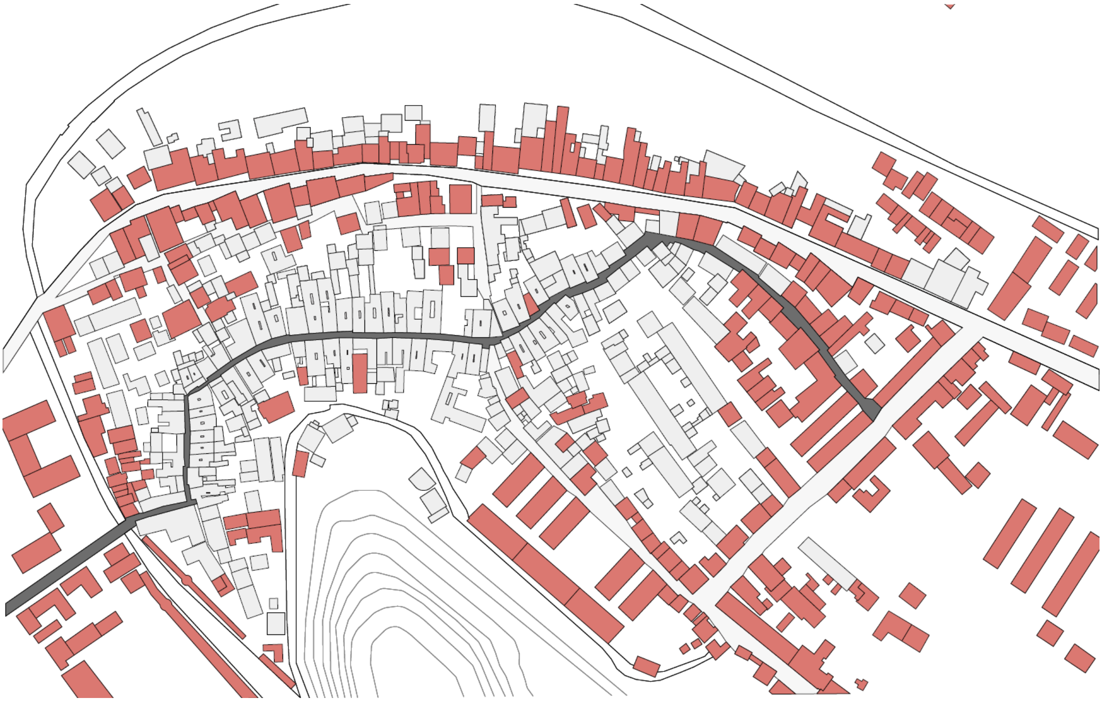


Fig. 5.36
Map that individuates the third level of protection for the buildings in Fenhuang Town

THIRD LEVEL OF PROTECTION

GENERAL RULES

- One of the main concerns of these buildings' maintenance should be the energy consumption improvement, when is possible, retrofitting should be considered.
- The retrofitting operations should be regulated based on the China Energy Efficient Building code
- The height of the buildings should be maintained as it is

STRUCTURAL INTERVENTIONS

The structural system of this buildings is usually a frame concrete system, the envelope is not insulated. There's also a case of prefabrication

COMPATIBLE INTERVENTIONS

- Consolidation of the structures
- Dehumidification of the structure in case of problem deriving from the humidity rise

Fig. 5.37
Prefabricated building in concrete, the opening as can be noticed, are composed with an aluminum frame and glass.

WALL INTERVENTIONS

The envelope is built with hollow bricks covered with plaster or tiles. Some cases of bricks facades are present in the town scenario.

COMPATIBLE INTERVENTIONS

- Consolidation of the plaster layers
- Surface cleaning
- Retrofitting of the envelope with the use of insulation and new layers of plaster

Fig. 5.38
White tile covered building - The exterior finish can vary in the town scenario, but it is usually composed by a layer of plaster, tiles or mortar

ROOF INTERVENTIONS

Concrete roof, usually flat or covered with metallic sheets.

COMPATIBLE INTERVENTIONS

- Impermeabilization of the roof
- Construction of eaves where necessary
- No structures should be added on the roof previous a detailed structural analysis

Fig. 5.39
Modern building with traditional decorations, the columns have no structural purposes

INTERIOR SLABS AND PAVEMENTS

The horizontal partitions are built with the use of a concrete slab with a layer of screed and tiles.

COMPATIBLE INTERVENTIONS

- Replacement of the tiles
- Insertion of floor heating system when a previous operation of retrofitting was performed
- Sound Proofing of the floor to reduce the sound dispersion and improve the quality of the locals

OPENINGS

DOORS

Usually single doors in wood, with wood frame

WINDOWS

Windows with aluminum frame and single glass pane

COMPATIBLE INTERVENTIONS

- Replacement of doors and windows with energy efficient ones, but only, when an entire retrofitting operation has been performed
- Alteration of the dimensions of the openings is allowed, but with a previous evaluation of the impact on the whole building image
- Additions of decorations that imitate the traditional buildings are totally forbidden
-

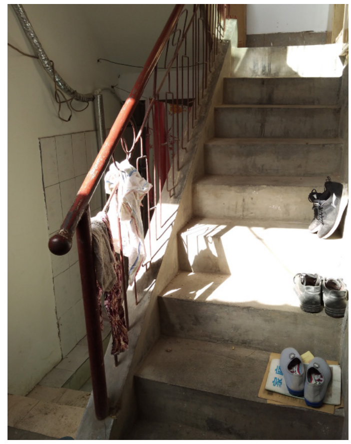


Fig. 5.40
Concrete stairs with red metallic rail - the steps are not covered with tiles or stone, the visible layer is the structural concrete

STAIRS

Stairs in these buildings are made of concrete with metallic railings.

COMPATIBLE INTERVENTIONS
- It is possible to fill the lack of material on the steps if present
- Cover of the steps with tiles

66666
66666
PROJEC
CTPROJ
ECTPRO
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6.1 URBAN STRATEGY

INTERPRETATION OF THE CITY STRUCTURE

In the next scheme, a vision of the city structure is proposed, where the existing Matou Qiang and short walls that divide the properties of the vegetable gardens are prolonged, showing how the modern buildings and the agricultural fields are following the same alignment. (**Fig. 6.1**)

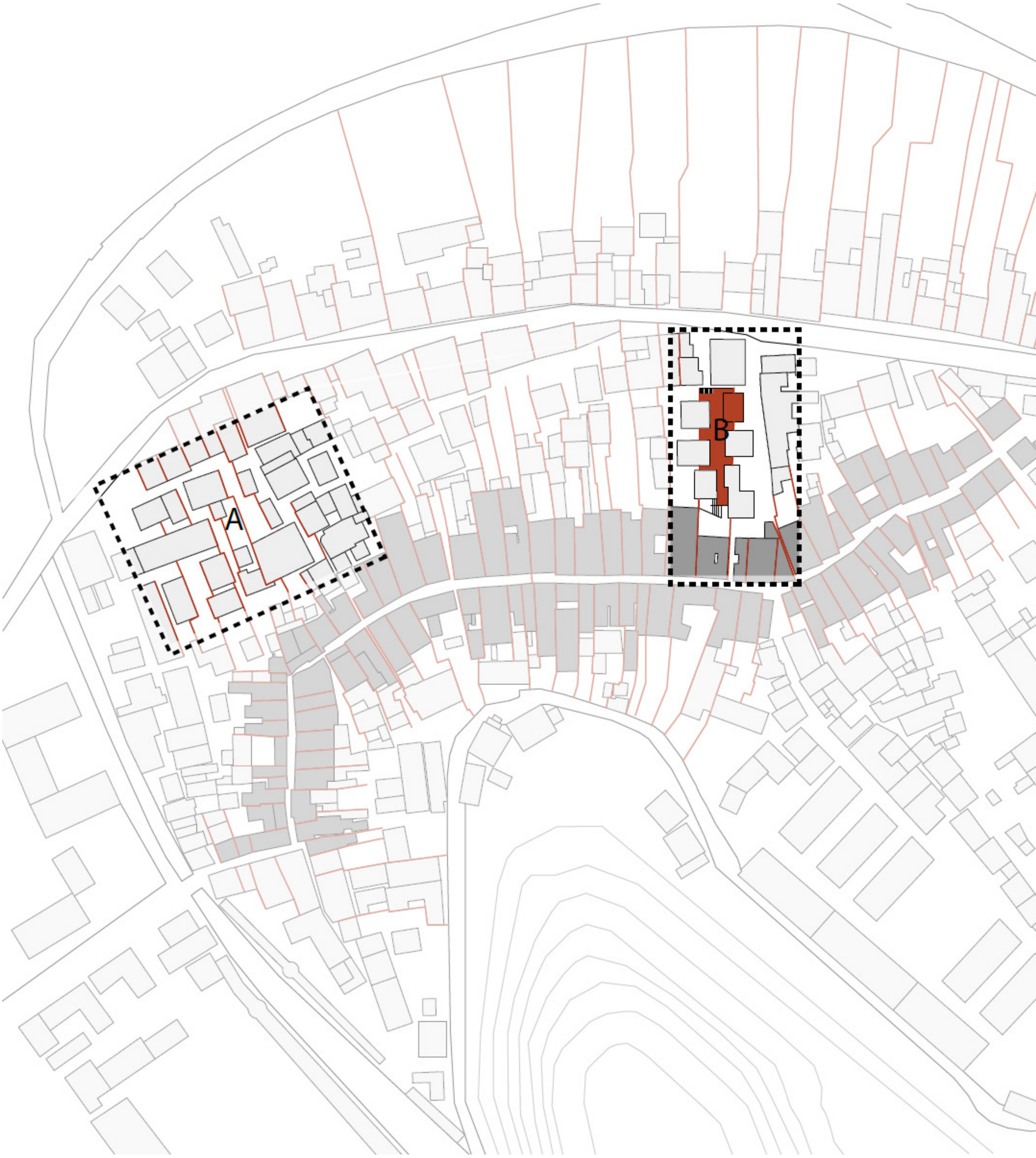
Fig. 6.1
Structure of the city, the rhythm of the whole town is defined by the Matou Qiang, its direction is followed by the backyard gardens, the modern buildings and the fields on the riverside


A
B

INTERRUPTIONS IN THE CITY STRUCTURE

In the previous scheme, we had noticed that the structure that the city follow gets interrupted in the areas A and B. **(Fig. 6.2)**

Fig. 6.2
Map showing the lack of structure in the evidenced parts A and B


A
B

MENDING OF THE TWO AREAS

The areas A and B, represents a fracture in the city structure.
In the area B the walls and the alignment derive from the Matou Qiang are totally missing, while in the area A, the lines are still readable. (**Fig. 6.3**)

Fig. 6.3
Map that illustrates the differences between the area A and the area B

The urban strategy is developed in two different ways, in the A area we will try to design different vegetable gardens and low walls to divide the properties, while in the B area, based on the dimensions of the missing lacuna, we decide to rebuild a Matou Qiang and follow its alignment to the design of a new building that also connects the buildings on the back of the lacuna **(Fig. 6.4)**

Fig. 6.4
Urban strategy definition

6.2 THE LACUNA AND THE FRAGMENT

The 2017 fire caused, as it was written before, the destruction of a courtyard and the collapse of the west wing of another one.

Fig. 6.5
Elevation of the state of the art

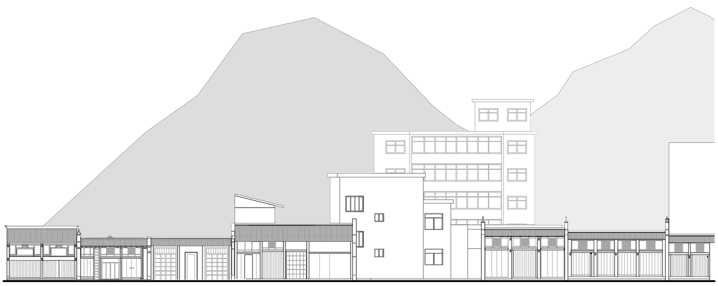


Fig. 6.6
Reconstruction of the *fragment*. It is not possible to reconstruct the burnt courtyard cause the lack of materials.

Fig. 6.7
Photograph from the ancient road, is possible to notice the collapsed part of the courtyard.

Fig. 6.8
Panoramic view of the "lacuna", is possible to see the traditional structural system in the remainings of the courtyard.

Fig. 6.9
Plan of the state of art of the fragment after the fire in 2017

Fig. 6.10
Section of the state of art

Fig. 6.11
Plan of the reconstruction of the fragment of the courtyard. For what it concerns, is possible to reconstruct only the outline of the collapsed courtyard since there's no information about the plan

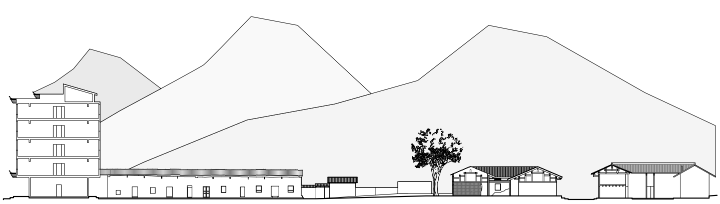


Fig. 6.12
Section of the state of art of the Fragment

6.3 THE ARCHITECTURAL PROJECT

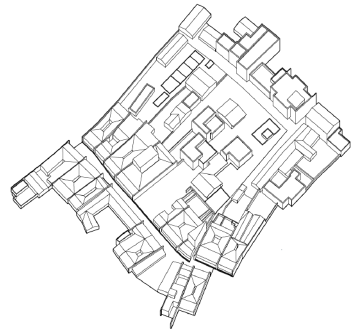
The project is divided in two main parts, the first one, related to the lacuna and the fragment and the second one, that tries to connect the existing modern buildings and to extend the structure of the city and the ancient road to them. (**Fig. 6.13**)

In the lacuna part, the main goal, is to fill the void that was left by the 2017 fire.
The strategy was to recreate the old courtyard, with the same proportions and same dimensions. Using wood as principal material for the structure and the interior finishes. The idea at the beginning was to use the traditional wooden structure system, but it was preferred to use a modern one, since it gives the possibility to have a more open plan compared to the traditional.

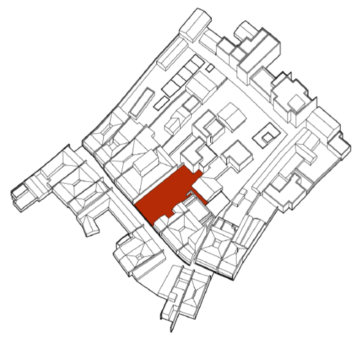
The Matou Qiang was designed to follow the original route of the demolished one, and it was built with as wood structure, covered with grey bricks instead of the use of rammed earth.

The New Courtyard follows the same proportions of the original building, but the roof is going to host PV panels, and it was designed, to allow the light to enter from the pitch.

In this new building, the idea was to follow the tradition of the commercial space in the front, facing the Ancient Road, for this reason this space is going to be destinated to host Restaurant functions.



State of the art



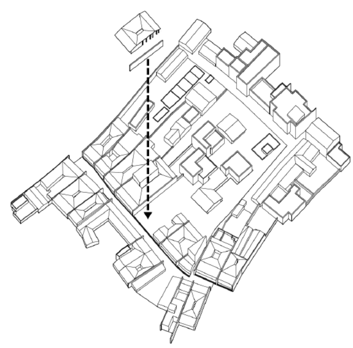
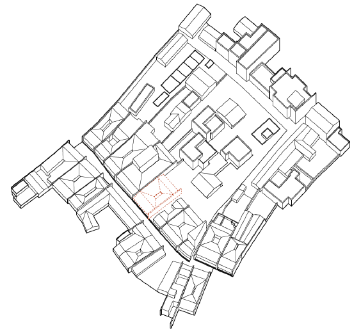


Fig. 6.13
Diagrams of the architectural strategy for the cultural center and the new courtyard

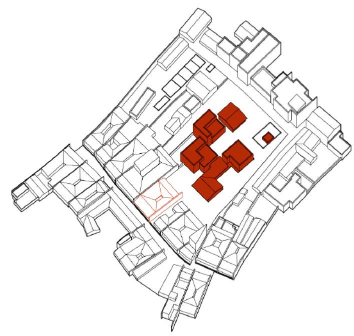
The fragment of the courtyard is going to be consolidated, and it will serve as a didactic building that can show the traditional constructive system, and it will serve as a connection between the principal road and the cultural center.

The second part of the project is going to be designed following the alignment of the two Matou Qiang that are present on the lacuna area.



New courtyard, Matou Qiang and Lacuna restoration

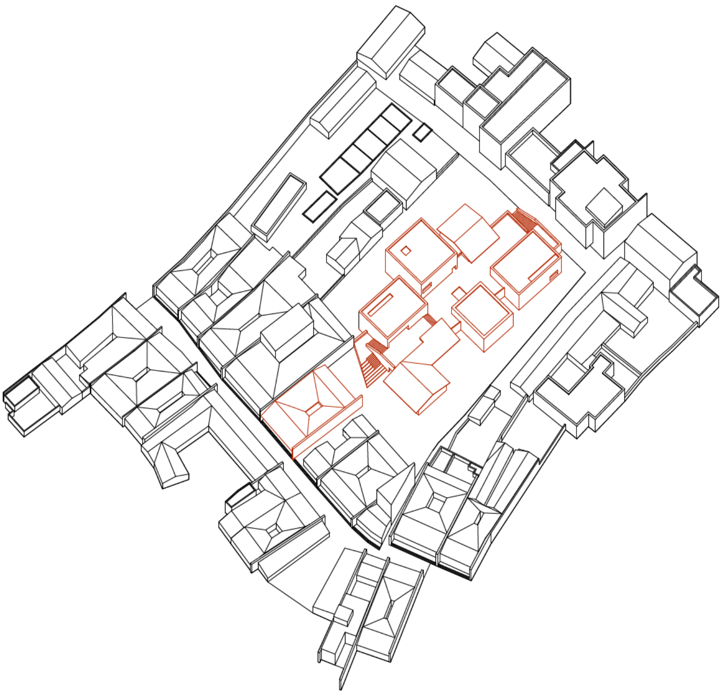
The existing building in this area, are not coherent with the structure of the city and they also have no coherence between them, they use different construction systems, they have different morphologies and are built with different materials.

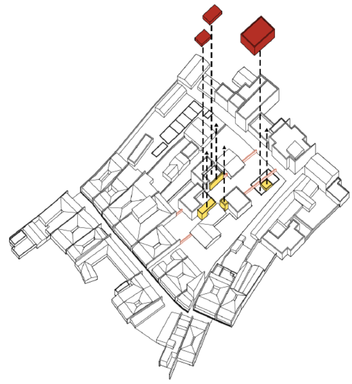


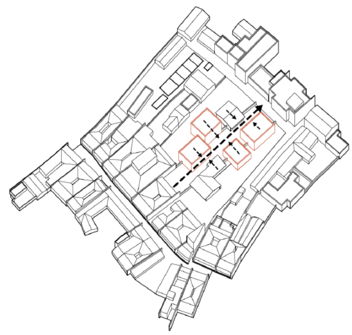
To pursue this goal, some volumetric operations were designed on the existing buildings, as well as the construction of a new building on north-east corner of the plot.
The building was designed around the purpose to be used as a Cultural Center, representing the city.

There’s going to be galleries, an auditorium where the traditional dances can be presented, a library and a small gaming center for the elderly.
The decision to maintain the existing buildings was also leaded by the desire to avoid the usage of new raw materials, improving the used techniques instead.

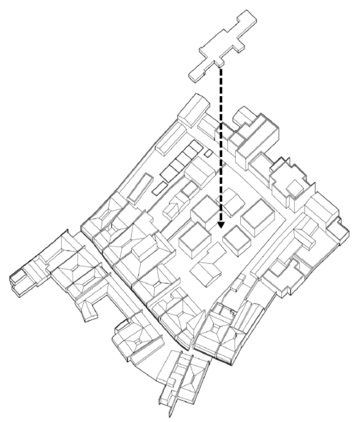
Need to confirm the Matou Qiang in the existing building structure







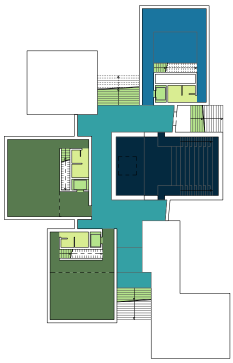
Flow from the courtyard



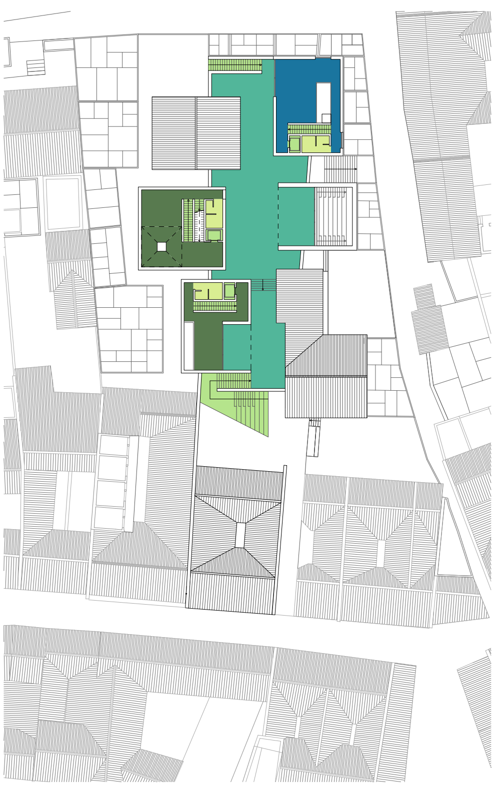
Circulation building

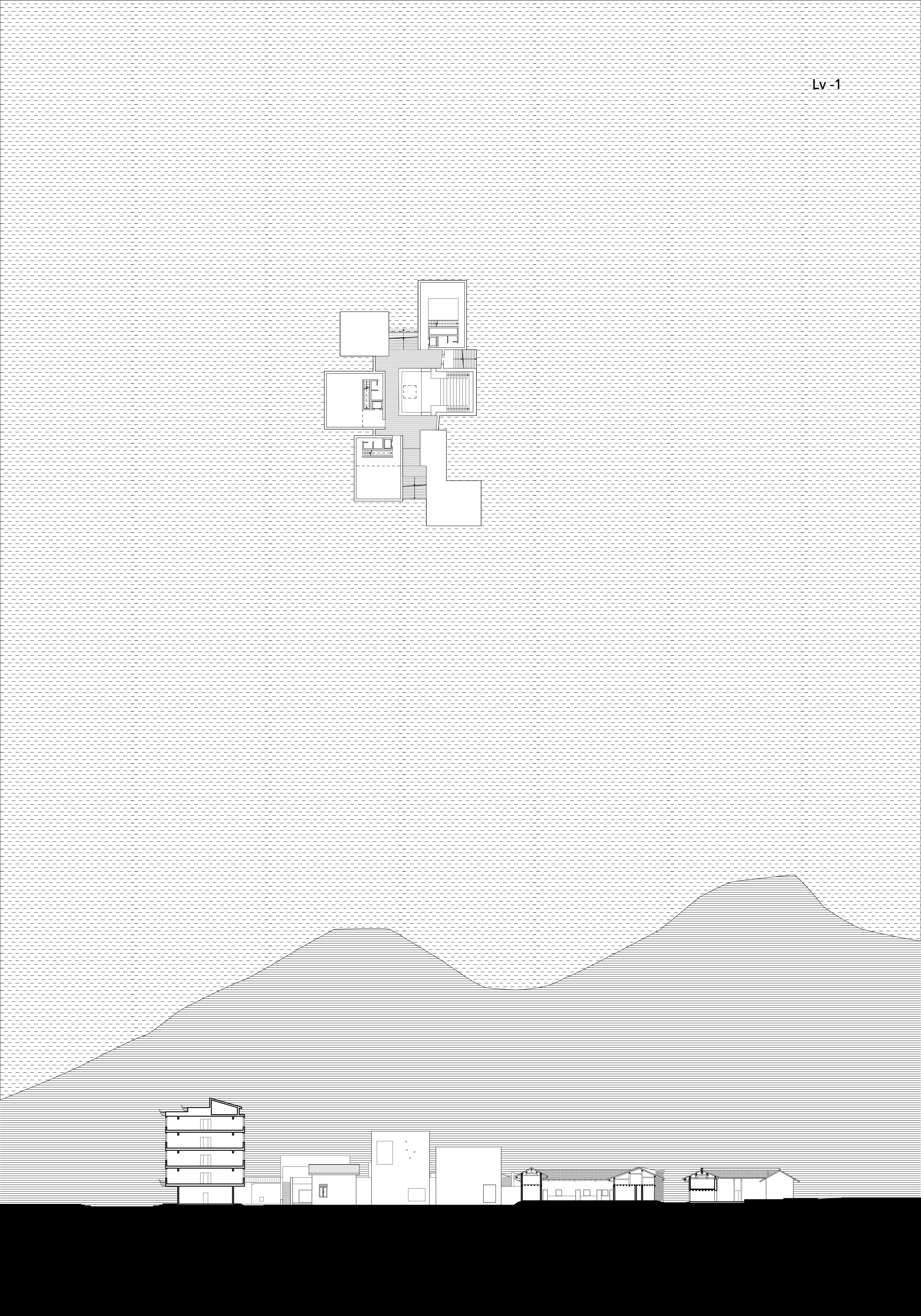
Fig. 6.14
On the left, axonometry of the architectural project

Fig. 6.15
On the next page, functional scheme



- Gallery
- Auditorium
- Leisure Center
- Workshop
- Lobby
- Restaurant
- Kitchen
- Pedestrian Roof
- Stairs/Elevators
- Restrooms




Lv -1

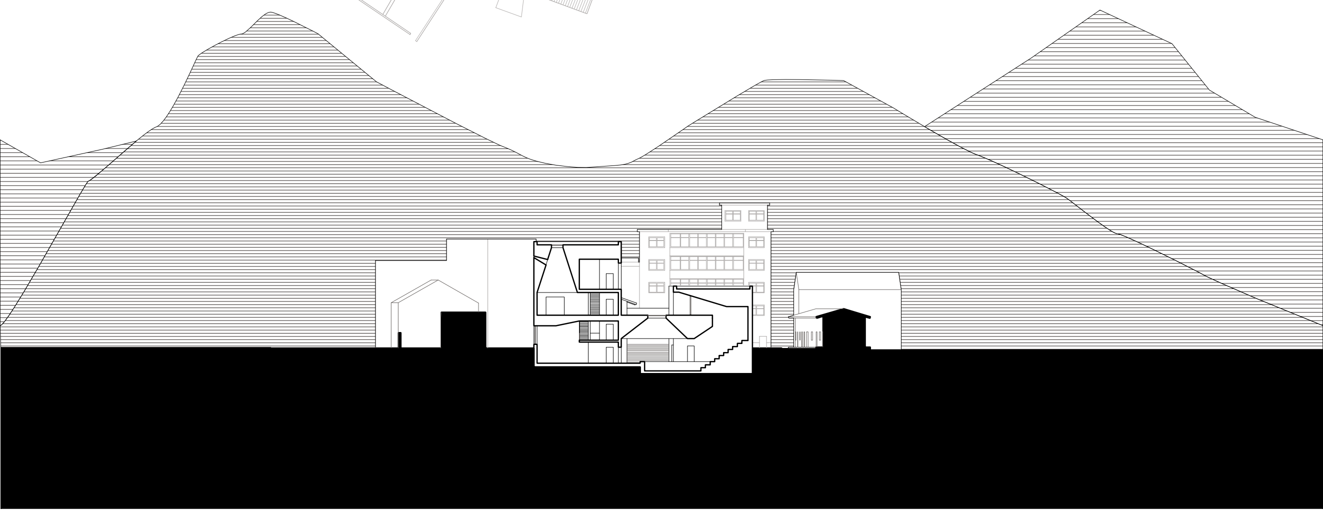
Lv 0

0 5 10 20

Lv 1

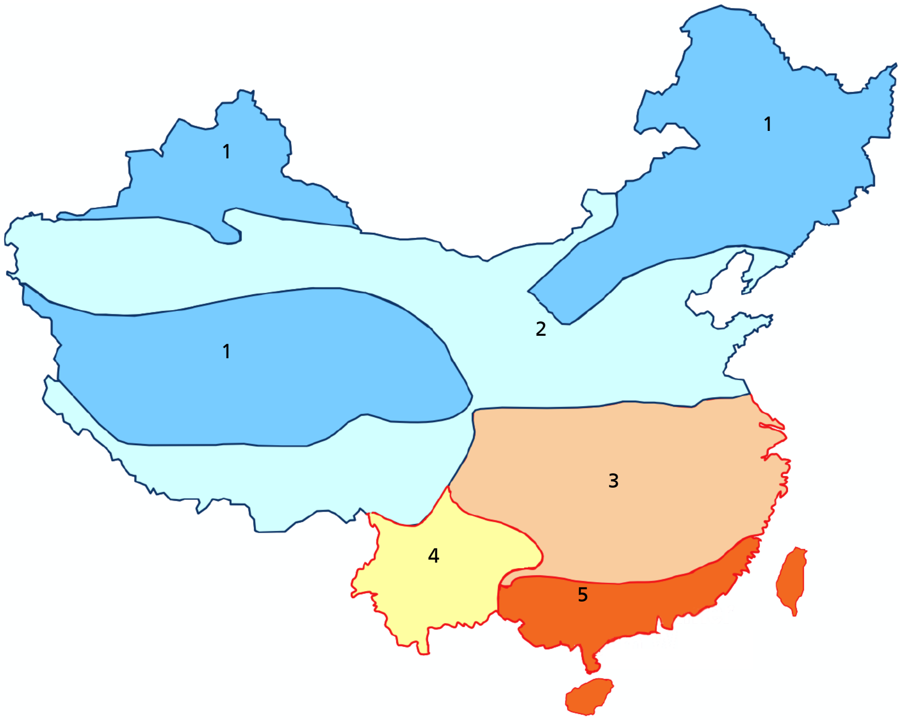
Lv 2

Roof Plan




0 5 10 20

7.1 CHINA'S BUILDING ENERGY EFFICIENCY CODE



1. Severe cold
2. Cold
3. Hot summer and cold winter
4. Temperate
5. Hot summer and warm winter

Fig. 7.1
China's climatic zones division

China Design Standard for Energy Efficiency in public buildings was published in 2005 when China completed the 10th Five-Year Plan. It was then updated in 2014 to increase the energy saving targets by 30%.

China's building energy standard divides China in five different climate zones: severe cold, cold, hot summer and cold winter, temperate and hot summer and warm winter. The energy efficiency code for buildings, is different for each one of the 5 climate zones. (**Fig. 7.1**)
Fenhuang town is located in the Cold Region, therefore, during the energy simulations and the decisions regarding the envelope, the HVAC system, the lighting system, the Cold Region code is going to be the reference.

The code has been divided in two different regulations, for public and residential buildings (**Table 7.1**), whilst the U-values are similar between the two, the most important part is the shading limitation in the public buildings. (**Table 7.2**)

Also, the lightning density is being limited in order to promote the use of new technologies such as LED lighting, instead of the incandescence bulbs that were used years ago. (**Table 7.3**)

Table 7.1
Limit U-values for the different elements of the envelope for residential buildings, based on the 2014 Standard Energy Efficiency code.

Building Envelope Component (residential buildings)		Heat transfer Coefficient (W/m^{2}K)		
		Cold A	Cold B	
			L. Const	H. Const
Roof	> 10 stories high	0.50	0.50	0.60
	7- 9 stories high	0.50	0.50	0.60
	4 - 6 stories high	0.50	0.50	0.60
	≤ 3 stories high	0.45	0.45	0.50.
Exterior Wall	> 10 stories high	0.50	0.50	0.60
	7- 9 stories high	0.50	0.50	0.60
	5 - 6 stories high	0.50	0.50	0.60
	≤ 3 stories high	0.45	0.45	0.50
Suspended or outward projecting floors exposed to outdoor air		0.50	0.60	
Walls and floors between unheated and heated spaces		1.20	1.00	
Entrance door		2.00	2.00	
Lower portion of balcony door		1.70	1.70	
Slab	Perimeter Slab	0.50		
	Non perimeter slab			
External Window	WWR ≤ 20%	2.80	3.20	
	20% < WWR ≤ 30%	2.80	3.20	
	30% < WWR ≤ 40%	2.50	2.80	0.70
	40% < WWR ≤ 50%	2.00	2.50	0.60

Building Envelope Component (public buildings)		Heat transfer Coefficient (W/m²K)			
		Cold A		Cold B	
Roof		0.55		0.45	
Exterior Wall		0.60		0.50	
Suspended or outward projecting floors exposed to outdoor air		0.60		0.50	
Walls and floors between unheated and heated spaces		1.50		1.50	
Exterior window		Heat transfer Coef.	Window shading	Heat transfer Coef.	Window shading
	WWR ≤ 20%	3.50		3.00	
	20% < WWR ≤ 30%	3.00		2.50	
	30% < WWR ≤ 40%	2.70	0.70	2.30	0.70
	40% < WWR ≤ 50%	2.30	0.60	2.00	0.60
	50% < WWR ≤ 70%	2.00	0.50	1.80	0.50
Roof Skylight area		2.7	0.5	2.7	0.5

Table 7.2
Limit U-values for the different elements of the envelope for commercial and public buildings, based on the 2014 Standard Energy Efficiency code.

Lightning Power Density (W/m²)		
Office	Office Room	9.00
	Conference room	9.00
	High Class office room	15.00
Hotels	Office Room	7.00
	Office Room	9.00
Schools	Class room	9.00
	Lab	9.00
Hospital	Exam/treatment	15.00
	Operating room	30.00
	Ward room	5.00
	Nurse station	9.00
	Pharmacy	15.00

Table 7.3
Limit lightning power density for the different locals in public buildings

7.2 FENHUANG TOWN CLIMATE ANALYSIS

From the graphs we can obtain information about the climatic situation of Fenhuang Town, unfortunately, there is no information about the town itself, so, to obtain the information the author, had to use the climatic database of the nearby city Lushi.

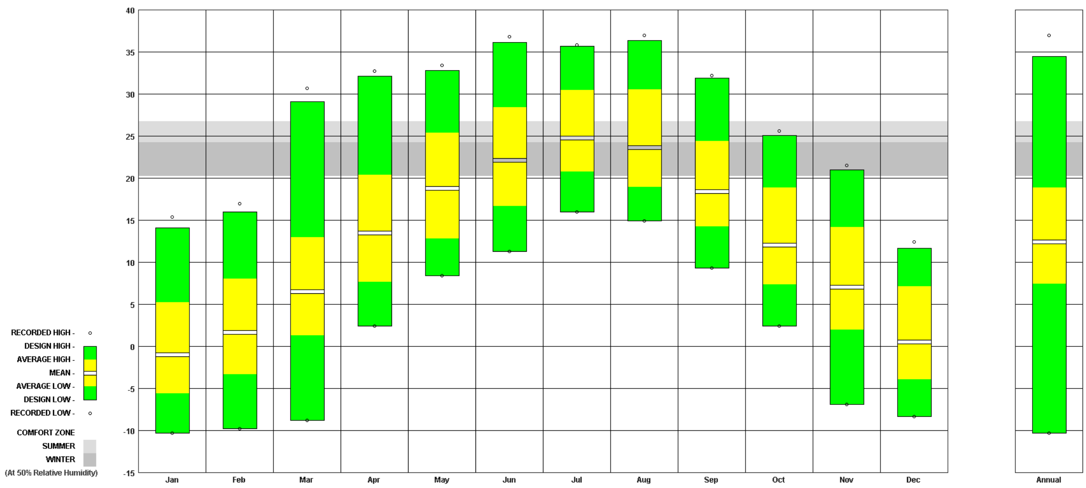
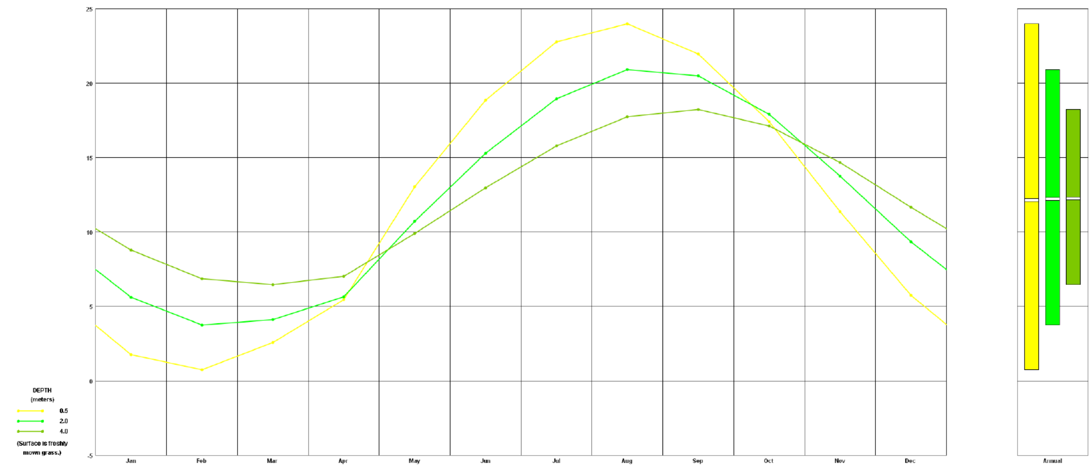


Fig. 7.2
Temperature ranges for Fenhuang Town

AIR TEMPERATURE

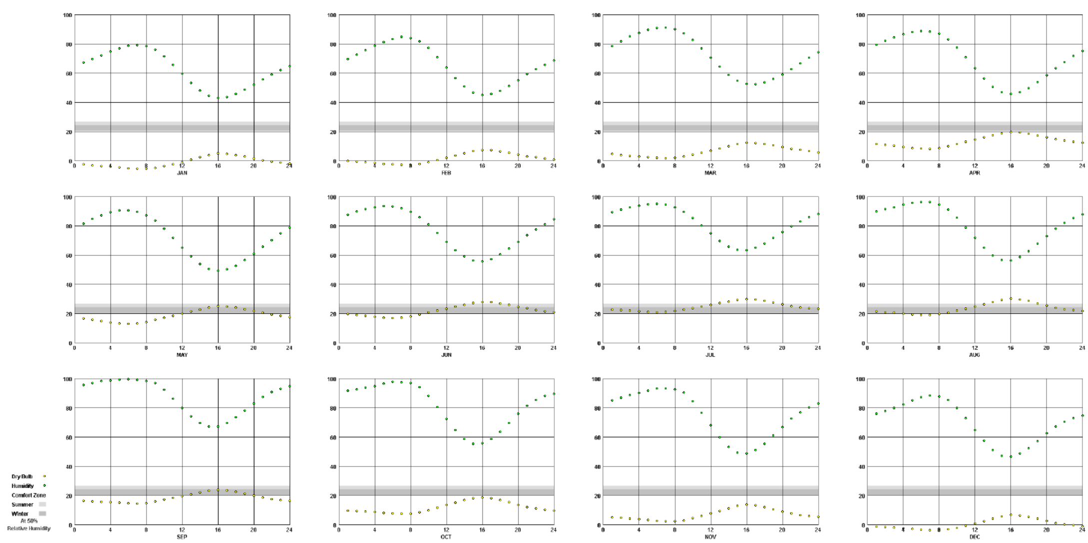
The average temperature (**Fig. 7.2**) maintains itself between -1 °C and 25 °C respectively during January and July. With the minimum recorded temperature of -10° C also in January, while the maximum temperature of 37°C was recorded during the months of June and August.
For the design purposes, we will consider a minimum temperature of -10° C and a maximum temperature of 36° C. With these data is possible to understand that during the year it will be necessary to intervene both during the hot season and the cold season to maintain the internal temperature in the comfort zone.



GROUND TEMPERATURE

The surface temperature varies from 1°C in the month of February to a maximum of 24° C in August. (**Fig. 7.3**)

Fig. 7.3
Ground temperature scheme in Fenhuang Town



RELATIVE HUMIDITY

The relative humidity graph (**Fig. 7.4**), illustrate us that in the case of residential activities dehumidification would be needed, since it always reaches levels between 80 and 100%, but since the schedule of utilization of the building is going to be like to an office, we can consider the range between 8 am and 8 pm, In this range, the necessity of dehumidification is mitigated since the values varies between 60% to 75%

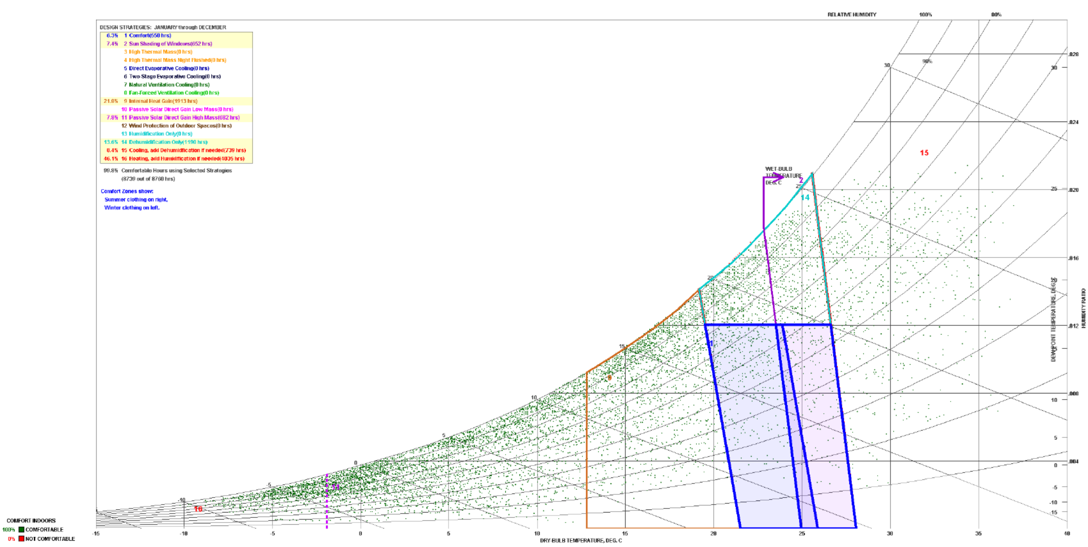
Fig. 7.4
Relative humidity and dry bulb temperature scheme in Fenhuang Town

BIOCLIMATIC CHART

With the bioclimatic chart (the base of the diagram is the psychometric chart) is possible to understand what kind of bioclimatic design solutions can effectively be used in a certain climate. (**Fig. 7.5**)

From this chart is possible to extract information about the comfort zone and the operations that are necessary to create those conditions inside a building. As we can observe based on the graphic only 6% of the time, an ideal building will reside in the comfort zone. The internal heat gains will help to increase this time by 22%. Active heating will be needed for the 46% of the hours during the year. The program also can give some general guidelines to reduce the energy consumption. Such as the lowering of the temperature during the non operative time of the building, the use of high thermal mass surface in the interiors to storage heat during winter.

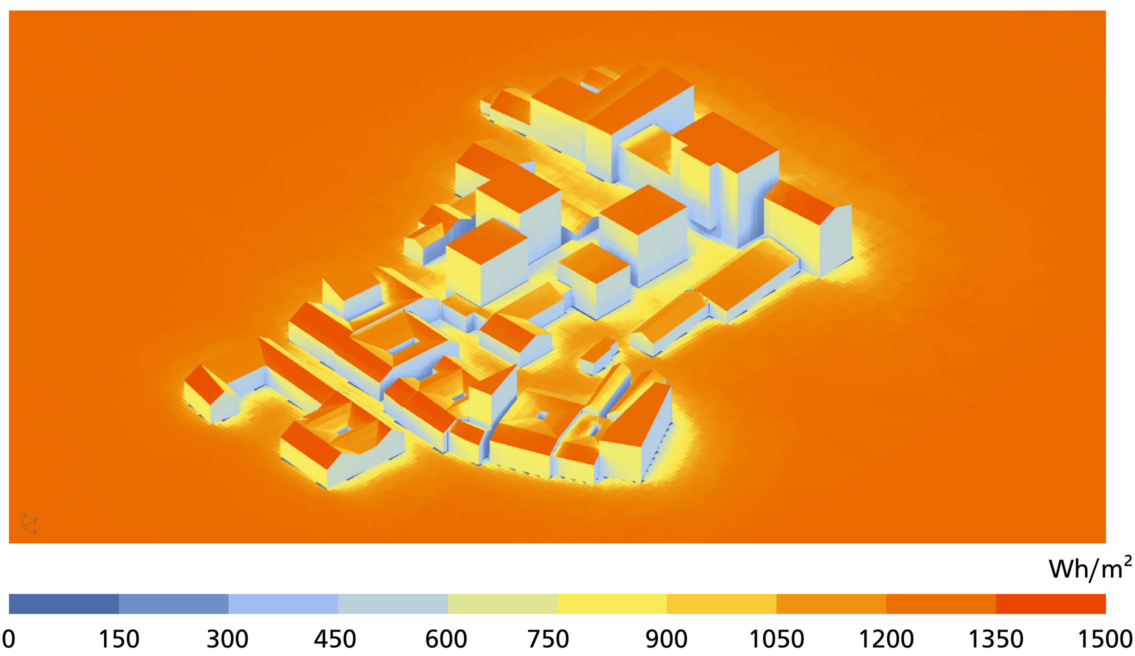
Fig. 7.5
Psychometric chart of Fenhuang Town



GRASSHOPPER AND THE PARAMETRIC MODEL

Grasshopper is a visual programming language and environment, that runs in Rhinoceros as a plug-in, it is capable to generate, control and modify simple and complex geometric elements, through algorithmic processes, it can be used in different fields such as architecture, engineering, and design.
Algorithms are generated dragging different components inside a canvas, these components can represent different functions, from geometric 2D shapes, to volumes, to movements in space etc..., the outputs from these modules can then be used as inputs in a chain of subsequent components; in this way Grasshopper allows the user to create complex 3D models, with the definition of a nodal diagram, that describes the mathematic and geometric relationship between different components of a project.

Fig. 7.6
Irradiation analysis of the context of the project



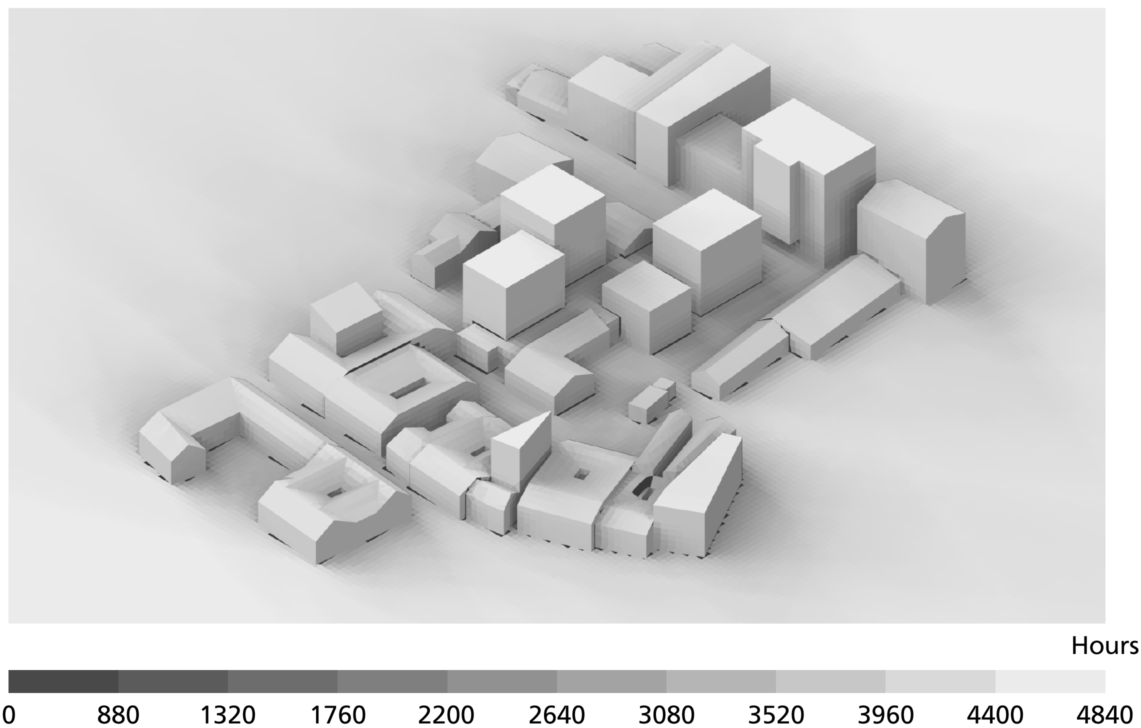
IRRADIATION ANALYSYS

From the irradiation analysis scheme (**Fig. 7.6**), is possible to understand which are the sides of the buildings that are more intensively affected by the solar radiation.
In this case is possible the most suitable zone could be the top surface of buildings A-B-D in the cultural center and the pitched roof of the new courtyard except for the north facing one.

HOURS OF SOLAR RADIATION

With this analysis (**Fig. 7.7**) is possible to obtain information about the solar behavior on the surfaces, these information cans be used for the architectural design to improve lighting usage in the building, to maximize the hours of natural light penetration. In this case, it is possible to notice that the backyard of the courtyard is darker than the ancient street, and that on the pedestrian roof the surrounding buildings will project a high number of shadows.

Fig. 7.7
Hours of solar radiation in the context of the cultural center



7.3 THE ENERGEY MODEL FOR THE CULTURAL CENTER

With the use of Rhinoceros and Grasshopper, it is possible to develop a detailed energy building model of a building.
To create this model, it is necessary to follow a path, that starting from a basic shape (a box) arrives to the definition of every environmental aspect of the project.
The process goes through different phases:

1- Geometry generation: In this phase, with the use of the thermal zone's definition, all the different zones should be generated, with the insertion of openings when necessary

2- Geometry intersection: after generating the single thermal zones is compulsory to understand the relationship between each of the thermal zones to understand, which walls are going to be considered as "internal" or "external" walls, same goes for the ceilings and floors

2- Materials definition: With the use of the grasshopper tool, is possible to generate different materials, each of them with physical characteristics (conductivity, thickness, specific heat, density)

3- Construction Generation and application: With the use of the materials that were defined in the previous step, is possible to generate the construction of walls, floors, ceilings, openings. These components can be then modified easily regarding the different thickness for any material that compose it. These construction systems will then be applied to the whole project

4- Definition of the behavior of any thermal zone: for each one of the various thermal zones is necessary to define parameters such as occupancy rate, temperature goal, electrical equipment consumption, internal infiltration rate etc.

5 - Schedules programming: In this phase the timetable of the different zones is defined and is possible to control when and how the heating and cooling system is turned on or not.

GEOMETRY CREATION

For the geometry modelling it was preferred to create the various thermal zones with the use of the surface modelling, since it was easier to control the various construction sets in this way.
It also fives more possibilities for the fine tuning of the single thermal zone, since each one of them is total independent from the others and will be "connected" to the others only in the last phase.
The building was divided in different sub-buildings to create an easier alphanumeric code to identify the singular thermal zones.

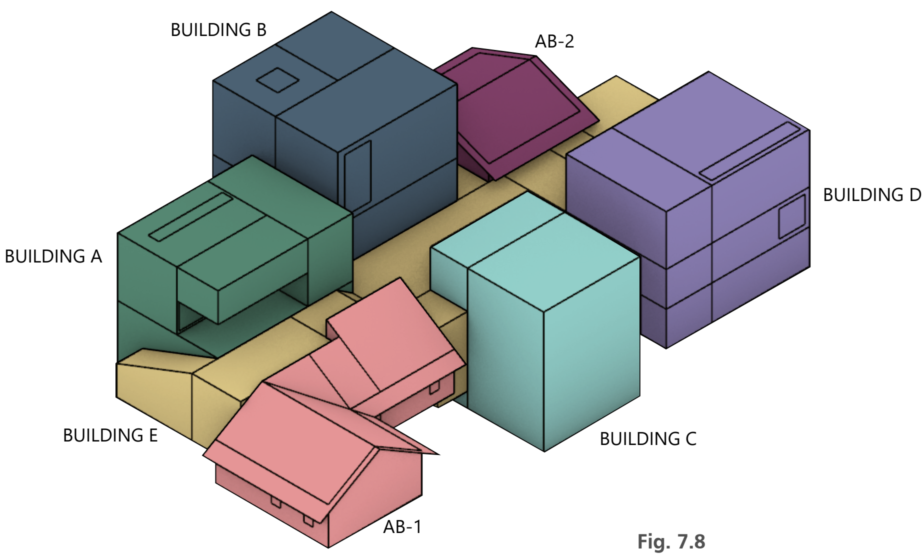


Fig. 7.8
Division of the building in different sectors, this allow and easier organization of the thermal zones

This codes is composed by a Letter (A, B, C ,D, E) that represents the sub building, and 2 numbers, the first one represents the level on which the thermal zone resides, the second one represents the thermal zone position into the building starting (in plan) from the S-E corner of the sub-building.
The two “ancient buildings” are called AB-1 and AB-2. (**Fig. 7.8**)

THERMAL ZONES DEFINITION

When the basic 3D model was finished, it was necessary to divide it in Thermal Zones, to understand the different behavior of various zones depending on the function, the usage, the internal gains of each of them.
An elevator shaft will behave differently from the restrooms, libraries, or conference rooms.
The model of the Fenghuang Town Cultural Center (**Fig. 7.9**) was divided in 30 different Zones, in the next page will be possible to examine the name and the destination of each zone. (**Table 7.4**)

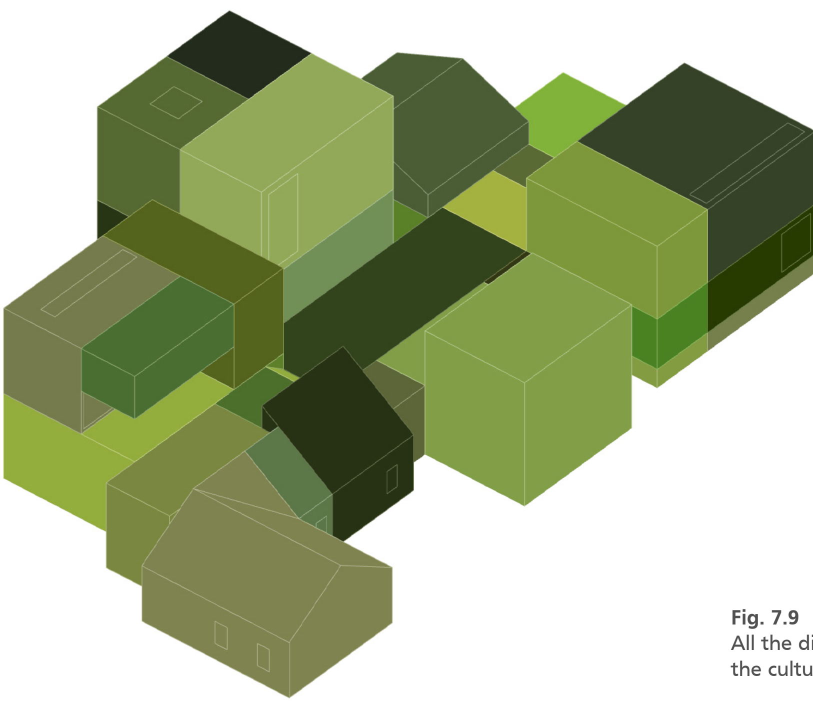


Fig. 7.9
All the different thermal zones in the cultural center

Building	Zone Name	Use	Floor Surface	Outdoor Surface	Volume	S/V
Building A	A_0_1	Gallery	293 m^2	643 m^2	1378 m^3	0.51
	A_0_2	Bathroom-Elevator				
	A_1_1	Gallery (				
	A_1_2	Bathroom-Elevator				
	A_2_1	Gallery				
	A_2_2	Bathroom-Elevator				
	A_3_1	Gallery				
	A_3_2	Plants space				
Building B	B_0_1	Gallery	410 m^2	835 m^2	1987 m^3	
	B_0_2	Bathroom-Elevator				
	B_1_1	Gallery				
	B_1_2	Gallery				
	B_1_3	Bathroom-Elevator				
	B_2_1	Gallery				
	B_2_2	Gallery				
	B_2_3	Gallery				
Building C	C_0_1	Auditorium	131 m^2	489 m^2	1045 m^3	
	C_0_2	Auditorium				
Building D	D_0_1	Bathroom-Elevator	363 m^2	506 m^2	1332 m^3	
	D_0_2	Library				
	D_1_1	Bathroom-Elevator				
	D_1_2	Elderly game center				
	D_2_1	Bathroom-Elevator				
	D_2_2	Elderly game center				
Building E	E_0_1	Lobby	353 m^2	792 m^2	1618 m^3	
	E_0_2					
	E_0_3					
	E_0_4					
	E_0_5					
	E_0_6					
	E_0_7					
	E_0_8					
	E_0_9					
	E_0_10					
Building_T_1	T_1	Workshop	134 m^2	425 m^2	680 m^3	
Building_T_2	T_2	Shop	156 m^2	365 m^2	523 m^3	

Table 7.4
All the different thermal zones and functions of the Cultural Center

MATERIALS DEFINITION

After the geometric construction of the model is important to understand which kind of stratigraphy is going to be used and to do so, is necessary to insert into the program all the physical characteristics of the materials that are going to be used in the project.
To evaluate the influence of the retrofitting operations is necessary to insert the materials of the existing buildings.
Using materials is possible to create the stratigraphy of the existing construction system, both for the traditional architecture and the contemporary buildings that are characterized by a concrete structure and hollow bricks walls. **(Table 7.5)**

Table 7.5
Physical characteristics of the materials that will be used in the building stratigraphies

Material	Conductivity (W/mK)	Density(Kg/m^3)	Specific Heat (J/Kg*K)
Rammed Earth	1.25	1540	1000
Concrete	0.80	2400	1200
Wood Planks	0.09	750	2090
Clay Shingles	0.58	1350	1000
Concrete Plaster	1.40	1540	1000
Firwood	0.12	450	2720
Hollow Bricks	0.19	950	1000
Standard Bricks	0.48	1600	1000
Ceramic Tiles	0.70	1800	1000
Lighweight Screed	0.25	1000	1000
Concrete Slab	1.35	1200	1200
Light Concrete	0.73	1540	1000

STRATIGRAPHIES DEFINITION

Stratigraphies define the construction of the envelope, that represents the barrier between the environment and the internal locals, creating the possibility to have a different climate inside the buildings.

THE TRADITIONAL BUILDINGS STRATIGRAPHIES

In this category (**Fig. 7.10**) we can individuate all those buildings that were constructed following the traditional techniques of the Qing and Ming Dynasties.
The original stratigraphies are composed as follows:
Ground floor: in the original construction, a layer of rammed earth and stones was used to prevent the absorption of humidity, original, then on top of that, right now a layer of concrete is present, in some cases covered with screed and ceramic tiles

Walls: The Matou Qiang is composed by rammed earth with a wood frame, whilst the exterior wood walls are just composed by one or two layer of wood planks

Interior Walls: This are composed by a wood frame and wood planks

Intermediate floor: composed by a structure of wood that sustains a layer of wood planks

Roof: for insulation a layer of rammed earth was used, then a layer of wood structure and planks is found, on top we can see the presence of the traditional black tiles

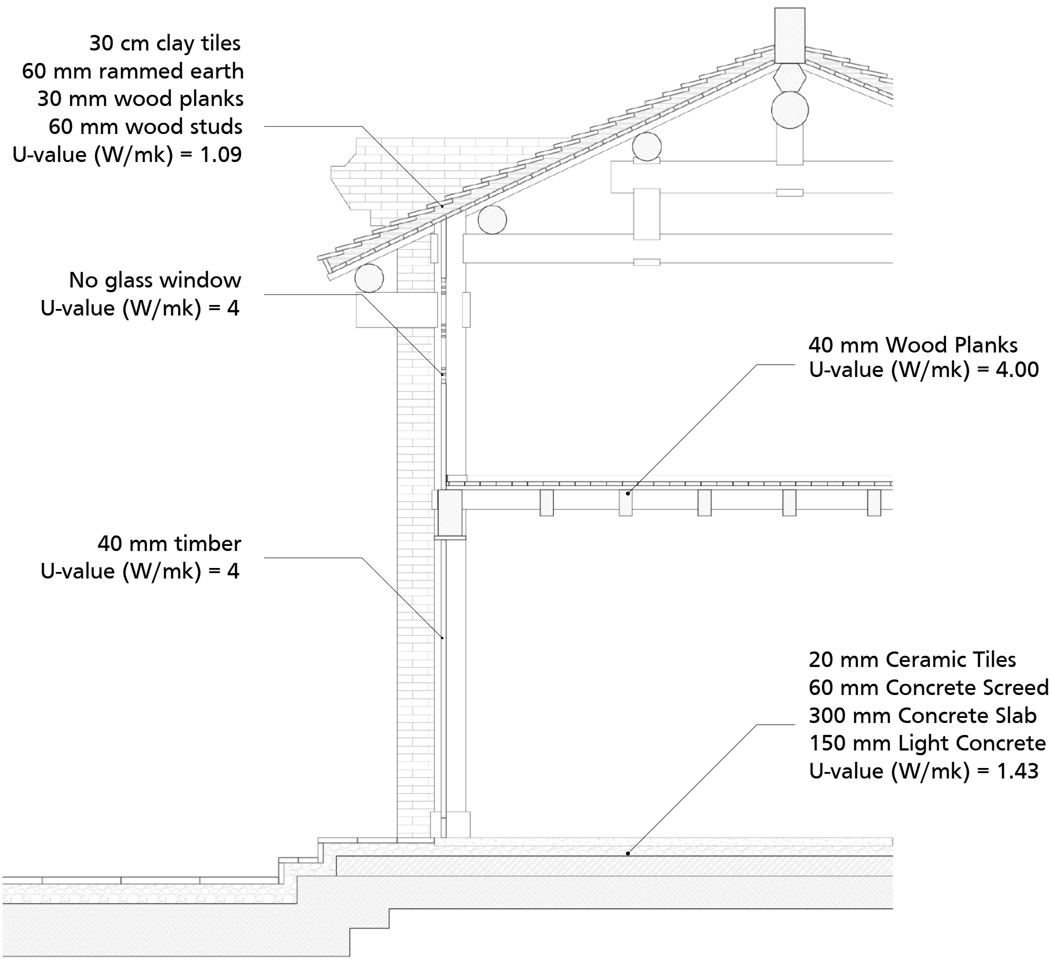


Fig. 7.10
1:20 section of a traditional building

NEW CONSTRUCTION WITH ANCIENT TECHNIQUES BUILDINGS

This category (**Fig 7.11**) is related to all those buildings that were built after the revolution in 1912, with the same techniques that were uses for the traditional buildings, unlike those, they are not based on the courtyard typology.
The original stratigraphies in these buildings are composed as follows:

Ground floor: As in the traditional buildings a layer of rammed earth and stones was used to prevent the absorption of humidity, this layer is now covered with concrete

Walls: These are composed by earth bricks and includes the wood frame in the building.

Interior walls: thinner earth bricks walls, with a thickness of 20 cm

Intermediate floor: composed by a structure of wood that sustains a layer of wood planks

Roof: composed as the traditional buildings with a wood structure, and covered with a layer of rammed earth and clay tiles

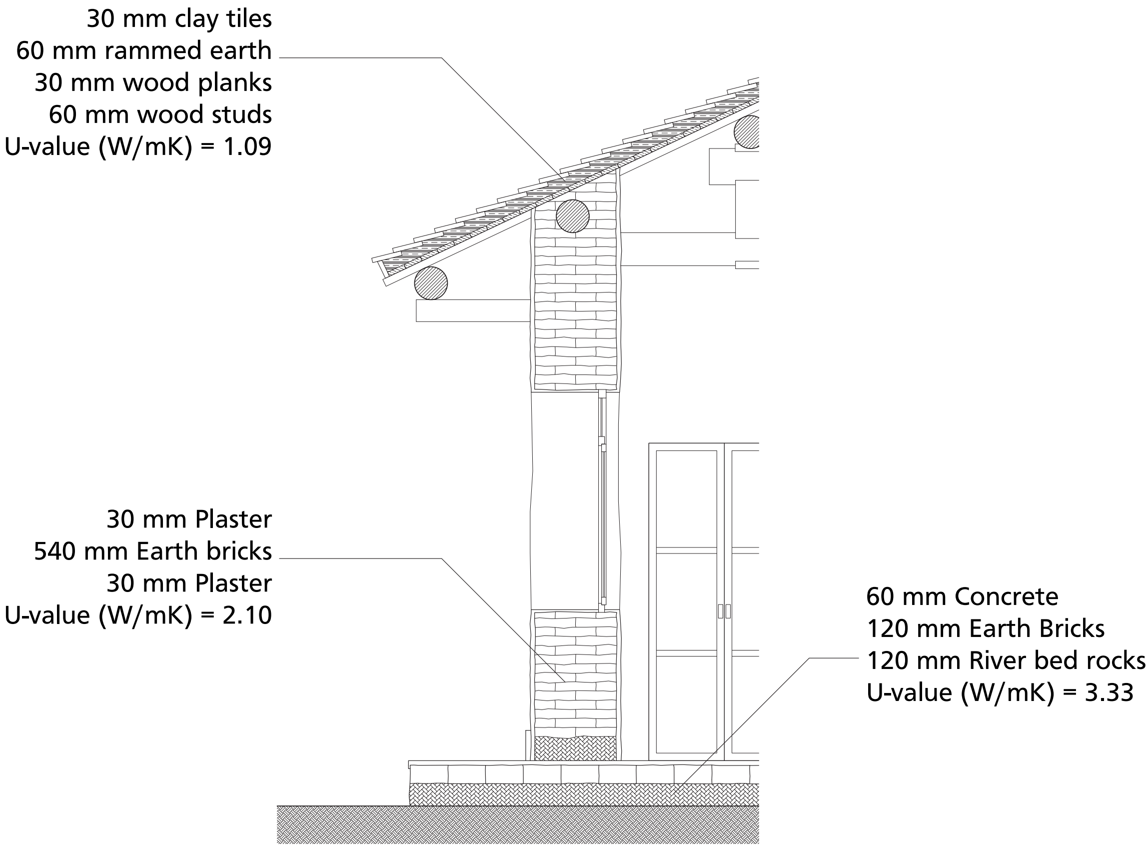


Fig. 7.11
1:20 section of a modern building with traditional construction techniques

THE CONTEMPORARY BUILDINGS STRATIGRAPHIES

Since in the project design, the existing buildings are re-used, these can be used as “study” for the contemporary buildings to understand in which range is possible to reduce the energy consumption of a buildings with the intervention on the envelope.
The original envelope (**Fig. 7.12**) is composed as follows:
Ground Floor: Is a typical concrete floor, covered with ceramic tiles, the presence or not of a layer of insulation is not identified.

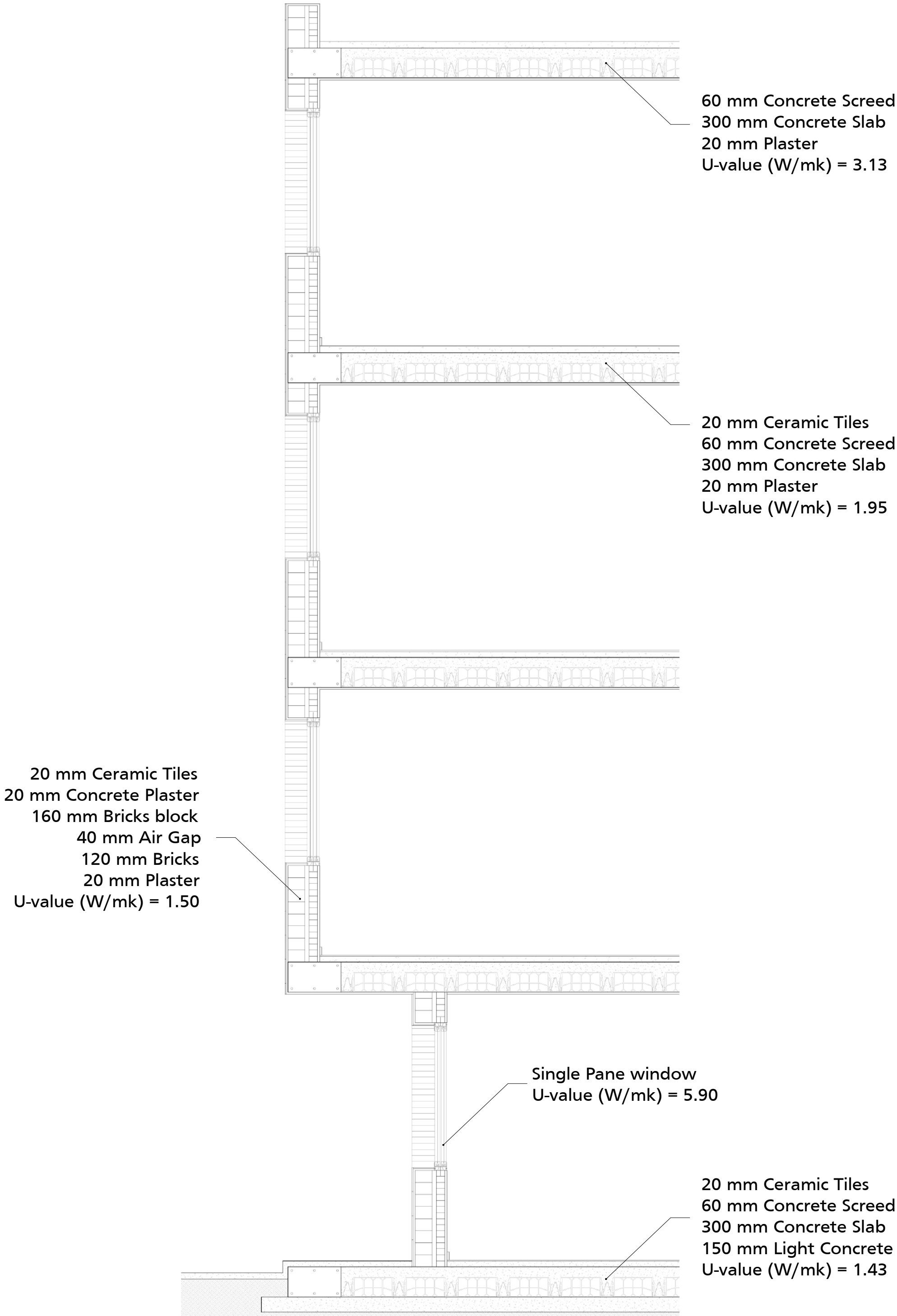
Exterior Walls: They’re building with a double layer of bricks, and covered in plaster in the interior, whilst in the exterior can be covered by plaster or tiles

Interior Walls: traditional interior wall constructed with the use of a perforated brick and plaster layers on both sides

Intermediate floor: Is composed by a concrete structural floor, with screed used for the plants disposition in the floor, and ceramic tiles, the visible layer on the bottom is covered with plaster

Roof: Concrete structure covered with tiles or concrete floor

Fig. 7.12
(On the next page)
1:20 section of modern building

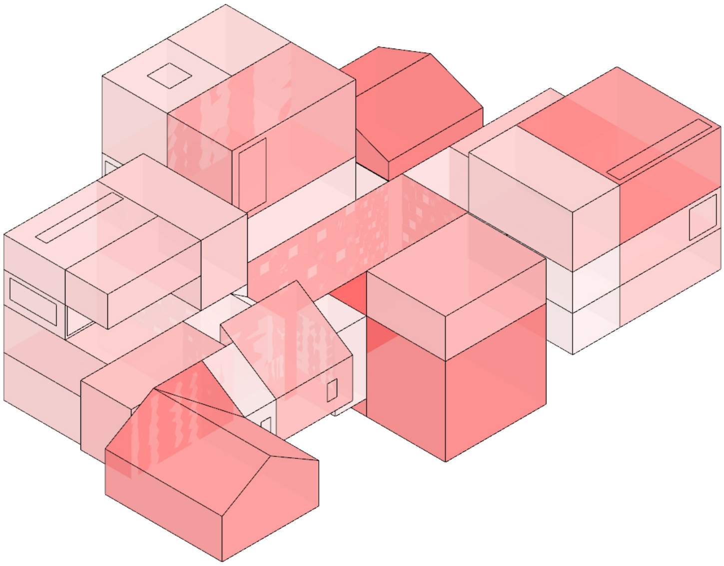

60 mm Concrete Screed
300 mm Concrete Slab
20 mm Plaster
U-value (W/mk) = 3.13
20 mm Ceramic Tiles
60 mm Concrete Screed
300 mm Concrete Slab
20 mm Plaster
U-value (W/mk) = 1.95
20 mm Ceramic Tiles
20 mm Concrete Plaster
160 mm Bricks block
40 mm Air Gap
120 mm Bricks
20 mm Plaster
U-value (W/mk) = 1.50
Single Pane window
U-value (W/mk) = 5.90
20 mm Ceramic Tiles
60 mm Concrete Screed
300 mm Concrete Slab
150 mm Light Concrete
U-value (W/mk) = 1.43

ENERGY REQUIREMENT FOR THERMAL COMFORT

To define the best stratigraphy, is necessary to try different combinations or just different thickness for the different layers of the envelope, to do this the best process is to make several simulations, each one with different parameters to find the most equilibrate solution.
The baseline will be calculated, with the internal gains as follows (the lighting density is calculated with LED efficiency lightning in the whole building), the heating and cooling setpoints are respectively 21°C and 28°C for the whole year.

Type of internal gain	Function	Value
Equipment Load per area (W/m^2)	Galleries	3.00
	Auditorium	0.75
	Lobby	0.75
	Shop	2.50
	Workshop	7.20
	Library	5.20
	Elderly game center	2.90
	Restrooms	4.00
Lightning Density per area (W/m^2)	Galleries	3.00
	Auditorium	
	Lobby	
	Shop	
	Workshop	
	Library	
	Elderly game center	
	Restrooms	
Number of people per area (ppl/m^2)	Galleries	0.04
	Auditorium	0.50
	Lobby	0.04
	Shop	0.20
	Workshop	0.11
	Library	0.05
	Elderly game center	0.10
	Restrooms	0.02

Table 7.6
Internal gains that were used for the baseline simulations in the Cultural center

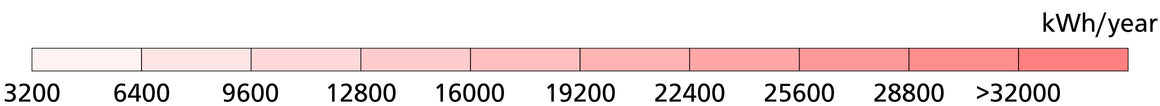


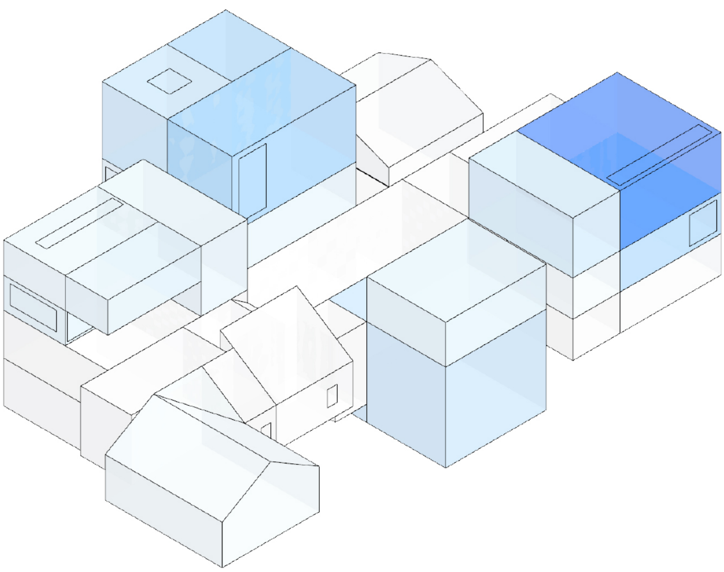
HEATING TOTAL ENERGY REQUIREMENT

In this first simulation, maintaining the existing envelope construction is

306'240 kWh/year
166 kWh/m²

Fig. 7.13
Energy demand for heating of each zone in the energetic model with the standard Fenhuang Town stratigraphy



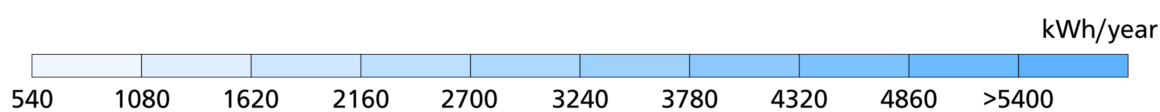


COOLING TOTAL ENERGY REQUIREMENT

In this first simulation, maintaining the existing envelope construction is

19'620 kWh/year
10.66 kWh/m²

Fig. 7.14
Energy demand for cooling of each zone in the energetic model with the standard Fenhuang Town stratigraphy



STRATIGRAPHY OPTIMIZATION

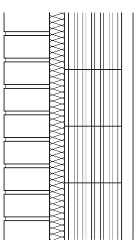
To find the best stratigraphy solution is necessary to run different simulations with different thickness.
To proceed with the retrofitting simulations is necessary to insert the new materials and the possible stratigraphies that are going to be used

Material	Conductivity (W/mK)	Density(Kg/m^3)	Specific Heat (J/Kg*K)
Grey Clay Bricks	0.48	1600	1000
Calcium Silicate Panels	0.04	180	1000
Thermal Plaster	0.09	410	1000
Limestone	1.33	2700	1000
Rockwool	0.035	120	1030

Table 7.7
Materials used in the stratigraphies for the retrofitting of the cultural center buildings

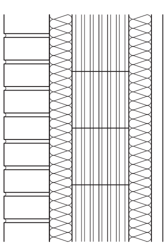
WALLS

The existing envelope in the modern buildings is composed by a layer of hollow bricks, to respect the Energy Efficiency Code is necessary just to add a 4 cm layer of insulating materials, to minimize the energy requirement for heating and cooling there's 8 different propositions, each one will be tested with a simulation to identify the best option.



1. Grey bricks(120 mm)
2. Wood Fiber Insulation (40/60/80/100 mm)
3. Hollow Brick (150 mm)
4. Thermal Plaster (30 mm)

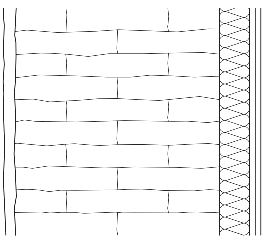
Fig. 7.15
Construction stratigraphy for the exterior walls in the modern buildings, single layer of insulant



1. Grey bricks(120 mm)
2. Wood Fiber Insulation (40/60/80/100 mm)
3. Hollow Brick (150 mm)
4. Wood Fiber Insulation (60/80 mm)
5. Thermal Plaster (30 mm)

Fig. 7.16
Construction stratigraphy for the exterior walls in the modern buildings, double layer of insulation

In the New Construction with Ancient Techniques, the situation is different, since the preservation of the most outer layer, composed by the traditional plaster, is compulsory to insulate the building from the interior, even though the difficulty to avoid thermal bridges is well known.
For this construction the possibilities were reduced to 4 different variations.
The insulating layer goes from 8 to 16 cm.
It is important to notice that the construction in this case is reversible, only dry materials are going to be used.

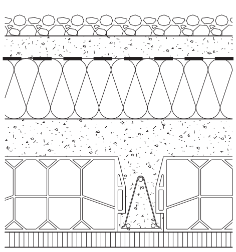


1. Lime Plaster (30 mm)
2. Rammed Earth (540 mm)
3. Calcium Silicate Panel (80/100/120/160 mm)
4. Double layer of drywall Panel (30 mm)

Fig. 7.17
Construction stratigraphy for the rammed earth wall in the modern buildings with ancient techniques

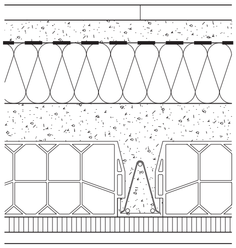
ROOF

The existing roof in the modern building is composed by a concrete slab, with plaster cover below and a light concrete layer on top.
To solve infiltration problems and insulate the building a 16 cm insulation layer has been added, as well as a bitominous sheet, covered with gravel to mitigate the solar energy absorption.
This last layer will be replaced with a limestone flooring when the roof can be reached by pedestrians.
In the buildings with traditional techniques, it



1. Gravel (50 mm)
2. Bitominous sheath (8 mm)
3. Lightweight Screed (60 mm)
4. Calcium Silicate Panel (160 mm)
5. Concrete Slab (300 mm)
6. Rockwool (40 mm)
7. Plaster (30 mm)

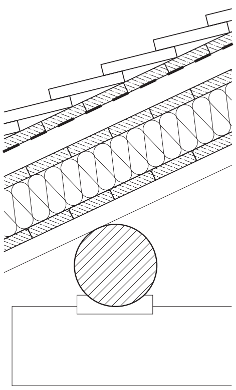
Fig. 7.18
Roof construction stratigraphy for the modern buildings



1. Limestone (40 mm)
2. Bitominous sheath (8 mm)
3. Lightweight Screed (60 mm)
4. Calcium Silicate Panel (160 mm)
5. Concrete Slab (300 mm)
6. Rockwool (40 mm)
7. Plaster (30 mm)

Fig. 7.19
Second option for the roof construction when the roof is reachable

was decided to modify the structure of the roof, to insulate it, the rotten parts of the original wood plans are modified with compatible wood, then insulated, the final layer of shingles is made with the recovered existing ones, when recovery is not possible, the shingles are replaced with distinguishable ones.



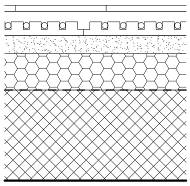
1. Shingles (20 mm)
2. Wood Planks (30 mm)
3. Firwood (60 mm)
4. Waterproof barrier (8 mm)
5. Wood planks (30 mm)
6. Wood Fiber Insulation (120 mm)
7. Wood Planks (30 mm)

Fig. 7.20
Construction stratigraphy for the traditional roof with wooden structure

GROUND FLOOR

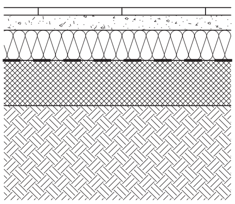
To improve the qualities of the ground floor in the modern buildings, it was necessary to add a waterproof barrier and insulation.

Since the traditional ground floor, was composed by just a layer of concrete, it was necessary to dig into the rammed earth layer, create a base of concrete, insulate it and insert a waterproof barrier.



1. Limestone floor (20 mm)
2. Lightweight screed/radiant panels (60 mm)
2. Lightweight Screed (60 mm)
3. XPS insulation (120 mm)
4. Bitominous Sheath (8 mm)
5. Concrete Slab (300 mm)

Fig. 7.21
Ground floor stratigraphy for the modern buildings

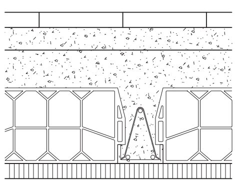


1. Limestone (20 mm)
2. Lightweight Screed (40 mm)
3. Calcium Silicate Panel (80 mm)
4. Bitominous Sheath (8 mm)
5. Concrete Slab (120 mm)

Fig. 7.22
Ground floor stratigraphy for the ancient buildings with modern techniques

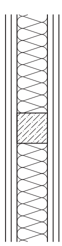
INTERMEDIATE FLOORS AND WALLS

Since the intermediate floors and walls are not relevant for the improvement of the comfort qualities and the energy requirement there was no insulation with that goal.
The insulation in the following stratigraphy has the purpose to soundproof the locals.



1. Limestone (40 mm)
2. Lighweight Screed (60 mm)
3. Concrete Slab (300 mm)
4. Rockwool (40 mm)
5. Plaster (30 mm)

Fig. 7.23
Intermediate floor construction stratigraphy in modern buildings



1. Drywall Panels (30 mm)
2. Wood Structure with Rockwool (80 mm)
3. Drywall Panels (30 mm)

Fig. 7.24
Intermediate walls in the modern buildings

WINDOWS

In the existing building, the windows were single pane windows with aluminum frames, all of them are going to be replaced with double pane windows with aluminum frames and low e-value.

ENERGY SIMULATIONS

In the following table we can find all the possible stratigraphies for each one of the construction elements, in the next simulations, we will consider each one of them to have the possibility to choose the best equilibrate option.

Construction Type	Construction name	U-value (W/m^2K)	Thickness
Wall	CCW_4	0.43	0.34
	CCW_6	0.36	0.36
	CCW_66	0.24	0.42
	CCW_68	0.21	0.44
	CCW_8	0.30	0.38
	CCW_88	0.19	0.46
	CCW_10	0.27	0.40
	CCW_108	0.18	0.48
Retrofitted Rammed Earth Walls	RTC_8	0.40	0.68
	RTC_10	0.34	0.70
	RTC_12	0.29	0.72
	RTC_16	0.22	0.76
Roof	CCR	0.17	0.63
Retrofitted Traditional Roof	RTR	0.25	0.32
Ground Floor	GF	0.29	0.52
Retrofitted Traditional Ground Floor	RTGF	0.46	0.26
Intermediate Floors	CCF	0.50	0.47
Interior Walls	CCIW	0.38	0.14
Windows	DP	1.6	-

Table 7.8
Stratigraphies for the initial simulations, in the case of a singular proposed stratigraphy for an element, this will become the standard for the building.
In the other cases it will be necessary to run several simulations to identify the best option.

Since the options for the Traditional Rammed Earth Walls are multiples, it was decided to divide the process of optimization in two different steps, the first one, optimizing the modern building walls, and then modifying the traditional rammed earths walls stratigraphies.

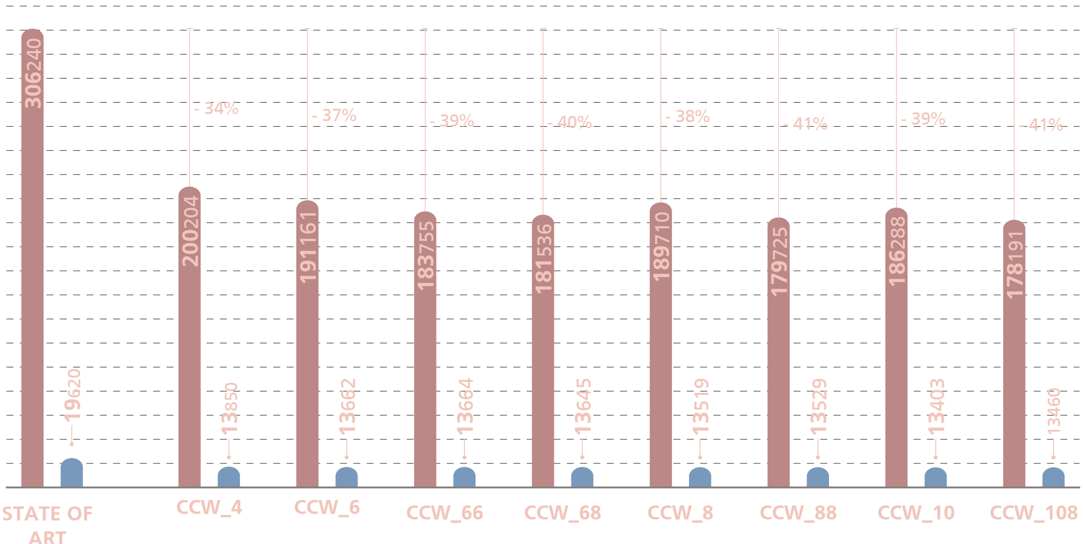


Table 7.9
Energy demand for each option, after the first run of simulations it was decided to proceed with the stratigraphy called **CCW_66** that presents a double insulation layer of 6 cm.

After the simulations, it was decided to continue with the retrofitting of the modern wall with the double layer 6 + 8 cm of insulation, that allows to reduce the energy demand by 40% for heating and 31% for cooling.
An interesting result is that in some case the addition of insulation layers does not improve the energy demand for cooling (CCW_6 and CCW_66) but instead we hit a point of diminishing returns, the strategies to reduce the energy demand for cooling are not influenced anymore by the stratigraphy of the building.

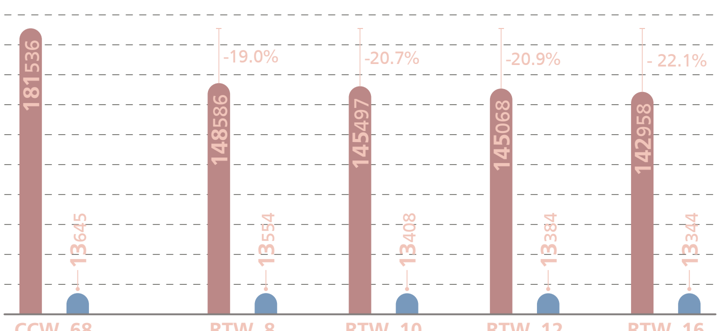
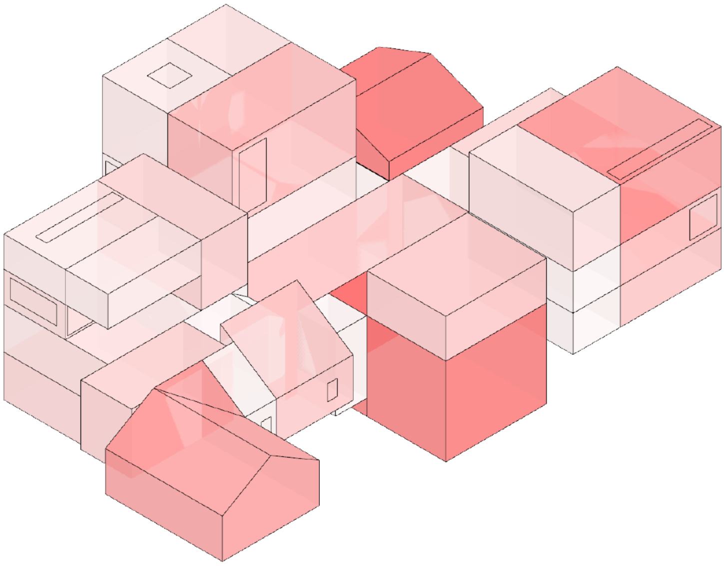


Table 7.10
Energy demand for each option for the traditional rammed earth wall.

The next step was to run simulations to understand which solution for the traditional walls would have the greater impact on the energy demand.
As the results are shown, the reduction of energy demand does not improve in a sensible way.
Therefore, the solution chosen is the RTW_10

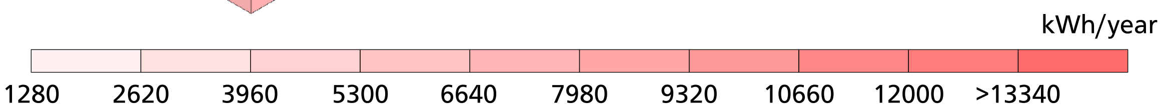


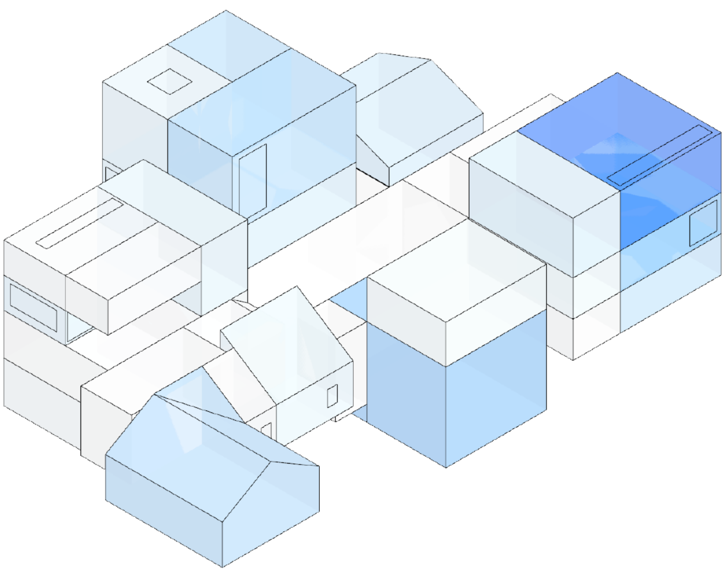
HEATING TOTAL ENERGY DEMAND

After the simulations the energy demand for heating is

145’497 kWh/year
79 kWh/m²

Fig. 7.25
Energy demand for heating after the first step of stratigraphy optimization



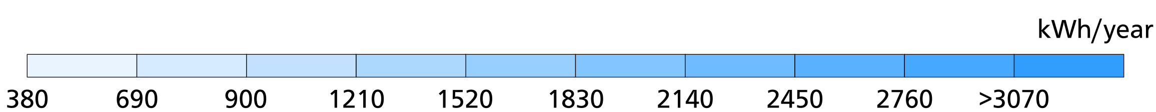


COOLING TOTAL ENERGY DEMAND

In this first simulation, maintaining the existing envelope construction is

13’408 kWh/year
7.28 kWh/m²

Fig. 7.26
Energy demand for heating after the first step of stratigraphy optimization



SETPOINTS OPTIMIZATION

The next step in the energy optimization process would be the setpoints optimization. Each zone since the different use, can be set to different temperatures, while still maintaining the conditions into the comfort zone.
In this step is possible to define the setpoint and the setbacks for temperature, respectively, they indicate the goal for heating and cooling when the local is in use, while the setback defines the temperature when the local is unused.
The first simulations were created with a fixed 21° C for heating and 28° C for cooling.

Function	Heating Setback and Setpoint	Cooling Setback and Setpoint
Galleries	19-21°C	25-27°C
Auditorium	12-20°C	28-33°C
Lobby	12-19°C	28-33°C
Shop	12-21°C	28-33°C
Workshop	12-20°C	28-33°C
Library	15-21°C	28-29°C
Elderly game center	12-21°C	28-33°C
Restrooms	10-18°C	29-34°C

Table 7.11
Heating and Cooling setpoints and setbacks for each function in the Cultural center

After the simulation it was possible to notice a reduction in the energy demand for heating, around 25% from the last analysis, that's possible since the temperature can be lowered in the service spaces like bathrooms and the lobby. Interestingly, the cooling energy demand has increased, because the galleries need to maintain a stable temperature between 19-25°C, for the whole day, even when not in use.

HEATING TOTAL ENERGY DEMAND

After the simulations the energy demand for heating is

109’235 kWh/year
59 kWh/m²

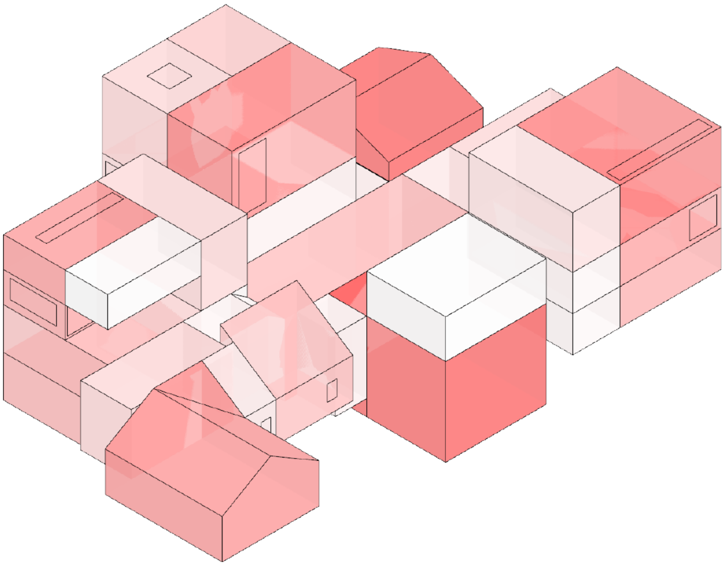
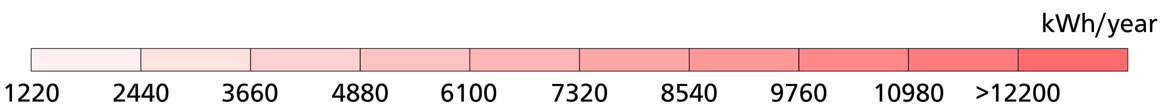


Fig. 7.27
Heating energy demand after the last step of setpoints optimizations.



COOLING TOTAL ENERGY DEMAND

In this first simulation, maintaining the existing envelope construction is

19.838 kWh/year
10.78 kWh/m²

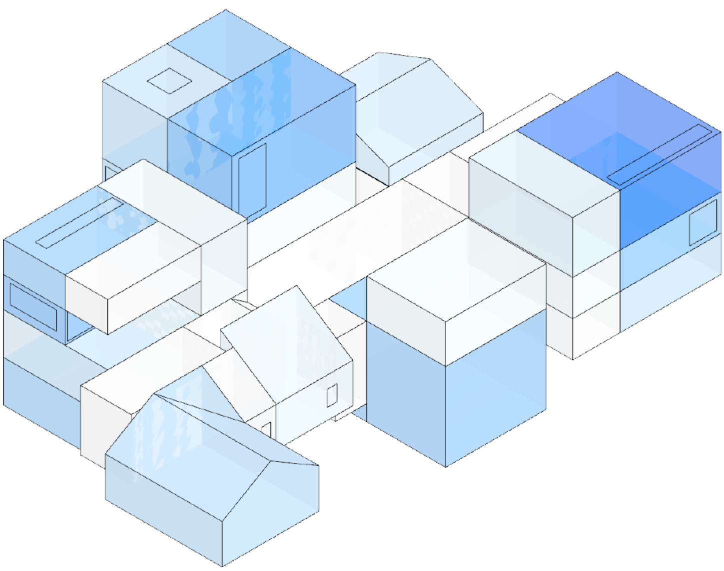
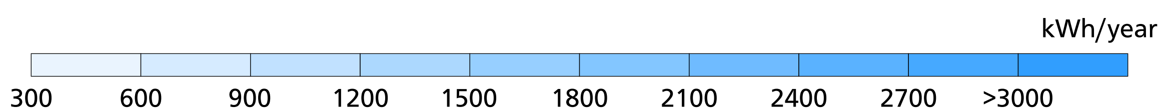
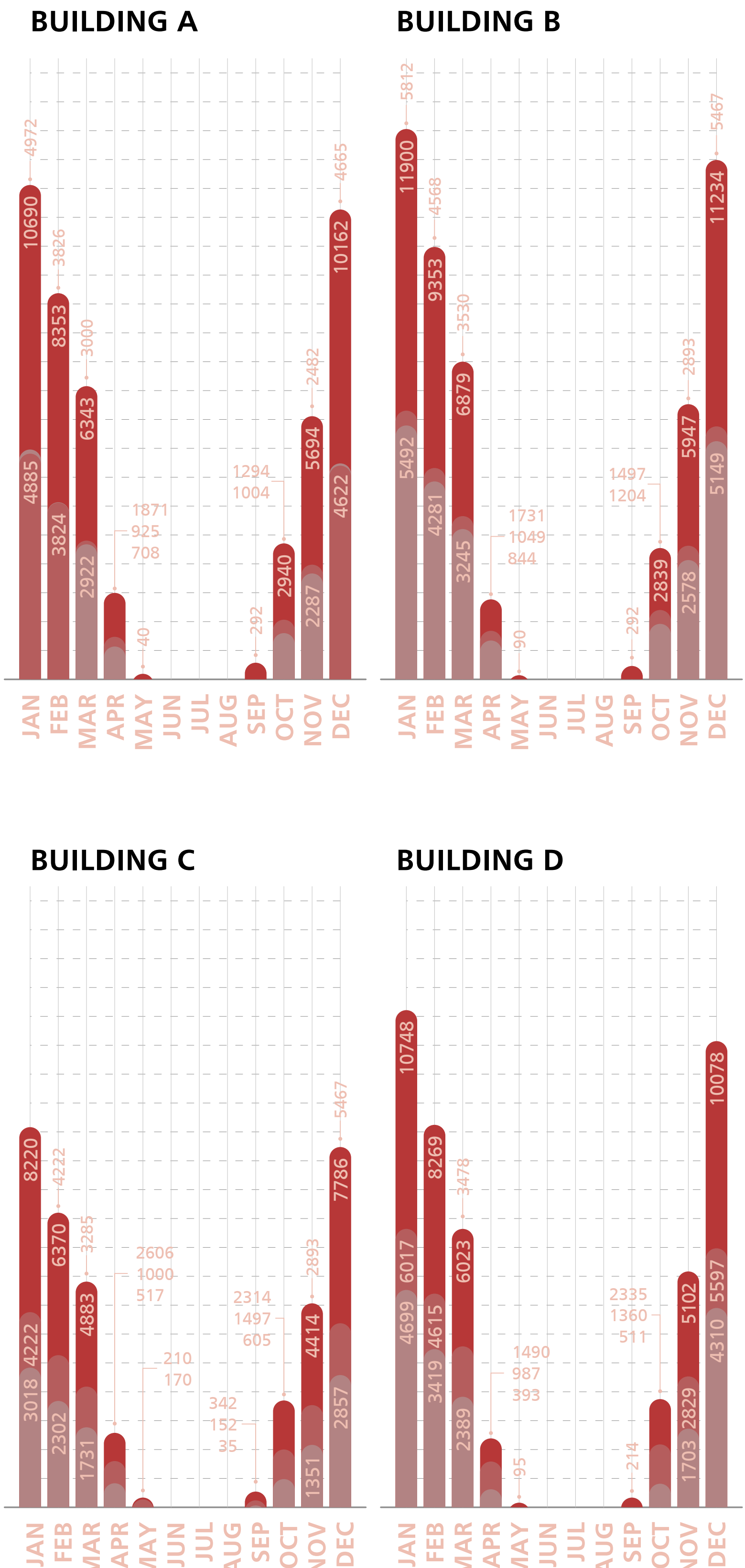


Fig. 7.28
Cooling energy demand after the last step of setpoints optimization.





MONTHLY HEATING ENERGY DEMAND COMPARISON

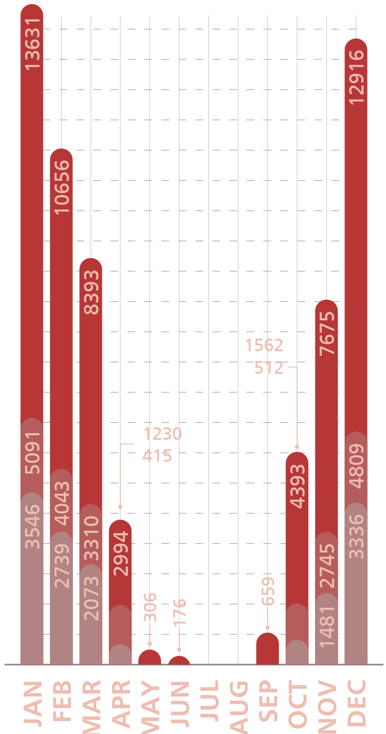
With the data from the simulations is possible to understand the variation on the energy demand for each part of the Cultural Center.

In the buildings A and B, there is not a great reduction of the energy demand between the second and the third simulation, since the heating setpoint and setback has to been set in order to maintain the temperature always between 21 and 25 °C.

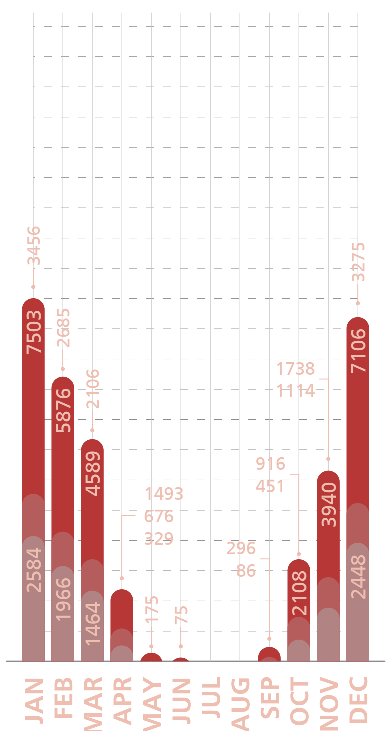
To what concerns the other buildings the reduction is sensible, specially thanks to the fact that diminishing the setpoint for heating when the building is not in use, allows to use a lower amount of energy between 11:00 pm and 06:00 am.
The most impressive

Fig. 7.29
Monthly heating energy demand for buildings A-B-C-D

BUILDING E



BUILDING AC_1



result was reached with Building E, with a 74% energy demand reduction during January and December

The traditional buildings have had a substantial reduction in the energy demand for heating, reducing it to 0 during the period between May and September in the case of AC_1 building and almost 0 in the case of AC_2

BUILDING AC_2

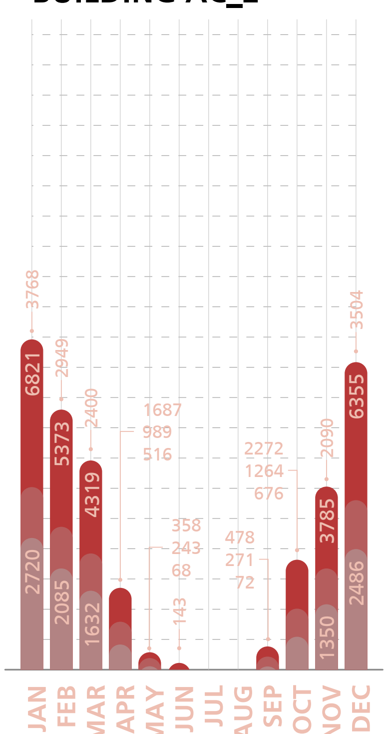


Fig. 7.30
Monthly heating energy demand for buildings E - AC_1 - AC_2

HEATING ENERGY DEMAND TOTAL REDUCTION

In conclusion is possible to observe that, according to the energy simulations it could be possible to reduce the energy demand by almost 66%.
The most important operation was represented by the retrofitting process since the energy demand was reduced by the 50% after this step.

The operation of setpoints optimization can reduce even more the requirement of heating energy.

If this kind of approach can be applied to many of the buildings it would be possible to reduce the energy footprint of the entire Fenhuang Town, providing the possibility to guarantee the comfort conditions inside the buildings.

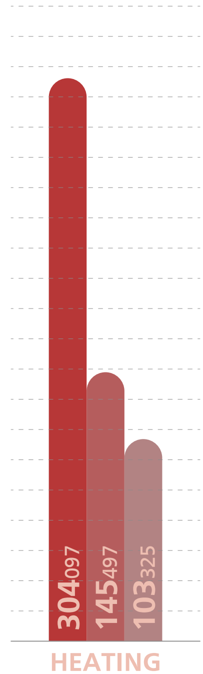
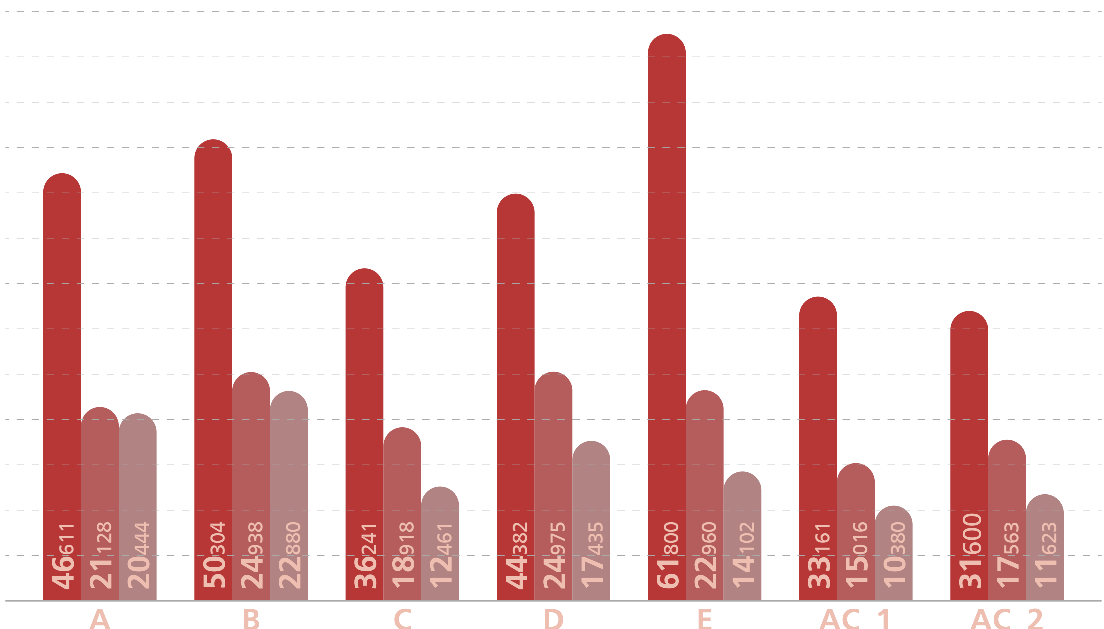
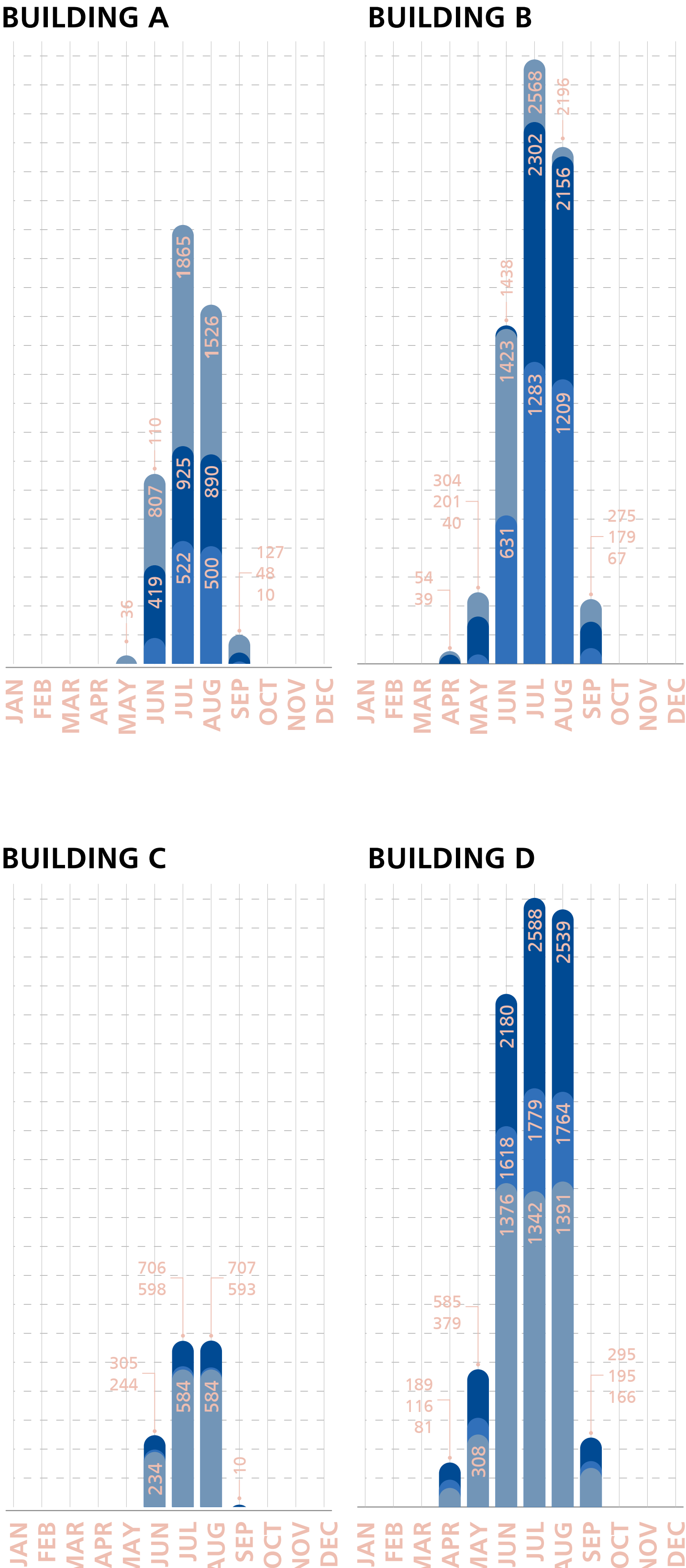


Fig. 7.31
Total energy demand for heating

Fig. 7.32
(below)
Total energy demand for heating divided for each building





MONTHLY COOLING ENERGY DEMAND COMPARISON

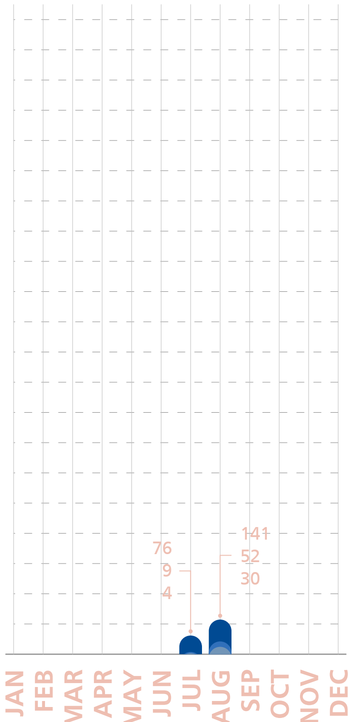
To what concerns the energy necessary to cool the different locals to maintain them in the comfort condition.

Looking at the charts is possible to understand that in the buildings A and B is necessary to always maintain a stable temperature, therefore the energy necessary increased from the quantity necessary with the standard conditions.

Also, in the traditional buildings we can observe the same behavior.

Fig. 7.33
Monthly heating energy demand for buildings A-B-C-D

BUILDING E



BUILDING AC_1

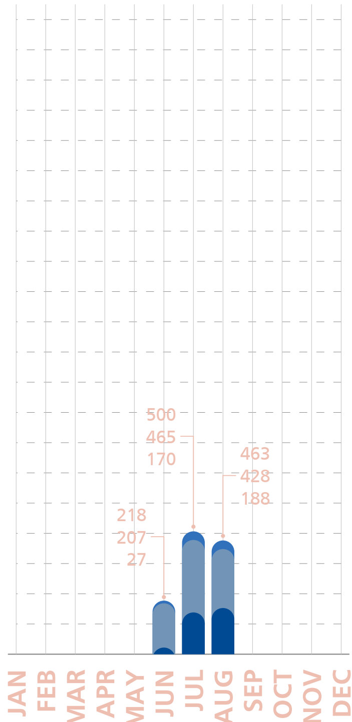


Fig. 7.34
Monthly heating energy demand for buildings E - AC_1 - AC_2

BUILDING AC_2

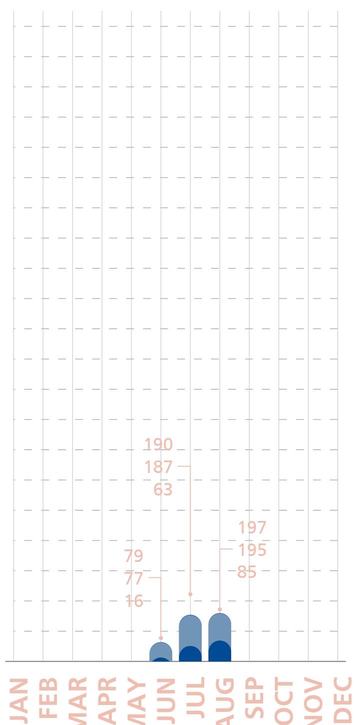
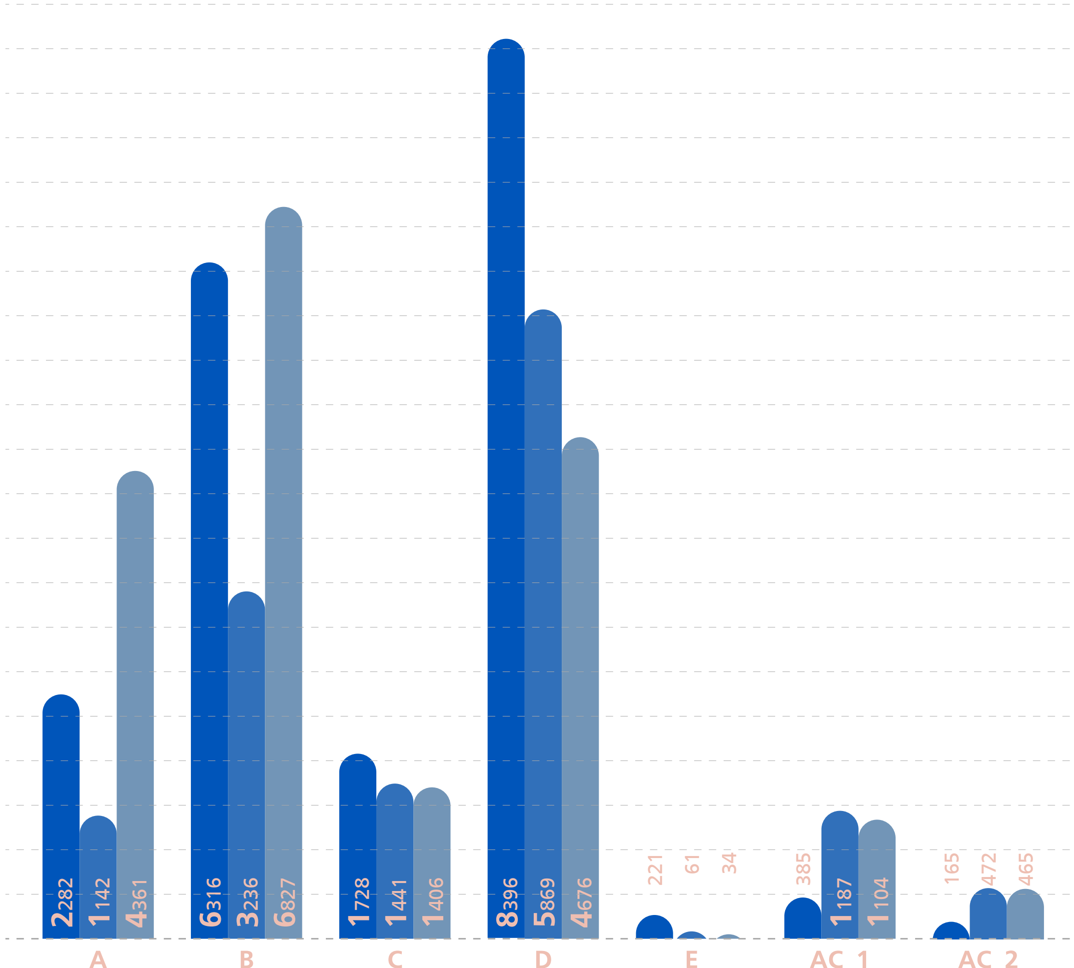


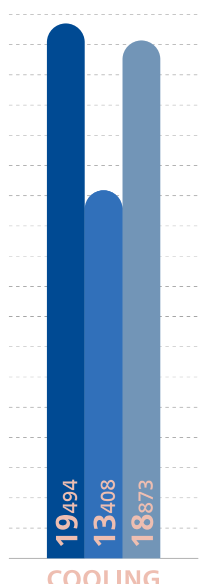
Fig. 7.35
(On the next page, on the top) Total energy demand for cooling divided by the singular buildings in the Cultural Center.

Fig. 7.36
(On the next page, on the bottom) Comparison on the energy demand for cooling through the different steps of the analysis



COOLING ENERGY DEMAND VARIATION

Compared to the necessity for energy for the heating of the locals, in this case there was a small decrease on the energy demand, due to the nature of the buildings (the traditional buildings experienced an increase in this energy demand) and the use of the different parts of the building (the galleries need to maintain a temperature of 25°C the whole day).
Even if the reduction was not substantial, the sum of energy necessary between cooling and heating, has been reduce by two thirds. Subsequently also the CO_2 emissions can be reduced and the energy consumption from the grid can be reduced



7.4 HEATING, COOLING AND RENEWABLE TECHNOLOGIES

Total Heating Energy Demand:
103’325 kWh/year
Peak Heating Demand:
18 kW

Total Cooling Energy Demand:
18’873 kWh/year
Peak Heating Demand:
10 kW

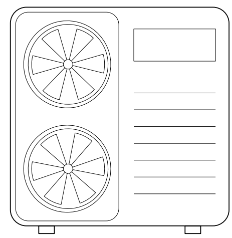
Fig. 7.37
Total energy demand for heating and cooling

The next step in the reduction of the GHG emissions and CO2 footprint of a building is the generation of clean energy, starting from renewable energy sources.

HEAT PUMP ELECTRIC CONSUMPTION

In this case it was decided to utilize an Air-Water heat pump that allows to heat and cool the different areas of the building.
The choice of the proper Air - Water heat pump is based on the greater between the Cooling and the Heating peak. While the electric consumption of the machine is going to be the result between its efficiency (COP and EER) and the total heating and cooling demand.

In this case a model from SPRSUN with maximum heat capacity of 20kW was selected, with a COP o 3.85 and EER of 2.80, the electric consumption for heating and cooling will be respectively 26’837 kWh/year and 6’740 kWh/year.



Brand: SPRSUN
Model: CGK050V3L
Max Heating Capacity: 20 kW
Max Cooling Capacity: 18.2
COP: 3.85
EER: 2.80

Fig. 7.38
Heat pump specs

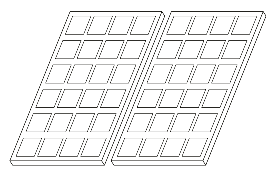
Table 7.12
Analytic calculation of the annual electricity consumption of the building

Function	Lighning type	Light Source	Electric Consumption (kWh)	n°	Annual consumption
Galleries	Artworks lightning	Spotlights	0.008	87	1676.664
		Wall wash	0.004	250	2409
	Artworks equipment	-	0.2	4	3504
Vertical connection	Staircase lightning	Spotlights	0.003	27	354.78
	Internal elevator lightning	LED	0.003	12	315.36
	Elevator motors	-	3.75	3	731.25

Auditorium	General lightning	Spotlights	0.005	25	547.5
	Equipment	-	1.2	1	876
Library	General lightning	Spotlights	0.003	35	344.925
	Equipment	-	0.2	6	2628
Elderly game center	General Lightning	Spotlights	0.003	12	7.92
	Equipment	-	0.5	3	330
Lobby	General Lightning	Spotlights	0.003	55	722.7
	Equipment	-	0.075	25	8212.5
Workshop	General Lightning	Spotlights	0.003	17	134.64
	Equipment	-	2	8	7040
Toilets	General Lightning	Spotlights	0.003	36	473.04
	Equipment	-	0.075	9	246.375
				Total	**30554.654**

LIGHTING AND APPLIANCES ELECTRIC CONSUMPTION

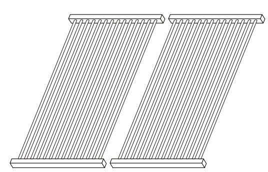
To understand the total electric consumption of the building is necessary to conduct a detailed study of the lightning and the equipment electric energy consumption of the building through the year.
The total energy consumption of the building is 64’132 kWh/year.



Brand: Sunpower
Model: Maxeon 3
PV module efficiency: 22.6 %
NOCT: 42°C

PHOTOVOLTAIC SYSTEM

To mitigate or even to zero the electric consumption is possible to use solar panels. Using selected solar panels is necessary to cover an area of 142 m^2, that are equivalent to 80 solar panels with a 28° inclination. The total energy production would be of 65’533 kWh/year.



Brand: Alternate Energy Technologies
Model: AE-21
Fr (tau alpha) coefficient: 0.71
Fr UL coefficient 4.91

DHW

In the next phase the quantity of thermal energy necessary to the production of the sanitary hot water is going to be calculated.
Firstly, an estimation of the people affluence is needed, in this case we can consider a daily affluence of 50 people, thus a daily consumption of 190 L of sanitary water at 60°C.
To fulfill this thermal energy demand is possible to utilize Water Heating solar panels, in this case it would be necessary to utilize 3 collectors with a total area of 15 m^2 that can generate 2’690 kWh of energy
This amount of energy produced by the panels account for the 70% of the energy necessary during the year.

Since the distribution system for heating and cooling will suffer from loss, due to the “not perfect” construction of them, is necessary to insert different coefficients.

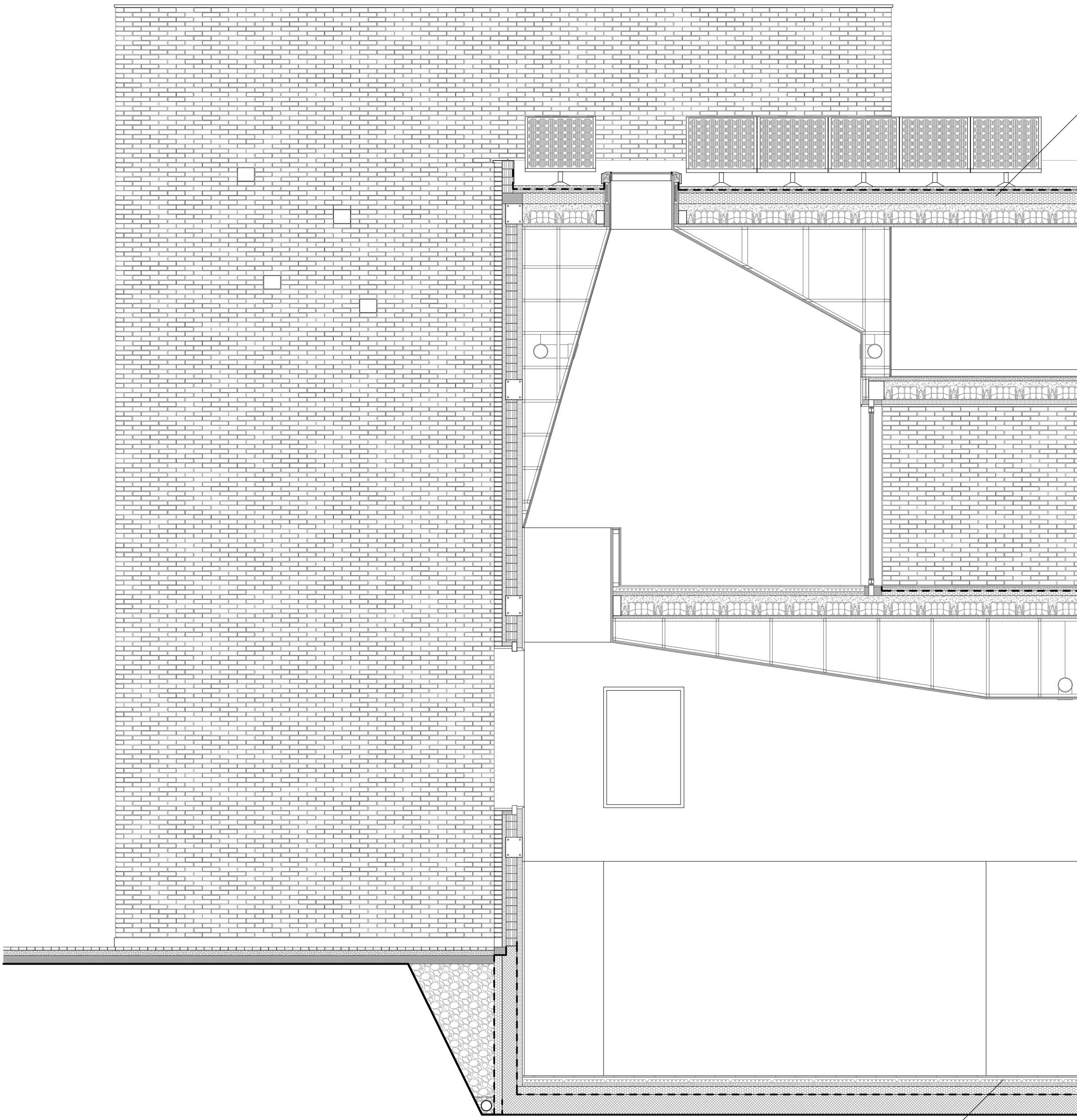
The electric consumption would be equal to:

Electric consumption of the Heat pump for heating and cooling + electric energy consumption of the equipment and lighting - Energy produced by PV x 0.98 x 0.98 = 27 MWh/year + 7 MWh/year + 25 MWh/year - (61 MWh/year x 0.98 x 0.98) = 0.42 MWh/year.

This consumption is equal to 0.22 kWh/m2.

The thermal energy necessary to produce sanitary hot water would be equal to 2.67 MWh/year - 1.84 MWh/year = 0.83 MWh/year

This energy must be produced by the utilization of a gas boiler or any other kind of fuel boiler.



1. Limestone Floor (20 mm)
2. Floor Screed (60 mm)
3. XPS Insulation (120 mm)
4. Concrete Slab (300 mm)

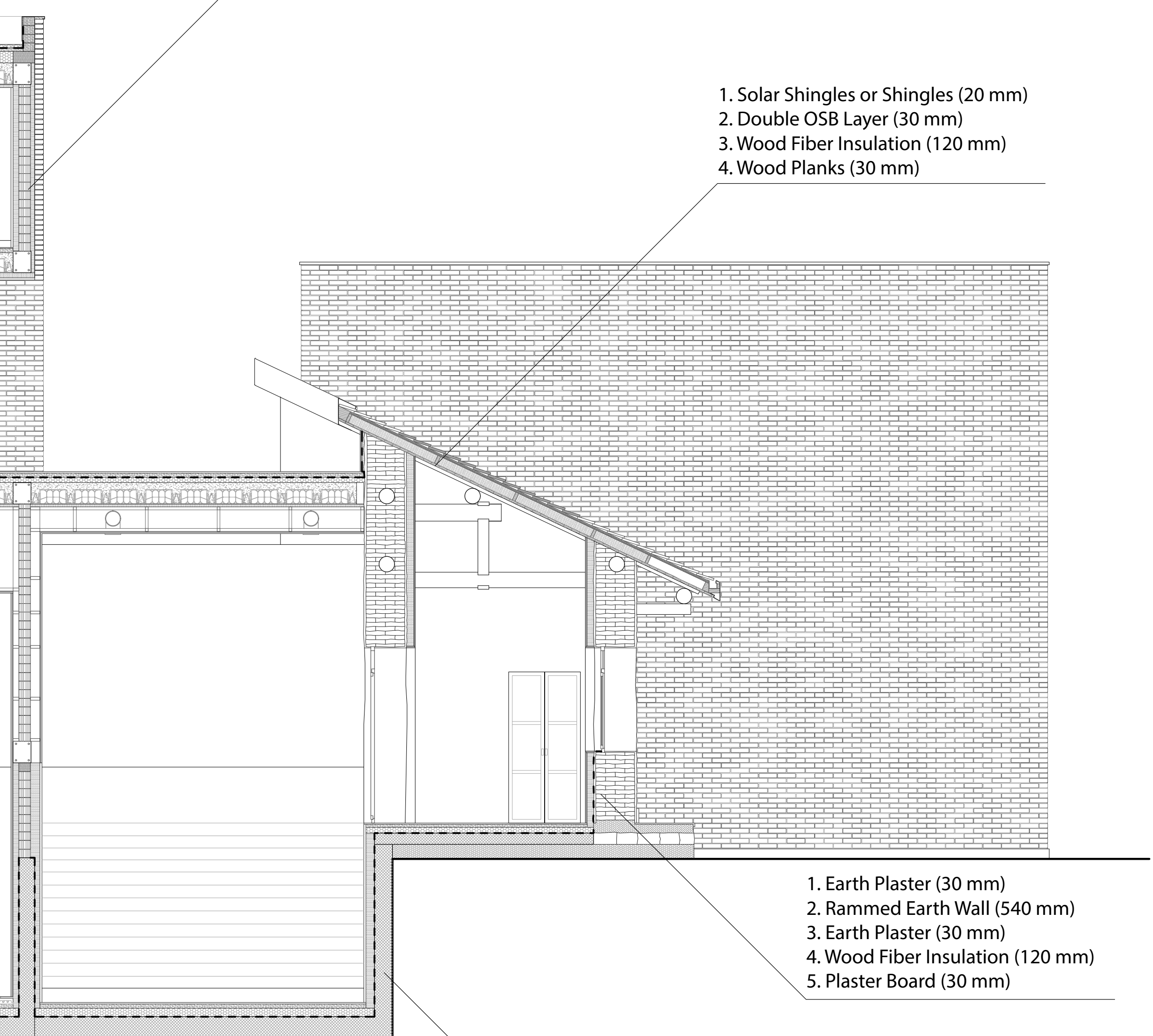


Fig. 7.39
Cultural Center
Detailed Section

7.5 THE COURTYARD RECONSTRUCTION

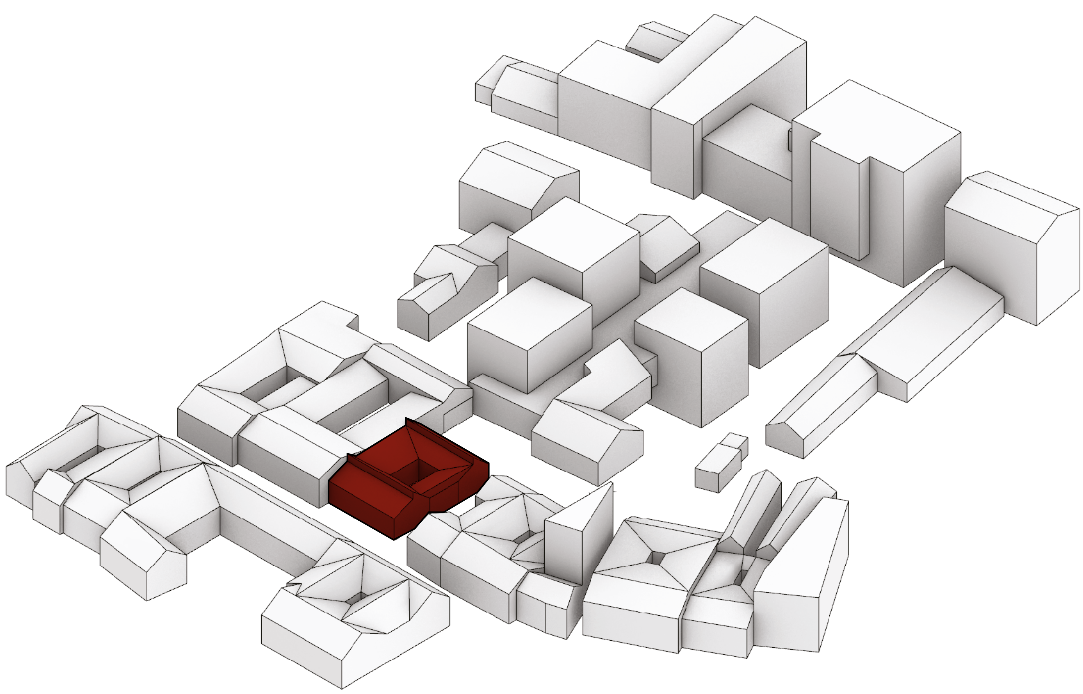
The lacuna that was created along the ancient road in Fenhuang Town, was decided to be filled with a new building, a reinterpretation of the ancient courtyard destinated to host a restaurant.

This building can also serve as an example to follow in the case of a reconstruction of a courtyard

THE MODEL

The energetic model of the cultural center was adapted to evaluate the energy demand and consumption of the new courtyard. In this case, also, since the envelope must respond to the project needs.

Fig. 7.40
Axonometry of the building and the urban fabric



Building	Zone Name	Use	Floor Surface	Outdoor Surface	Volume	S/V
New Courtyard	NC_01	Dining	112 m^2	689 m^2	755 m^3	0.91
	NC_02	Kitchen	53 m^2			
	NC_03	Restroom	10 m^2			

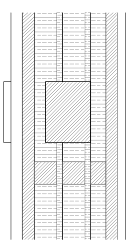
Table 7.13
Geometric Values of the New Courtyard

THE EXTERNAL ENVELOPE OF THE NEW COURTYARD

The new Courtyard resembles, with its proportions the original building that was present in the area. To maintain a coherence with the surrounding it was decided to use a similar language of the traditional architecture and the same materials are present in the city (also to reduce the necessity of "imported" materials, reducing furthermore the GHG emissions of the building).

WALLS

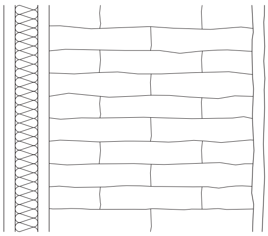
The original walls were composed by a single layer of wood planks, in this case the wall was created by several layers of wood in insulation. The wood fiber allows the building to be "breathable" while maintaining the thermal comfort and sound proofing of the building.
The internal layers (OSB panels) are created by compressed and glued wood flakes.



1. Wood Plank (30 mm)
2. Wood Fiber Insulation (60 mm)
3. OSB Panel (15 mm)
4. Wood Fiber Insulation (60 mm)
5. OSB Panel (15 mm)
6. Wood Fiber Insulation (40 mm)
7. Wood Planks (30 mm)

Fig. 7.41
Exterior Wood Wall stratigraphy of the new courtyard

In regards of the Matou Qiang it was decided to proceed with the same stratigraphy that was selected for the cultural center since it represents



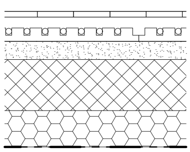
1. Drywall panel (30 mm)
2. Wood Fiber Insulation (60 mm)
3. Plaster (30 mm)
4. Rammed Earth Brick Wall (540 mm)
5. Plaster (30 mm)

Fig. 7.42
Stratigraphy of the Matou Qiang insulation

the more coherent solution.

FLOORS

The floor is created with the use of a wood decking that relies on a lightweight screed. The concrete slab is insulated from the ground



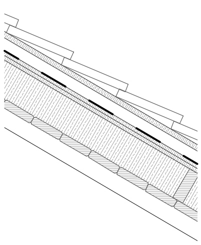
1. Wood Floor or ceramic floor (20 mm)
2. Floor Screed and radiant panels (60 mm)
3. Floor Screed (60 mm)
4. Concrete slab (180 mm)
5. XPS Insulation (120 mm)

Fig. 7.43
Ground Floor Stratigraphy

with a XPS layer of 120 mm.

ROOF

The roof is a ventilated roof, composed by a layer of shingles that could be recycled from the original courtyard that was destroyed.
The internal layers are composed by an OSB panel, a 60 mm Stud that creates the ventilated chamber, a double layer of 15 mm OSB panel that hosts the wood fiber insulation of 120 mm, on the interior the visible layer is composed by 30 mm wood



1. Recycled Shingles (25 mm)
2. OSB panel (60 mm)
3. Concrete Slab (260 mm)
4. XPS Insulation (120 mm)

Fig. 7.44
New Courtyard Roof Stratigraphy

Construction Type	U-value (W/m^2K)	Thickness
Exterior Wall	0.19	0.25
Matou Qiang	0.34	0.71
Ventilated Roof	0.25	0.28
Ground Floor	0.26	0.45
Interior Walls	0.38	0.14
Windows	1.4	-

Table 7.14
New Courtyard Envelope Thermal Performances

planks.

THERMAL ZONES, INTERNAL GAINS AND THRESHOLDS

The new courtyard has been divided in 3 different thermal zones, each one with his proper function: dining room, kitchen, and restroom.
For each of them has been defined different values for the internal gains and the temperature thresholds.

Table 7.15
New Courtyard internal gains values

Table 7.17
(Below) New Courtyard Setpoints

Zone Name	Use	Equipment	Lightning	People
NC_1	Dining Room	24.00	3.00	0.30
NC_2	Kitchen	250.00	3.00	0.15
NC_3	Restroom	4.00	3.00	0.02

Function	Heating Setback and Setpoint	Cooling Setback and Setpoint
Dining Room	/ - 21° C	27° - / °C
Kitchen	/ - 19° C	27 - / °C
Restrooms	12-19°C	28-33°C

HEATING TOTAL ENERGY DEMAND

After the simulations the energy demand for heating is

7'766 kWh/year
44 kWh/m²

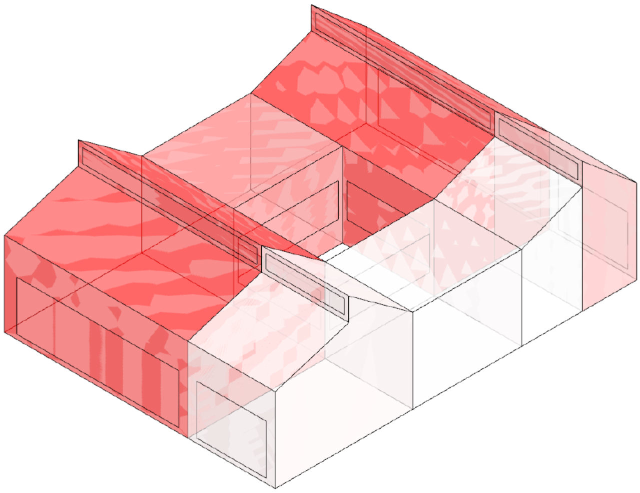
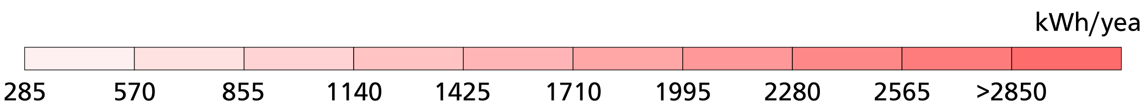


Fig. 7.45
Heating energy demand diagram



COOLING TOTAL ENERGY DEMAND

In this first simulation, maintaining the existing envelope construction is

637 kWh/year
3.64 kWh/m²

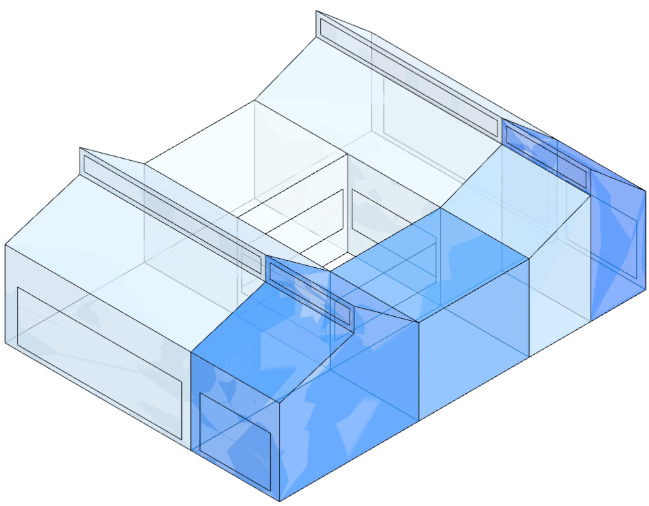
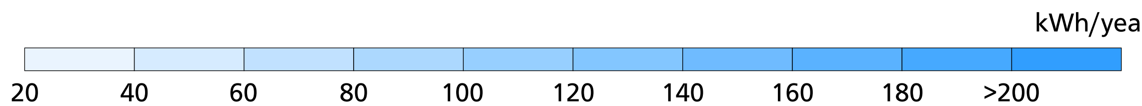
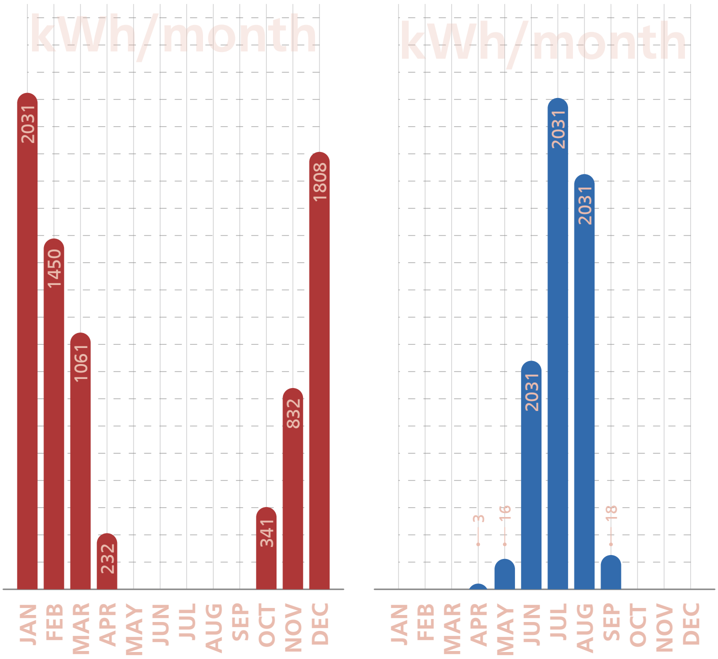


Fig. 7.46
Cooling energy demand diagram





MONTHLY ENERGY DEMAND

As is possible to notice in the graphs, the energy demand of the building has been minimalized thanks to the utilization of different strategies.

Is possible to reduce even more the energy demand during summer with natural ventilation, utilizing the roof windows and the stack effect in the center of the courtyard.

In the next paragraph, the author is going to calculate the energy consumption of the building with utilizing renewable sources for energy production.

Fig. 7.47
Monthly energy demand of the new courtyard

RENEWVABLE SOLUTIONS

As it was done for the Cultural Center, is necessary to evaluate the amount of energy that is required to maintain the optimal comfort conditions in the building.
The first data that is required is the Total Heating and Cooling demand of the building, followed by the relative peaks that represent the power that the Heat Pump requires.

HEAT PUMP ELECTRIC CONSUMPTION

In this case the Heating demand is 7’776 kW/h and the cooling demand is 637 kW/h, with the relatives peaks being 10 and 8 kW.
To produces this quantity of energy it was decided to use a Air-Water heat pump with a respective COP of 4.39 and EER of 3.51, with the selected model, the quantity of electricity consumed would be 1’950 kWh/year, equal to 11.14 kWh/m².

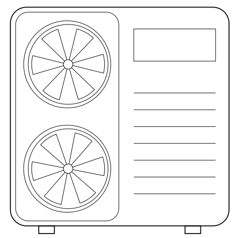
LIGHTING AND APPLIANCES ELECTRIC CONSUMPTION

The electric consumption can be estimated for a value of 75 kWh/m² for the kitchen (Energy Check Up) per year, while for the bathroom the consumption can be estimated to a total consumption of 80 kWh/year (following the same principle that was used in the Cultural Center restrooms), the dining room electric consumption would be strictly connected to the lighting of the space, the author would suppose the presence of 30 light spots in the room, for a total consumption of 420 kWh
The electric consumption amounts to 6’425 kWh/year.

Total Heating Energy Demand:
7’766 kWh/year
Peak Heating Demand:
8 kW

Total Cooling Energy Demand:
637 kWh/year
Peak Heating Demand:
8 kW

Fig. 7.48
Total energy demand of the new courtyard

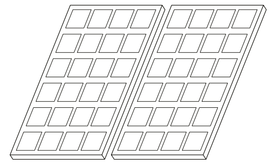


Brand: Chofu
Max Heating Capacity: 10 kW
Max Cooling Capacity: 8 kW
COP: 4.39
EER: 3.51

Fig. 7.49
Heat pump specs

DHW

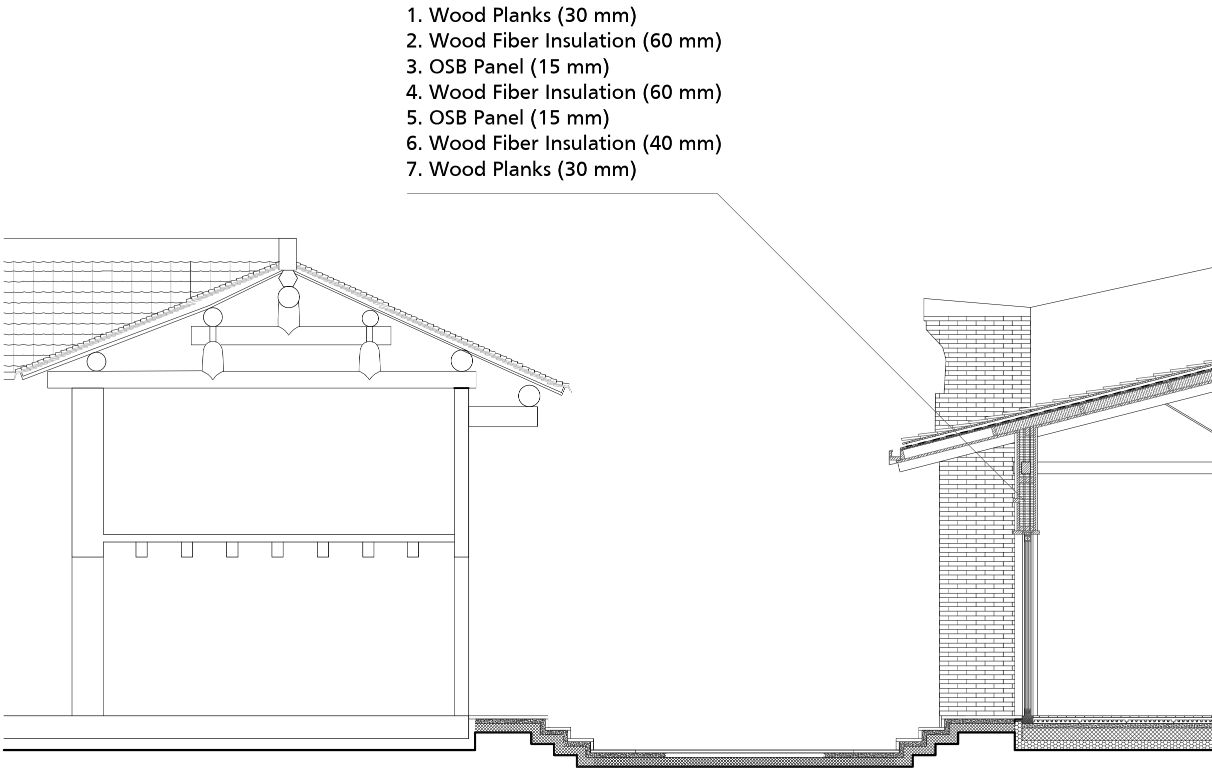
The integration of the solar collectors into the design building is not a feasible solution, therefore, the author has decided to use the heat pump to produce the domestic hot water necessary for the building.
Using the software SWH3 it was possible to estimate a hot water demand of 50L/day that translate to a total energy demand of 1010 kWh/year.
This amount of energy can be produced by the Heat pump consuming 230 kWh/year.
The total electric consumption would be of 6’655 kW/year



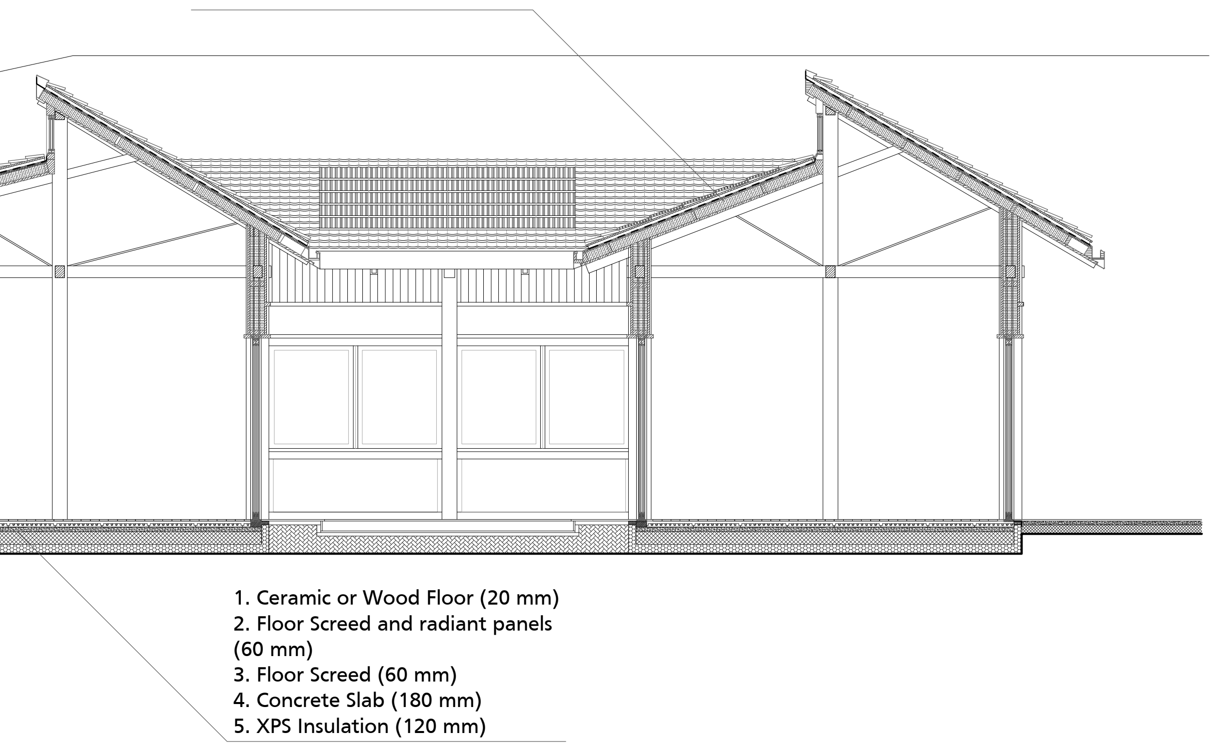
Brand: Suntegra
Model: Single STS 114
PV module efficiency: 17.2 %
NOCT: 57°C

PHOTOVOLTAIC SYSTEM

The electricity needed to cover the operation of the building can be produced with a photovoltaic system.
Since the position of the building restricts the surfaces that can be used only to the ones that do not face the ancient road, the total available surface is 20 m².
In this case, the best solution would be to integrate the system in the building design, using solar shingles instead of the traditional panels.
Using the Suntegra Shingles is possible to deliver 7’000 kWh/year.
Since the energy production system and the energy distribution system are not “perfect build” is necessary to consider a coefficient of 2% of losses for both the system.
Therefore, the energy production of the panels will be reduced to 6’723 kWh/year.
In this case the building can be considered as a **Zero energy building**.


1. Wood Planks (30 mm)
2. Wood Fiber Insulation (60 mm)
3. OSB Panel (15 mm)
4. Wood Fiber Insulation (60 mm)
5. OSB Panel (15 mm)
6. Wood Fiber Insulation (40 mm)
7. Wood Planks (30 mm)

1. Shingles or Photovoltaic Shingles (20 mm)
2. OSB Panel (20 mm)
3. Ventilated Air Chamber (40 mm)
4. OSB panel (30 mm)
5. Wood Fiber insulation (120 mm)
6. Wood Planks (30 mm)



1. Ceramic or Wood Floor (20 mm)
2. Floor Screed and radiant panels (60 mm)
3. Floor Screed (60 mm)
4. Concrete Slab (180 mm)
5. XPS Insulation (120 mm)

Fig. 7.50
New courtyard detailed section

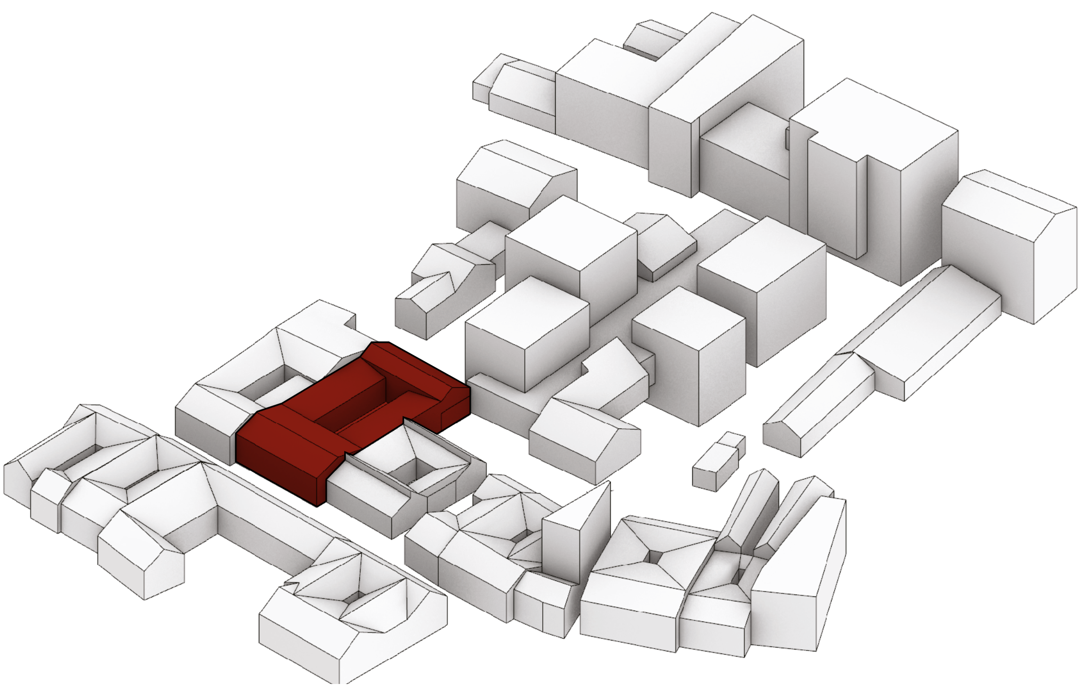
8.1 THE GENERAL CONDITION OF THE TRADITIONAL BUILDINGS

As it was described before, all the traditional buildings are built with wood traditional construction system.
The main problem is the lack of comfort conditions inside the buildings.

THE MODEL

The prototype that we decided to use is a traditional building, that we had the possibility to find the original plans and from them it was possible to reconstruct the original state of the building before the elevation of part of the courtyard.
This analysis is going to be useful to understand what kind of improvement can be obtained with retrofitting solutions.

Fig. 8.1
Axonometry of the building and the urban fabric



The energetic model is simpler that the last one, since the number of materials, thermal zones, therefore, the threshold and so on can be controlled faster.

Building	Zone Name	Use	Floor Surface	Outdoor Surface	Volume	S/V
Ancient Building	A_0_1	Retail	486 m^2	574 m^2	1394 m^3	0.41
	A_0_2	Storage				
	A_0_3	Rooms				
	A_0_4	Rooms				
	A_0_5	Living Room				
	A_1_1	Storage				
	A_1_2	Storage				
	A_1_3	Storage				

Table 8.1
Geometric important values of the ancient building

THE ENVELOPE OF THE TRADITIONAL BUILDINGS

The following table, illustrates the different U-values of the traditional constructions in Fenhuang Town (a more in-depth description, and drawings can be found in the last chapter while describing the traditional buildings and in the paragraph 5.4 “Guidelines for the preservation of Fenhuang Town”)

Construction Type	U-value (W/m^2K)	Thickness
Exterior Wood Wall	4.00	0.04
Exterior Earth Wall	3.50	0.31
Roof	0.70	0.18
Ground Floor	1.88	0.25
Intermediate Floors	4.00	0.04
Interior Walls	3.50	0.31
Windows	5.2	-

Table 8.2
Existent stratigraphies of the ancient building

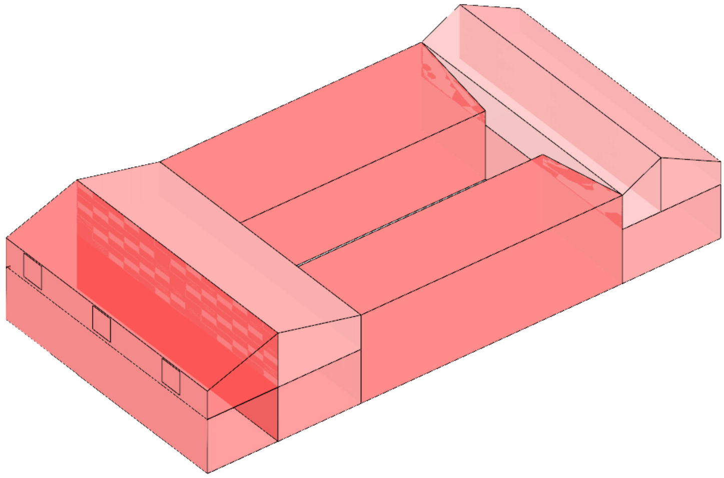
THERMAL ZONES, INTERNAL GAINS AND THRESHOLDS

The building has been divided mainly in 9 different thermal zones, mostly because of the geometric constrictions of grasshopper.
Ideally it has been divided in two different parts “retail” and “rooms”.

Zone Name	Use	Equipment	Lightning	People
TB_1	Retail	5.20	11.30	0.03
TB_2	Room	2.70	11.30	0.02
TB_3				
TB_4				
TB_5				
TB_6				
TB_7				
TB_8				
TB_9				

Table 8.3
Internal gains of the building

Since the building has a residential use destination, the threshold for heating has been set for 21° C during the day and 13 °C during the night, for cooling instead the temperature has been set at 28° C for the whole day when is necessary.

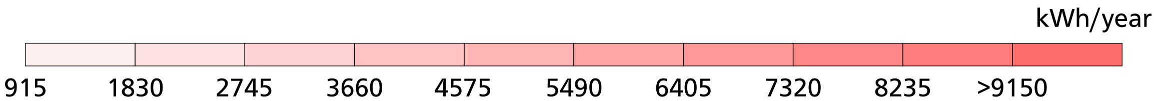


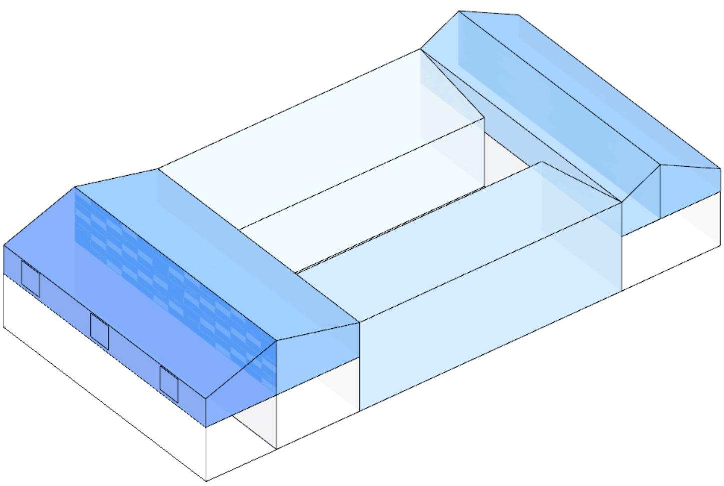
HEATING TOTAL ENERGY DEMAND

After the simulations the energy demand for heating is

49’043 kWh/year
114 kWh/m²

Fig. 8.2
Heating energy demand of the ancient building



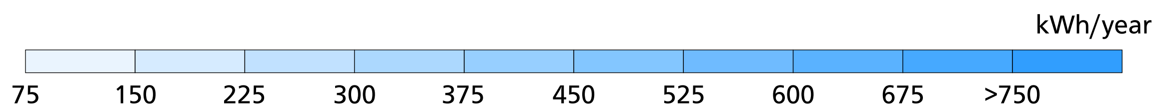


COOLING TOTAL ENERGY DEMAND

In this first simulation, maintaining the existing envelope construction is

1’685 kWh/year
3.91 kWh/m²

Fig. 8.3
Cooling energy demand of the ancient building

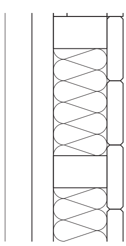


8.2 RETROFITTING PROPOSED SOLUTIONS

As was said in the 5.4 paragraph, the solutions that must be used in the retrofitting of the traditional buildings has to be reversible and should only imply the use of “dry” solutions, with the less possible attachment points to the original structure.

WALLS

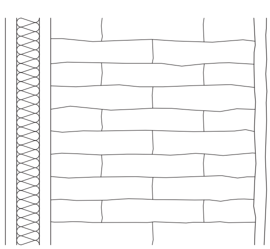
The existing wall, composed by a single layer of wood should be insulated, to do that, the proposed solution is to create a second wall for this purpose, the solution is going to build into the building, even if the insulation of the building from the inside is not as effective as from the exterior because of the thermal bridges. In this way is possible to maintain the original aspect from the ancient road.



1. Wood Planks (40 mm)
2. Wood fiber panels /Wood Studs (100 mm)
3. Wood Planks (30 mm)

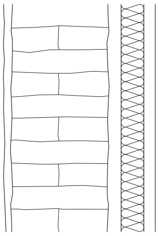
Fig. 8.4
Proposed stratigraphy for the external wood walls of the ancient building

For the Matou Qiang, to avoid the reduction of the internal space, it is necessary to opt for a thin internal layer of insulation, in this case a 6 cm layer was decided to be used.



1. Drywall panel (30 mm)
2. Wood Fiber Insulation (60 mm)
3. Plaster (30 mm)
4. Rammed Earth Brick Wall (540 mm)
5. Plaster (30 mm)

Fig. 8.5
Proposed stratigraphy for the external rammed earth walls of the ancient building



1. Plaster (30 mm)
2. Rammed Earth Brick Wall (250 mm)
3. Plaster (30 mm)
4. Wood Fiber Panel (60 mm)
5. Plaster (30 mm)

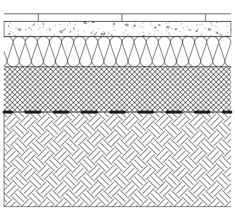
Fig. 8.6
Proposed stratigraphy for the external walls composed by brick layers of the ancient buildings

For the exterior walls, composed by the earth bricks layer, covered with plaster, is possible to retrofit them intervening on the exterior, in this way is possible to avoid the space reduction on the inside of the building.

FLOORS

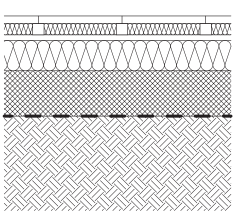
The floors in the traditional building are only of two different types, the ground floor and the intermediate floor.

In the first case, since there's no historic value in the floor (most of them have been built with a layer of concrete.
To improve the insulation from the ground humidity and ensure the resistance of the floor, is possible to create a new insulated floor with a concrete resistant base, insulation and covered with wood pavement.



1. Ceramic tiles or stone finish (12-20 mm)
2. Lightweight Screed (40 mm)
3. Calcium Silicate Panel Insulation (80 mm)
4. Concrete Slab (150 mm)

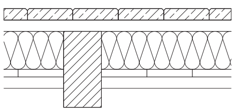
Fig. 8.7
Proposed solution for the ground floor with a ceramic finishing



1. Wood Finish (20 mm)
2. Wood Insulated structure (30 mm)
3. OSB Panel (15 mm)
4. Calcium Silicate Panel Insulation (60 mm)
5. Concrete Slab (120 mm)

Fig. 8.8
Proposed solution for the ground floor retrofitting with a wood finishing

The intermediate floor is composed by a single layer of wood planks, this is always what separates the “external” environment of the retail shop from the upper part of the house.
To insulate, is possible to construct a light structure insulated structure in aluminum or wood and then cover it with a second layer of wood planks.

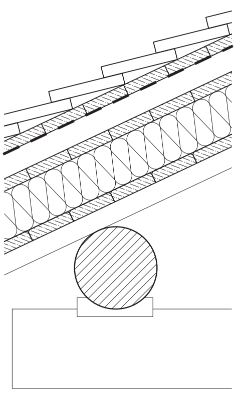


1. Wood Planks (30 mm)
2. Wood Fiber Insulation (100 mm)
3. Wood Planks (30 mm)

Fig. 8.9
Proposed stratigraphy for the intermediate wood floor

ROOF

The roof will follow the same options of the past cases, it will be insulated, and the original tiles will be recovered.



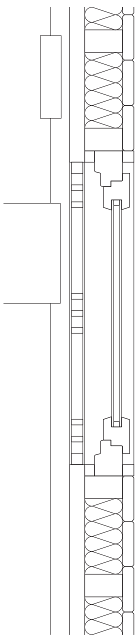
1. Shingles (20 mm)
2. Wood Planks (30 mm)
3. Firwood (60 mm)
4. Waterproof barrier (8 mm)
5. Wood planks (30 mm)
6. Wood fiber insulation (120 mm)
7. Wood Planks (30 mm)

Fig. 8.10
Proposed stratigraphy for the roof of the ancient buildings

OPENINGS

The modular opening for the retail space is going to be substituted by insulated panels that resemble the same proportion of the traditional ones, the materials were chosen to maintain the weight of the single panel under 2kg.
The doors with no historic value will be replaced with new ones that can guarantee a higher level of air tightness.

The windows that are present on the frontal facade of the building are going to be maintained as they are, to guarantee the possibility to regulate the ventilation, a second window will be laid into the second wall that is going to be built. This window will be a double glass pane window.



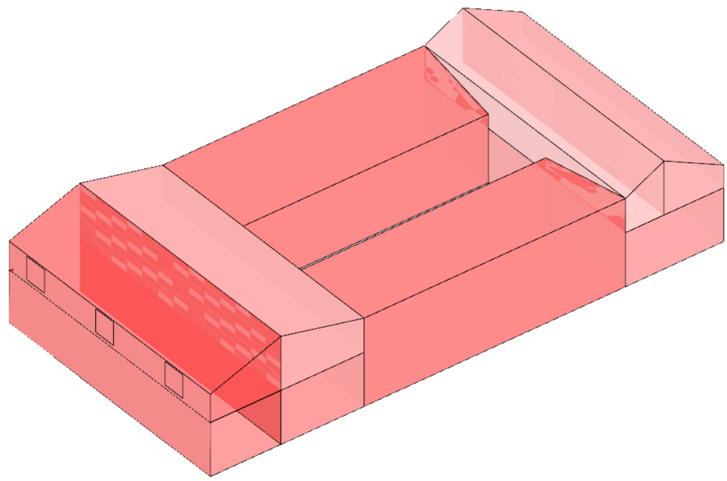
1. Wood Planks (30 mm)
2. Wood Fiber Insulation (100 mm)
3. Wood Planks (30 mm)

Fig. 8.11
Proposed solution for the window placement in the building

Table 8.4
Stratigraphies physical characteristics

Construction Type	U-value (W/m^2K)	Thickness (m)
Retrofitted_Roof	0.24	0.27
Retrofitted Matou Qiang	0.49	0.66
Retrofitted Ext Wood Wall	0.30	0.18
Retrofitted Ext Wall	0.56	0.37
Intermediate Floor	0.30	0.18
Retrofitted Ground Floor	0.46	0.26
Double Pane Windows	1.6	-

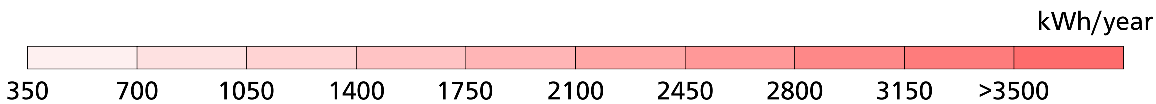
HEATING TOTAL ENERGY DEMAND



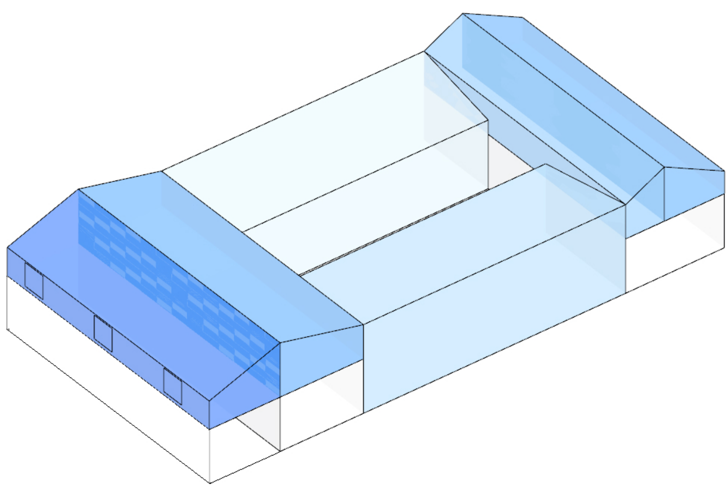
After the simulations the energy demand for heating is

17’385 kWh/year
39.81 kWh/m²

Fig. 8.12
Heating energy demand of the ancient building



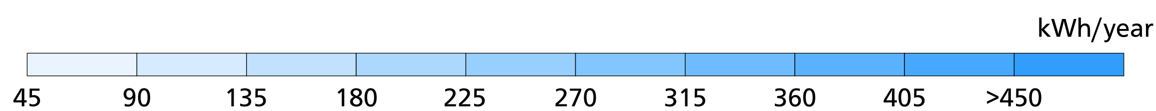
COOLING TOTAL ENERGY DEMAND



After the simulation, maintaining with the new envelope construction, the energy demand for cooling is

2’323 kWh/year
5.32 kWh/m²

Fig. 8.13
Cooling energy demand of the ancient building



MONTHLY ENERGY DEMAND COMPARISON

As is possible to notice in the graphs, like in the previous case, after the intervention the energy demand for the cooling of the building. The most probable reason is the insertion of the new windows and the fact that the insulation decrease the possibility to natural dissipate the heat from the interior of the building.

Concerning the heating energy demand is greatly reduced, noticing a 60% reduction over the months of January and December.
In the months of May and September, the energy demand was almost eliminated.

Fig. 8.14
Graph of the monthly energy consumption of the ancient building

8.3 RENEWVABLES SOLUTIONS FOR THE PROTECTED ARCHITECTURE

Like in the previous case is necessary to evaluate the energy how to provide the energy necessary to maintain the optimal thermal conditions in the building.

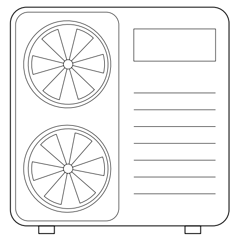
Total Heating Energy Demand:
17’385kWh/year
Peak Heating Demand:
2 kW

Total Cooling Energy Demand:
2’323 kWh/year
Peak Heating Demand:
2 kW

Fig. 8.15
Total energy demand of the ancient building

HEAT PUMP ELECTRIC CONSUMPTION

Since the dimension and the quantity of energy necessary it was decided to use an air to water heat pump, that can generate 4kW of thermal energy and 4.8 kW of cooling power.
Thanks to its 3.3 COP and 3.4 EER, to maintain the comfort conditions in the building a total of 5’951 kWh during the whole year.



Brand: ARIANEXT
Model: 40 M LINK
Max Heating Capacity: 4.1 kW
Max Cooling Capacity: 4.8 kW
COP: 3.3
EER: 3.4

Fig. 8.16
Heat pump specs

LIGHTNING AND APPLIANCES ELECTRIC CONSUMPTION

The electric consumption per capita in China is estimated to be 732 kWh/year per capita (CEIC data), in this case, since the household is occupied by 5 people, is possible to estimate a consumption of 3’600 kWh/year.

The total electricity energy demand would be 9’551 kWh/year.

PHOTOVOLTAIC SYSTEM

To mitigate the electricity consumption is possible to utilize PV panels to be installed on the roof of the building.
In this case, since the intervention has to be on a protected building is necessary to evaluate also the impact of the PV on the facade of the building.
Along the main street, it is not possible to utilize

any kind of solar panels since they would disrupt the identity of the traditional Fenhuang town courtyards.
The only solution is to utilize solar panel into the courtyard, since the visual from the interior wouldn't be affected. It is possible to increase also the integration utilizing solar shingles.

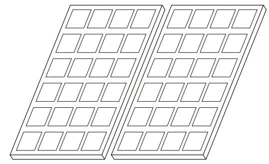
For example, using the Suntegra Shingles, is possible to produce 10'771 kWh/year with a 40 m2 of panel surfaces, this can be distributed between the 3 slopes of the courtyard roof.

With the application of this technology, it would be theoretically possible to cover the whole electric demand from the building.
Since the energy production system and the energy distribution system are not perfect, it's necessary to introduce two coefficients of 98%

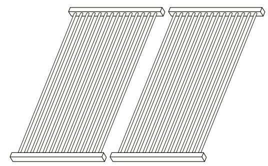
In this case, the energy production of the photovoltaic system can be estimated to be 10'344 kWh/year, maintaining a surplus of energy produced of 427 kWh/year.

DHW

For what concerns the sanitary water is possible, following the SWH software estimations, is necessary to heat 300L/d of water, with a total energy demand of 6030 kWh.
Part of this energy can be supplied using solar collectors, with the alternate energy collectors is possible to deliver 4370 kWh, covering the 72% of the total demand, the remaining must be heated with the usage of another kind of boiler.



Brand: Suntegra
Model: Single STS 114
PV module efficiency: 17.2 %
NOCT: 57°C



Brand: Alternate Energy Technologies
Model: AE-21
Fr (tau alpha) coefficient: 0.71
Fr UL coefficient 4.91

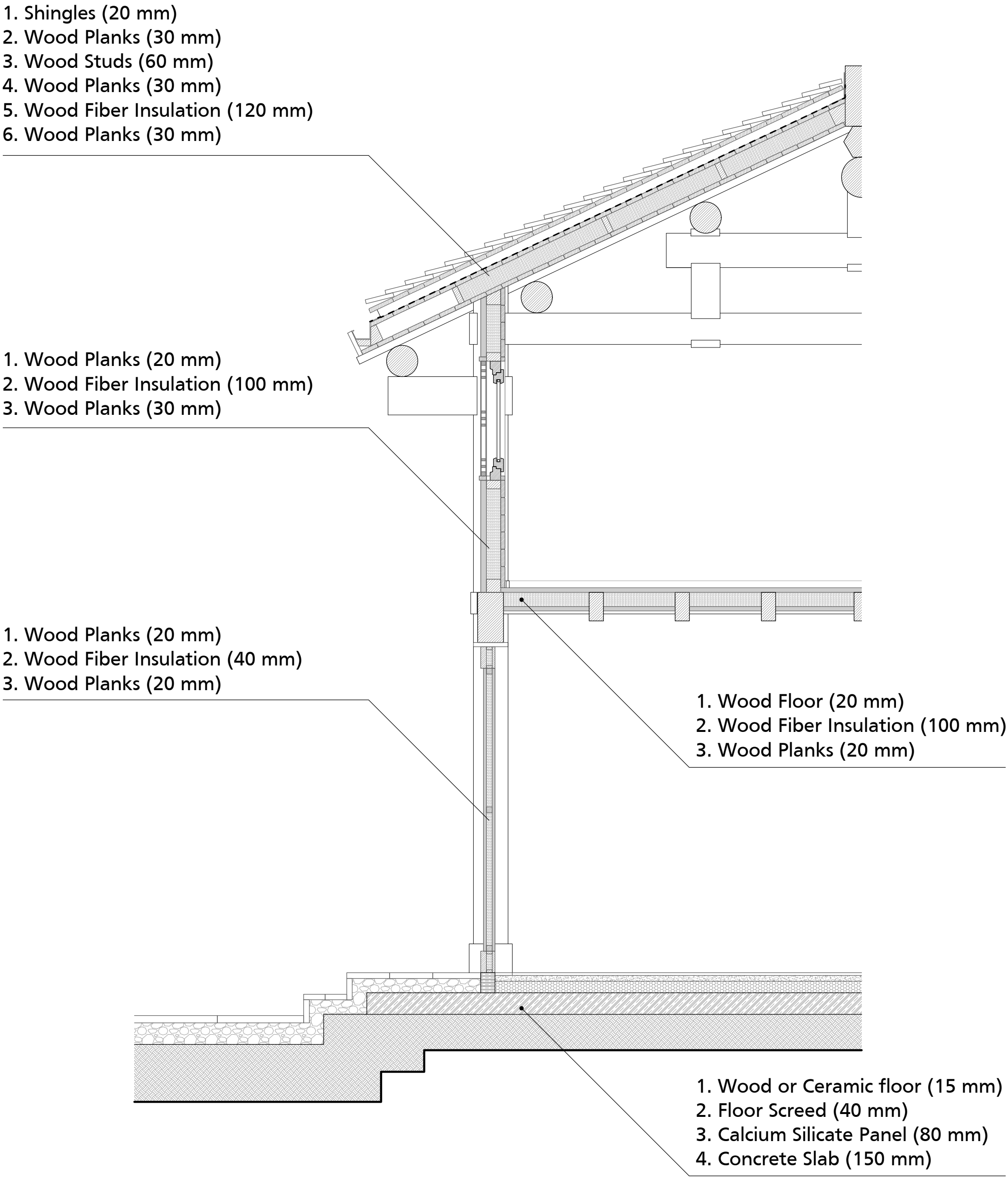


Fig. 8.17
Detailed section of the retrofitted ancient building

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9. CONCLUSION

The reduction of CO_2 and GHG gas emissions has to be reduced in order to make possible to maintain the temperature increment below 1.5 °C in 2050.

In this thesis work, a study concerning the improvement of comfort conditions inside the buildings through operations of retrofitting was carried out.
After having developed in-depth analyzes of the entire urban fabric, enabling the possibility to categorize all the buildings in the city, then dividing them according to the construction techniques and the level of protection that would be necessary to maintain the characteristics of the building.

Five main categories were found: Ancient Buildings, Modern Buildings with Traditional Techniques, Modern Buildings, Contemporary Buildings and Contemporary Style Buildings.

Thanks to these categories, it was easier to create the levels of protection that should have been applied to the city. Each level of protection provides a set of rules to be applied and procedures to be followed when is necessary to intervene on the different buildings of the city.

These levels provide for more or less restrictive measures based on the historical and cultural importance of the artifacts.

The design of the Cultural Center followed these rules for all the decisions concerning the retrofitting operations to be applied to the various structures.

An iterative process was used to select the best options, thanks to a parametric computer model.
The process involves a series of simulations with modifications to the stratigraphies to understand how they influence the amount of energy needed to maintain the comfort conditions.
Following this first step, it was possible to reduce the energy demand for the buildings by a variable amount from 60 to 70%.

Subsequently, in the second step it was possible to reduce the consume with the optimizations of the different setpoints, avoiding energy waste when the different locals are not used.

The last step was to project the different technologies that would be used to produce the energy necessary, from renewable sources.
In this way the result of the retrofitting and the project of the Cultural Center, was a nearly zero energy building, having as single impact the quantity of the energy inside the materials used for the construction.

To reduce the embodied energy of the materials, natural derivates insulants like wood fiber or rock fiber panels.

It’s clear that the use of heat pumps and solar panels requires a considerable economic commitment, but this thesis works allows us to highlight that is possible to reduce the quantity of emission by 60% by the solely envelope improvement.

The model built with the use of grasshopper can also be easily adapted to be used throughout the city of Fenghuang.

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APPENDIX

APPENDIX

A - CLIMATE ANALYSIS WITH GRASSHOPPER

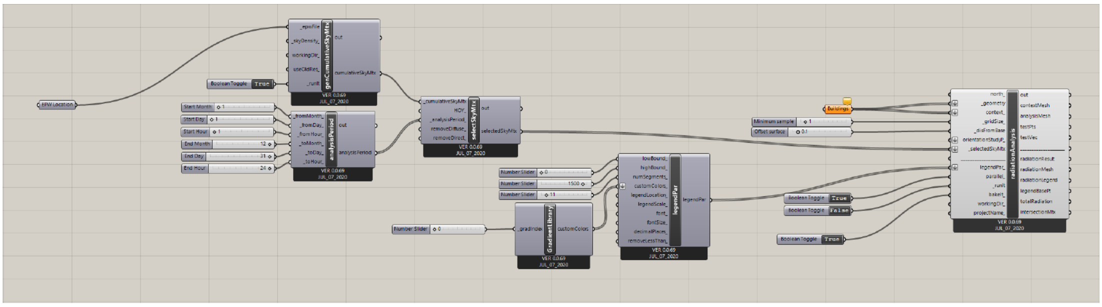


Fig. 1
Radiation analysis node

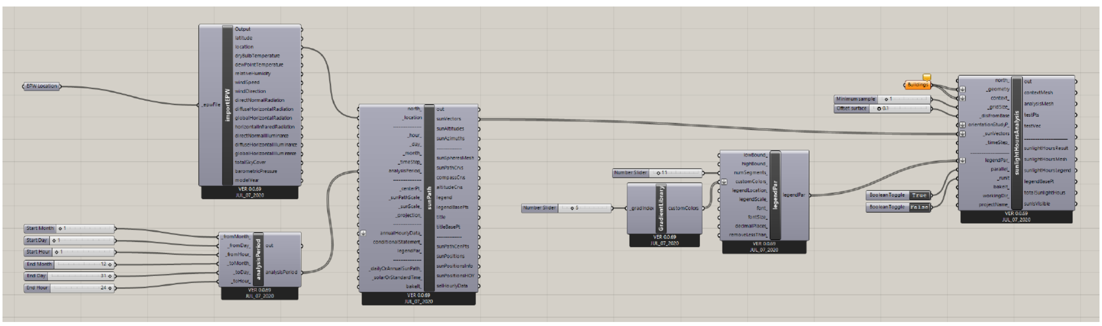


Fig. 2
Sun hours analysis node

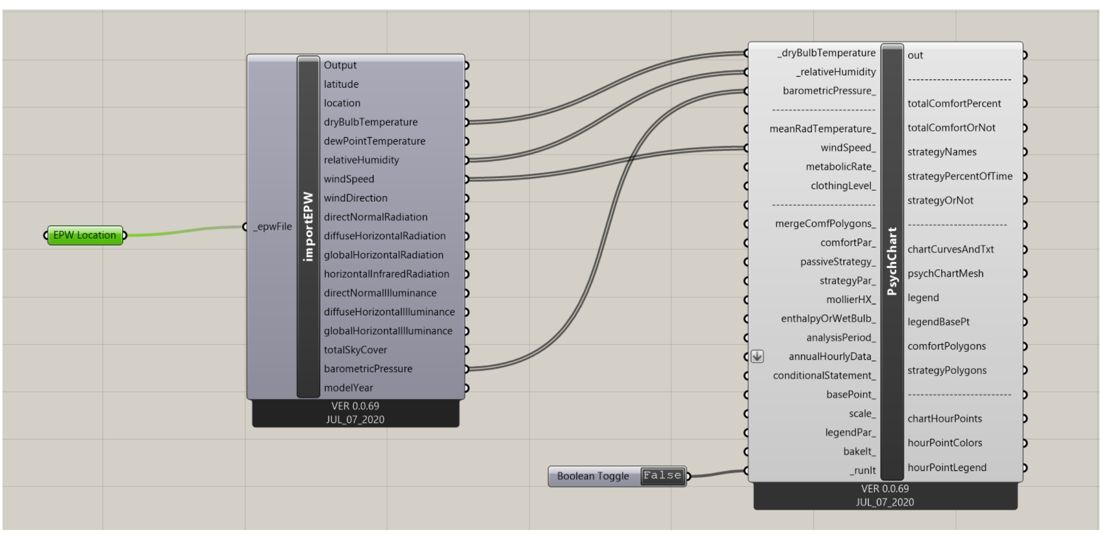


Fig. 3
Bioclimatic Chart node

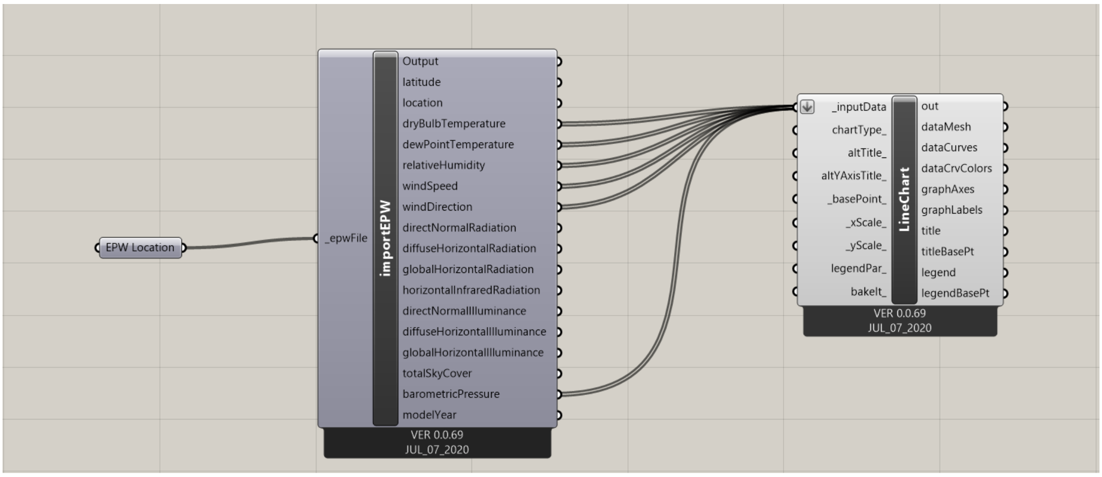


Fig. 4
Dry bulb, dew point, relative humidity, wind speed, wind direction graphs node

B - MATERIAL AND STRATIGRAPHY DEFINITION

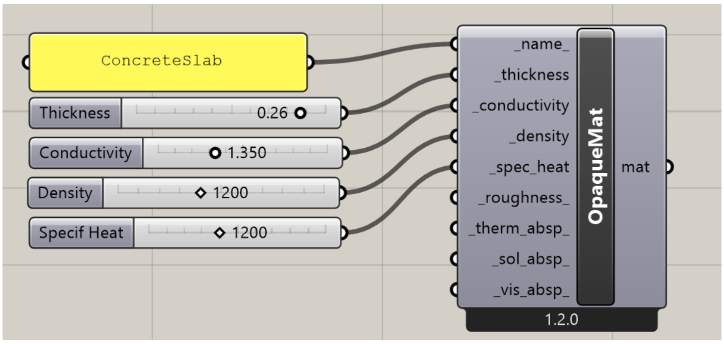


Fig. 5
Definition of physic and thermal characteristics of materials

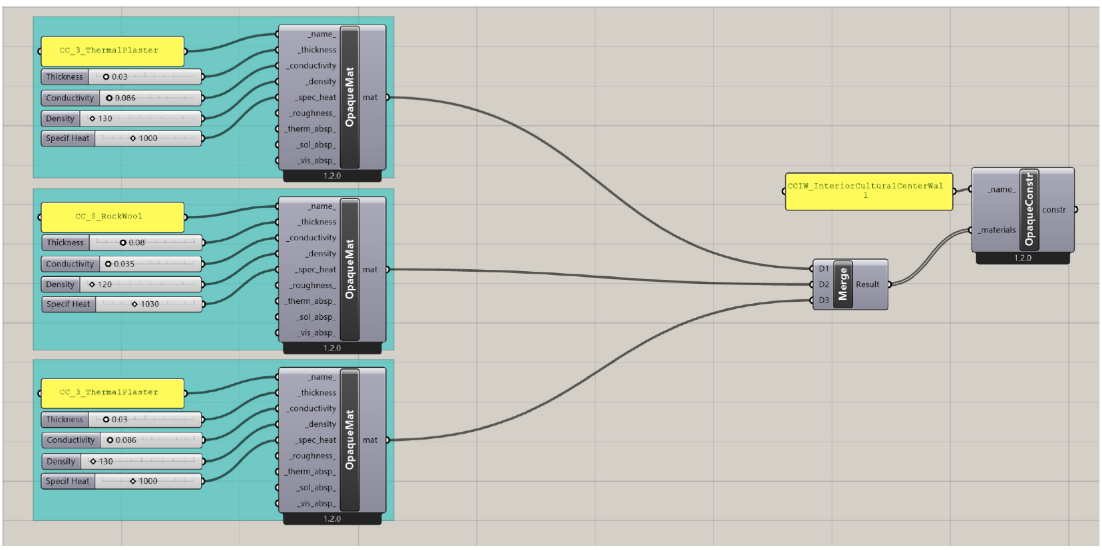
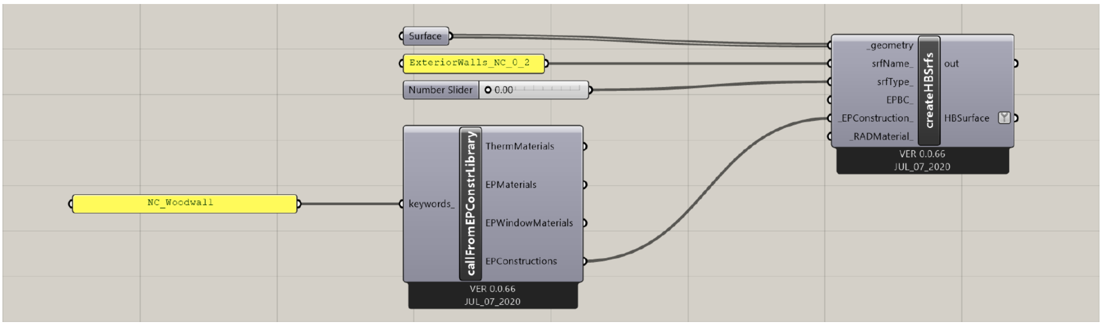


Fig. 6
Definition of a stratigraphy

C - SURFACES, THERMAL ZONES AND ADJANCENCIES

Fig. 7
Definition of a single surface of a building, in this node is also defined the stratigraphy of that surface



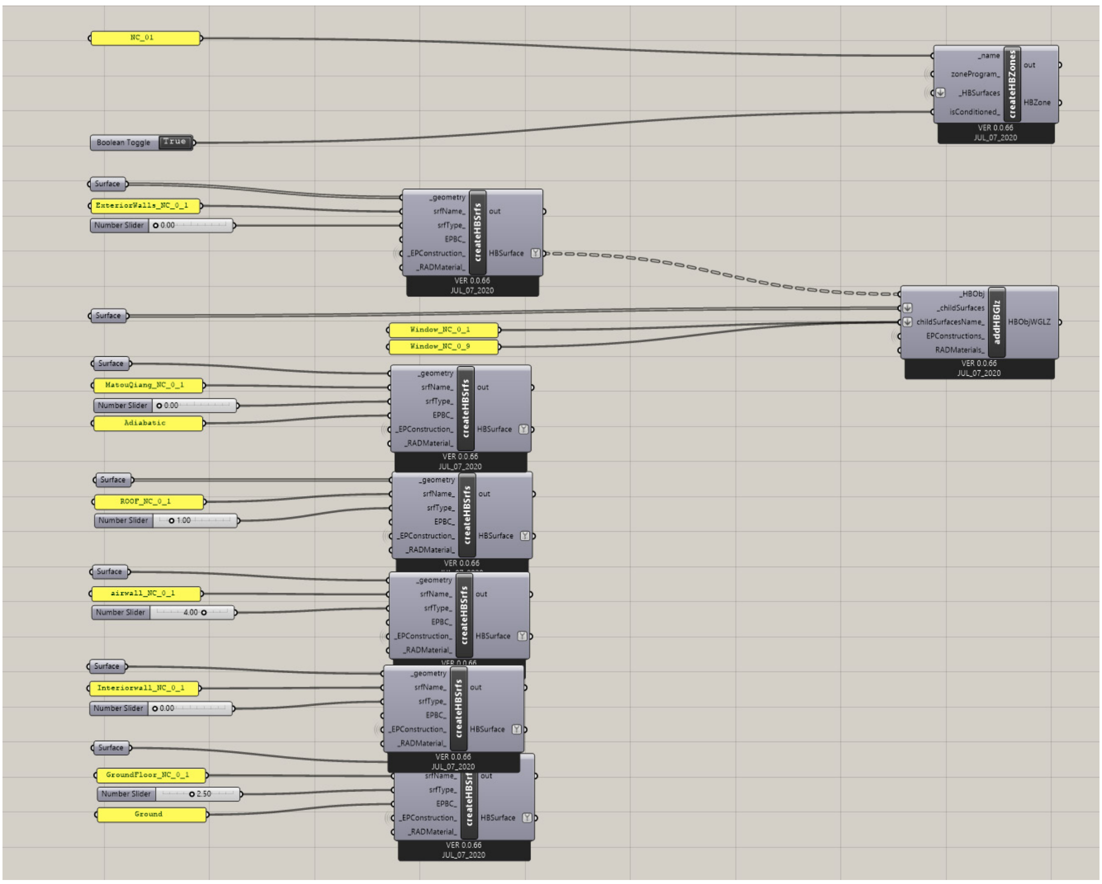


Fig. 8
Definition of a thermal zone (the stratigraphy components are hidden in order to improve the clarity of the process)

Fig. 9
Adjacencies and programs resolution (allows the program to understand the limit conditions for each surface in the building)

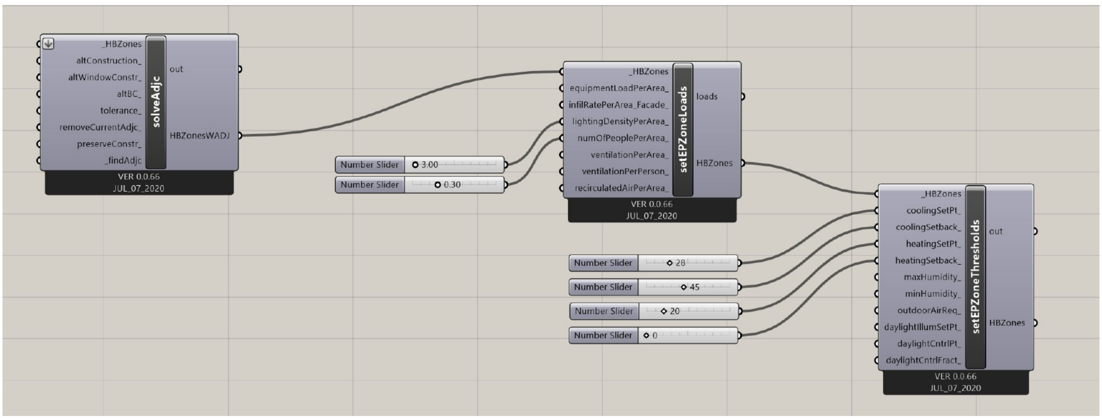


Fig. 10
Internal gains and Threshold definition

D - SIMULATION

Fig. 11
Simulation node

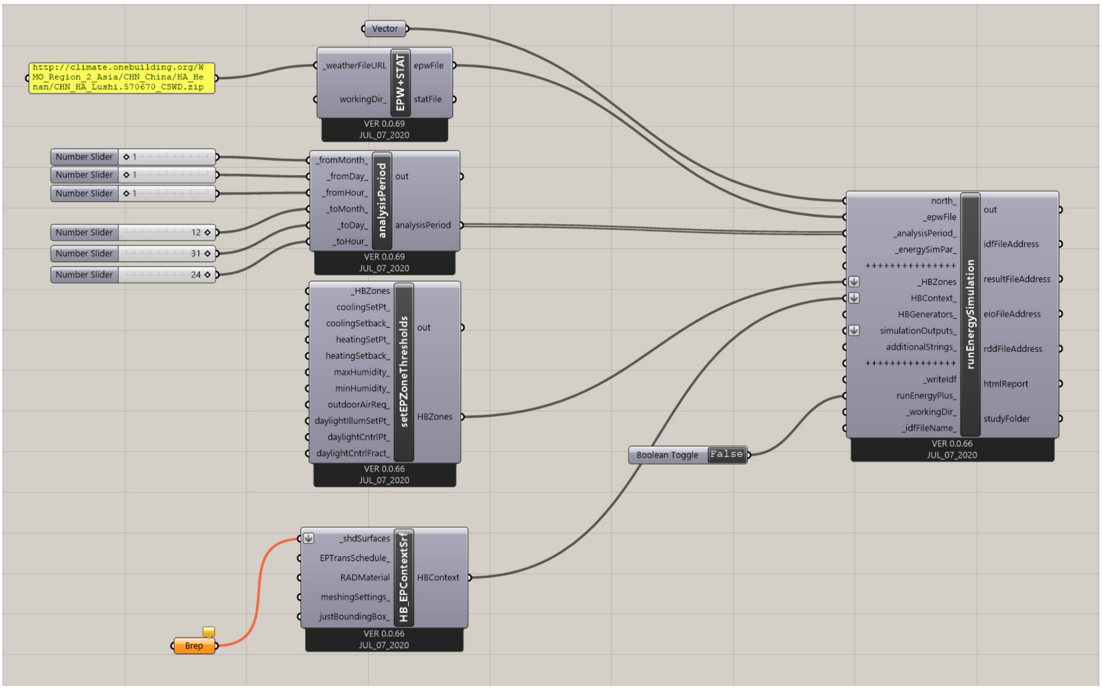
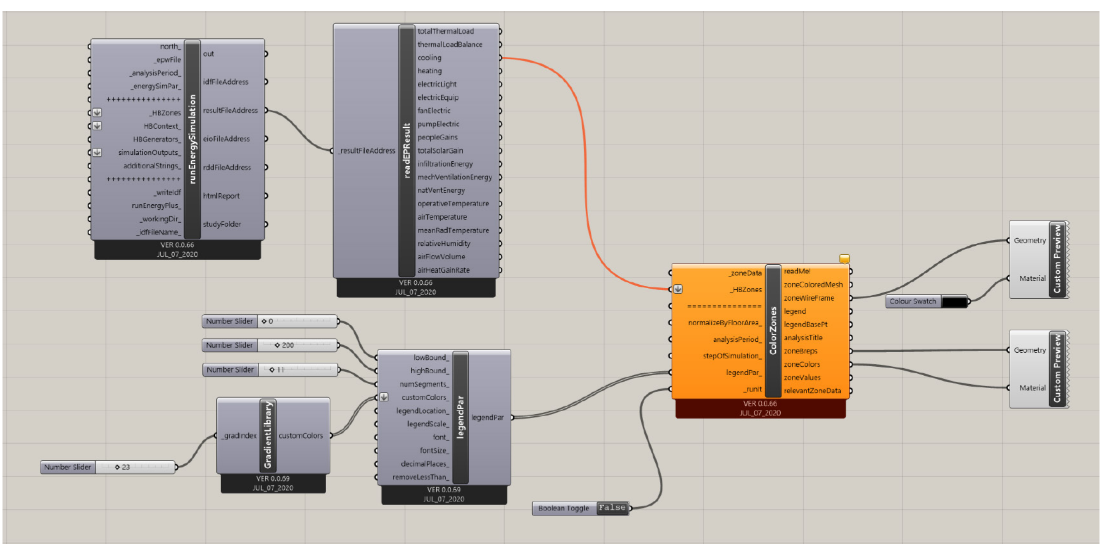


Fig. 12
Graphic visualization of the results



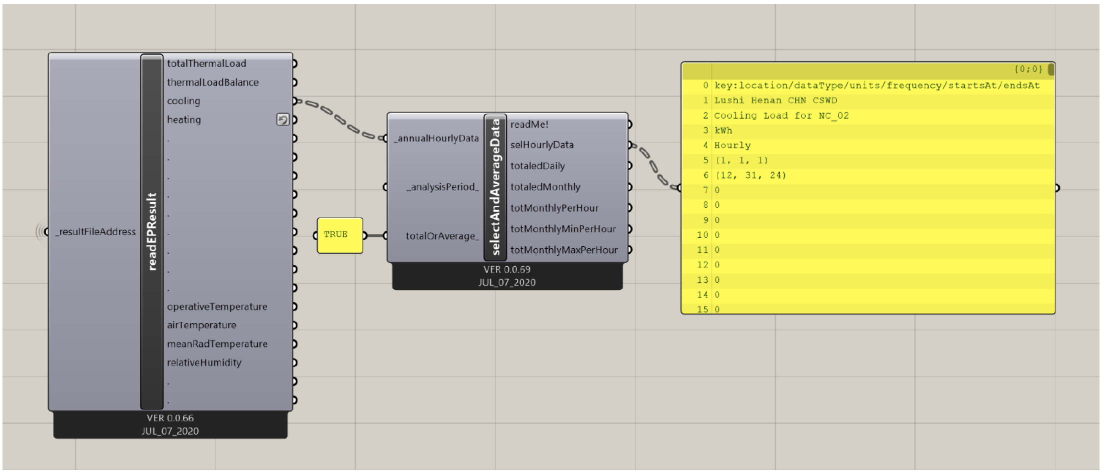


Fig. 13
Textual visualization of the results

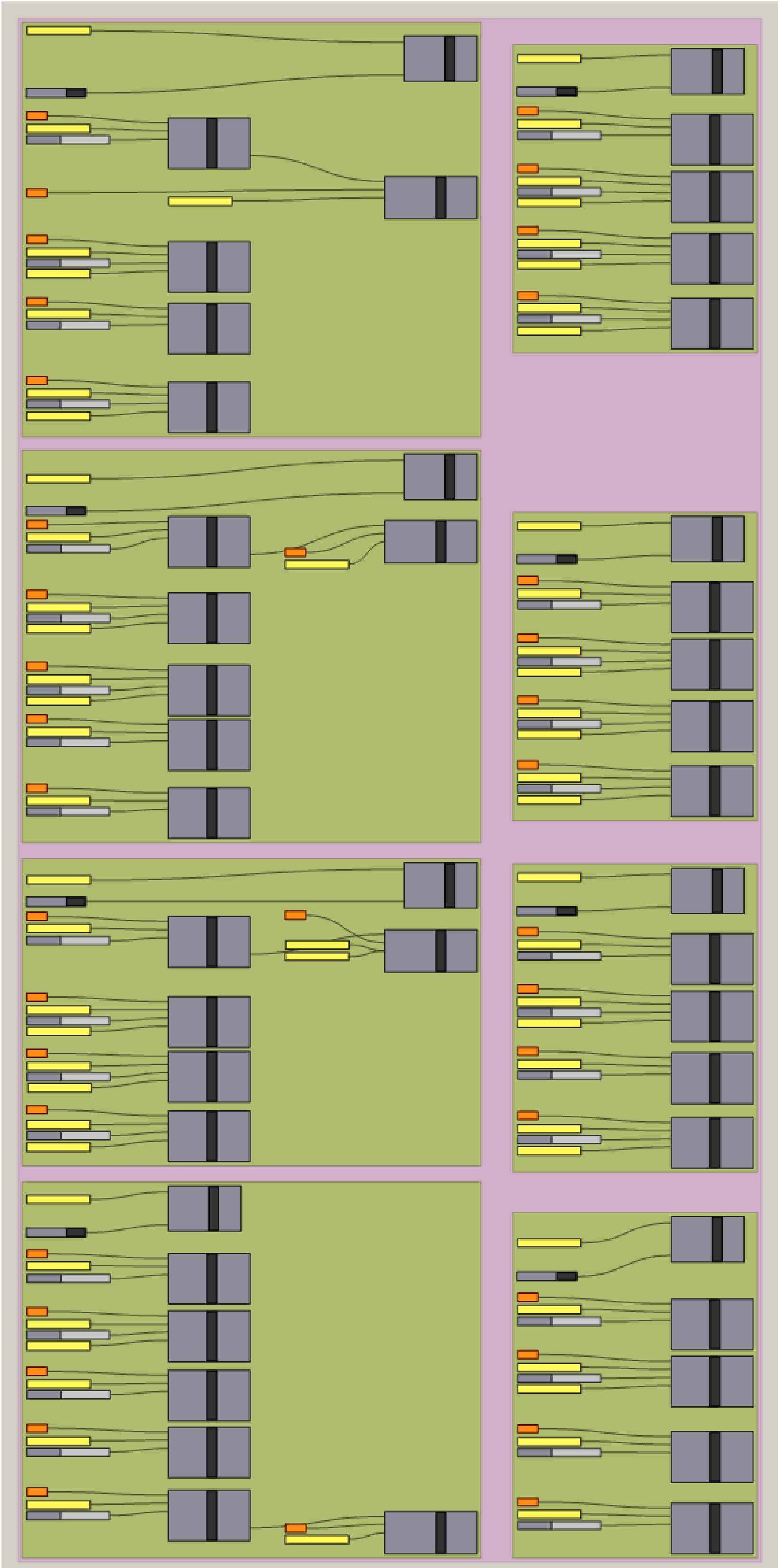


Fig. 14
Classical conformation of a building composed by several thermal zones

E - CULTURAL CENTER

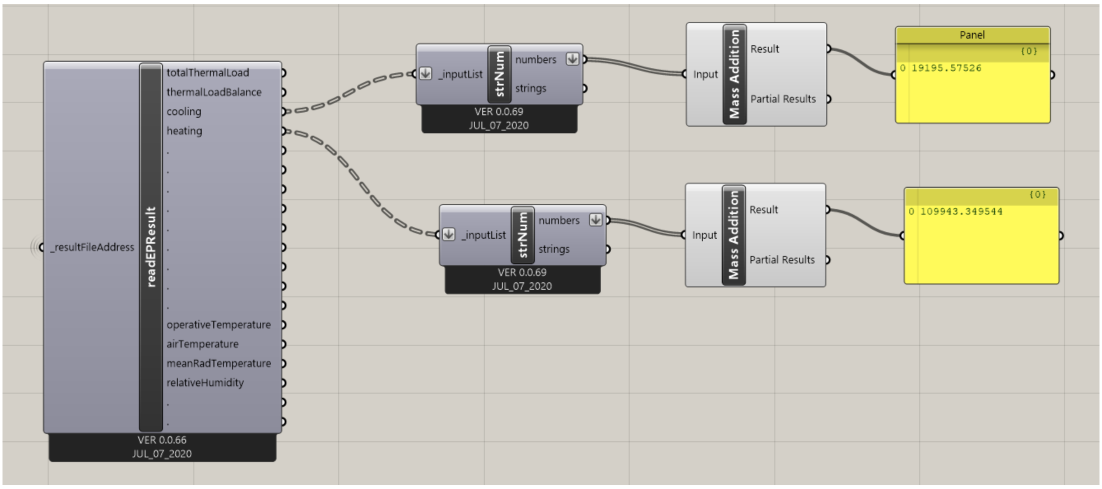


Fig. 15
Heating and Cooling energy demand for the retrofitted courtyard

RETScreen® Energy Model - Photovoltaic Project — Training & Support

Site Conditions		Estimate	Notes/Range
Project name		Cultural Center	See Online Manual
Project location		Fenhuang Town, China	
Nearest location for weather data	-		Complete SR&SL sheet
Latitude of project location	°N	34.1	-90.0 to 90.0
Annual solar radiation (tilted surface)	MWh/m²	2.02	
Annual average temperature	°C	12.8	-20.0 to 30.0

System Characteristics		Estimate	Notes/Range
Application type	-	On-grid	
Grid type	-	Central-grid	
PV energy absorption rate	%	100.0%	
PV Array			
PV module type	-	User-defined	
PV module manufacturer / model #		Sunpower Maxeon 3	See Product Database
Nominal PV module efficiency	%	22.6%	4.0% to 15.0%
NOCT	°C	42	40 to 55
PV temperature coefficient	% / °C	0.29%	0.10% to 0.50%
Miscellaneous PV array losses	%	-5.0%	0.0% to 20.0%
Nominal PV array power	kWp	**32.00**	
PV array area	m²	141.6	
Power Conditioning			
Average inverter efficiency	%	98%	80% to 95%
Suggested inverter (DC to AC) capacity	kW (AC)	31.4	
Inverter capacity	kW (AC)	72.0	
Miscellaneous power conditioning losses	%	0%	0% to 10%

Annual Energy Production (12.00 months analysed)		Estimate	Notes/Range
Specific yield	kWh/m²	462.8	
Overall PV system efficiency	%	22.9%	
PV system capacity factor	%	23.4%	
Renewable energy collected	MWh	66.870	
Renewable energy delivered	MWh	**65.533**	
	kWh	65'533	
Excess RE available	MWh	**0.000**	
			Complete Cost Analysis sheet

Version 3.2 NRCan/CETC - Varennes

Fig. 16
PV3 - Cultural Center

RETScreen® Energy Model - Solar Water Heating Project

Training & Support

Site Conditions		Estimate	Notes/Range
Project name		Cultural Center	See Online Manual
Project location		Fenghuang Town, China	
Nearest location for weather data		St Hubert A, QC	Complete SR&HL sheet
Annual solar radiation (tilted surface)	MWh/m²	1.60	
Annual average temperature	°C	12.8	-20.0 to 30.0
Annual average wind speed	m/s	4.4	
Desired load temperature	°C	60	
Hot water use	L/d	190	
Number of months analysed	month	12.00	
Energy demand for months analysed	MWh	3.82	

System Characteristics		Estimate	Notes/Range
Application type		Service hot water (with storage)	
Base Case Water Heating System			
Heating fuel type	-	Electricity	
Water heating system seasonal efficiency	%	250%	50% to 190%
Solar Collector			
Collector type	-	Glazed	See Technical Note 1
Solar water heating collector manufacturer		Alternate Energy Technologies	See Product Database
Solar water heating collector model		Alternate Energy AE-21	
Gross area of one collector	m²	1.93	1.00 to 5.00
Aperture area of one collector	m²	1.78	1.00 to 5.00
Fr (tau alpha) coefficient	-	0.71	0.50 to 0.90
Fr UL coefficient	(W/m²)/°C	4.91	1.50 to 8.00
Temperature coefficient for Fr UL	(W/(m·°C)²)	0.00	0.000 to 0.010
Suggested number of collectors		2	
Number of collectors		3	
Total gross collector area	m²	5.8	
Storage			
Ratio of storage capacity to coll. area	L/m²	45.9	37.5 to 100.0
Storage capacity	L	245	
Balance of System			
Heat exchanger/antifreeze protection	yes/no	Yes	
Heat exchanger effectiveness	%	95%	50% to 85%
Suggested pipe diameter	mm	10	8 to 25 or PVC 35 to 50
Pipe diameter	mm	38	8 to 25 or PVC 35 to 50
Pumping power per collector area	W/m²	0	3 to 22, or 0
Piping and solar tank losses	%	1%	1% to 10%
Losses due to snow and/or dirt	%	3%	2% to 10%
Horz. dist. from mech. room to collector	m	5	5 to 20
# of floors from mech. room to collector	-	2	0 to 20

Annual Energy Production (12.00 months analysed)		Estimate	Notes/Range
SWH system capacity	kW_{th}	4	
	MWth	0.004	
Pumping energy (electricity)	MWh	**0.00**	
Specific yield	kWh/m²	465	
System efficiency	%	29%	
Solar fraction	%	70%	
Renewable energy delivered	MWh	**2.69**	
	GJ	9.69	
			Complete Cost Analysis sheet

Version 3.1 NRCan/CETC - Varennes

Fig. 17
SWH - Cultural Center

Model		CGK050V3L			CGK-050V3L		
Power Supply / Refrigerant	V/Hz/Ph	220-240/50/1 - R32			380-420/50/3 - R32		
Max. Heating Capacity (1)	kW	20			20		
C.O.P (1)	W/W	4.75			4.76		
Heating Capacity Min./Max.(1)	kW	9.2	/	20	9.2	/	20
Heating Power Input Min./Max.(1)	W	1549	/	4211	1546	/	4202
C.O.P Min./Max. (1)	W/W	4.75	/	5.94	4.76	/	5.95
Max. Heating Capacity (2)	kW	19.2			19.2		
C.O.P (2)	W/W	3.85			3.81		
Heating Capacity Min./Max.(2)	kW	8.83	/	19.20	8.83	/	19.20
Heating power input Min./Max.(2)	W	1957	/	5053	1953	/	5042
C.O.P Min./Max. (2)	W/W	3.80	/	4.51	3.81	/	4.52
Max. Cooling Capacity (3)	kW	18.2			18.2		
E.E.R (3)	W/W	3.73			3.69		
Cooling Capacity Min./Max.(3)	kW	8.39	/	18.24	8.39	/	18.24
Cooling Power Input Min./Max.(3)	W	1897	/	5783	1893	/	5771
E.E.R Min./Max. (3)	W/W	3.15	/	4.42	3.16	/	4.43
Max. Cooling Capacity (4)	kW	14.4			14.4		
E.E.R (4)	W/W	2.80			2.77		
Cooling Capacity Min./Max.(4)	kW	6.62	/	14.40	6.62	/	14.40
Cooling Power Input Min./Max.(4)	W	1702	/	5371	1699	/	5360
E.E.R Min./Max. (4)	W/W	2.68	/	3.89	2.69	/	3.90
Rated Current	A	20.1			8.9		
Max Current	A	29.21			12.86		

Fig. 18
Heat pump spec sheet

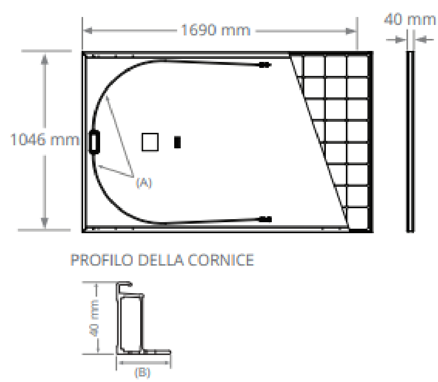
Fig. 19
PV panel spec sheet

MAXEON® 3 | 400 W Modulo residenziale

Dati Elettrici			
	SPR-MAX3-400	SPR-MAX3-390	SPR-MAX3-370
Potenza nominale (Pnom) [7]	400 W	390 W	370 W
Tolleranza di potenza	+5/0%	+5/0%	+5/0%
Efficienza del modulo	22,6%	22,1%	20,9%
Tensione al punto di massima potenza (Vmpp)	65,8 V	64,5 V	61,8 V
Corrente al punto di massima potenza (Impp)	6,08 A	6,05 A	5,99 A
Tensione a circuito aperto (Voc)	75,6 V	75,3 V	74,7 V
Corrente di cortocircuito (Isc)	6,58 A	6,55 A	6,52 A
Tensione massima del sistema		1000 V IEC	
Corrente massima del fusibile		20 A	
Coeff. temp. potenza		−0,29% / °C	
Coeff. temp. tensione		−176,8 mV / °C	
Coeff. temp. corrente		2,9 mA / °C	

Test e Certificazioni	
Test standard [8]	IEC 61215, IEC 61730 Classe di reazione al fuoco Tipo 1 UNI 9177
Certificazione di gestione della qualità	ISO 9001:2015, ISO 14001:2015
Conformità EHS	RoHS (in attesa), OHSAS 18001:2007, senza piombo, Schema di riciclaggio, REACH SVHC-163 (in attesa)
Compatibilità Ambientale	Certificato Cradle to Cradle™ (in attesa)
Test dell'ammoniaca	IEC 62716
Test di resistenza alle tempeste di sabbia	10.1109/PVSC.2013.6744437
Test di resistenza all'acqua salata	IEC 61701 (livello massimo superato)
Test PID	1000 V: IEC 62804
Catalogazioni Disponibili	TUV [9]

Condizioni Operative e Dati Meccanici	
Temperatura	−40° C a +85° C
Resistenza all'impatto	Grandine del diametro di 25 mm a una velocità di 23 m/s
Celle solari	104 celle monocristalline Maxeon di III generazione
Vetro	Antiriflesso, temperato ad alta trasmissione
Scatola di giunzione	IP-68, Stäubli (MC4), 3 diodi di bypass
Peso	19 kg
Carico massimo [10]	Vento: 4000 Pa, 408 kg/m² fronte e retro Neve: 6000 Pa, 611 kg/m² fronte
Cornice	Alluminio anodizzato nero classe 1, massima classificazione AAMA



A. Lunghezza del Cablaggio: 1200 mm +/-10 mm
B. Lato Lungo: 32 mm
Lato Corto: 24 mm

F - RECONSTRUCTED COURTYARD

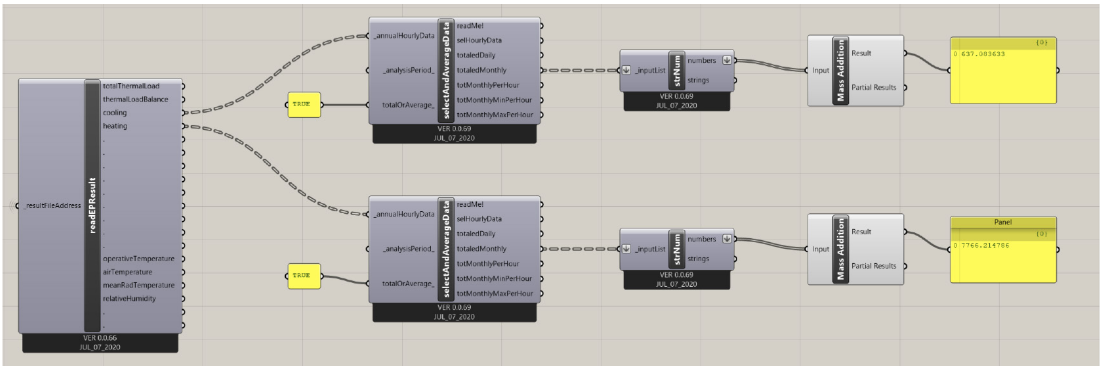


Fig. 15
Heating and Cooling energy demand for the new courtyard

RETScreen® Energy Model - Photovoltaic Project

Training & Support

Site Conditions		Estimate	Notes/Range
Project name		Restaurant	See Online Manual
Project location		Fenhuang Town, China	
Nearest location for weather data	-		Complete SR&SL sheet
Latitude of project location	°N	34.1	-90.0 to 90.0
Annual solar radiation (tilted surface)	MWh/m²	2.02	
Annual average temperature	°C	12.8	-20.0 to 30.0

System Characteristics		Estimate	Notes/Range
Application type	-	On-grid	
Grid type	-	Central-grid	
PV energy absorption rate	%	100.0%	
PV Array			
PV module type	-	User-defined	
PV module manufacturer / model #		Suntegra Shingles	See Product Database
Nominal PV module efficiency	%	17.2%	4.0% to 15.0%
NOCT	°C	57	40 to 55
PV temperature coefficient	% / °C	-0.40%	0.10% to 0.50%
Miscellaneous PV array losses	%	-2.0%	0.0% to 20.0%
Nominal PV array power	kWp	**3.25**	
PV array area	m²	18.9	
Power Conditioning			
Average inverter efficiency	%	98%	80% to 95%
Suggested inverter (DC to AC) capacity	kW (AC)	3.2	
Inverter capacity	kW (AC)	72.0	
Miscellaneous power conditioning losses	%	0%	0% to 10%

Annual Energy Production (12.00 months analysed)		Estimate	Notes/Range
Specific yield	kWh/m²	370.5	
Overall PV system efficiency	%	18.4%	
PV system capacity factor	%	24.6%	
Renewable energy collected	MWh	7.144	
Renewable energy delivered	MWh	**7.001**	
	kWh	7'001	
Excess RE available	MWh	**0.000**	
			Complete Cost Analysis sheet

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Fig. 16
PV3 Calculation for the reconstructed building

Fig. 17
DHW Restaurant

Water Heating Load Calculation		Estimate	Notes/Range
Application type	-	Service hot water	
System configuration	-	With storage	
Building or load type	-	Restaurant	
Number of units	Meal/d	3	
Rate of occupancy	%	100%	50% to 100%
Estimated hot water use (at ~60 °C)	L/d	27	
Hot water use	L/d	50	
Desired water temperature	°C	60	
Days per week system is used	d	7	1 to 7
Cold water temperature	-	Auto	
Minimum	°C	8.1	1.0 to 10.0
Maximum	°C	17.0	5.0 to 15.0
Months SWH system in use	month	12.00	
Energy demand for months analysed	MWh	1.01	
	GJ	3.61	
			Return to Energy Model sheet

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ELECTRICAL PERFORMANCE	STS 114	STS 110	STS 105
Peak Power (Wp)	114 W	110 W	105 W
Power Tolerance	+5/-3 %	+5/-3 %	+5/-3 %
Panel Efficiency*	17.2 %	16.6 %	15.9 %
- Watts / Sq ft*	15.9	15.4	14.7
Voltage at Peak Power (Vmp)	12.78 V	12.72 V	12.65 V
Current at Peak Power (Imp)	8.92 A	8.66 A	8.30 A
Open Circuit Voltage (Voc)	15.52 V	15.46 V	15.39 V
Short Circuit Current (Isc)	9.68 A	9.41 A	9.06 A
Maximum System Voltage	600 V	600 V	600 V
Series Fuse Rating	15 A	15 A	15 A

Temperature Coefficients		
Power (Wp)	-0.404	(%/C)
Voltage (Voc)	-0.291	(%/C)
Current (Isc)	+0.038	(%/C)
NOCT (+/-2C)	57	C

Fig. 18
Suntengra Shingles specs

Model	6kW	10 kW	16 kW
Type	Heating and Cooling Monobloc Type DC Inverter (Reverse cycle)		
Power	1N ~ 230V 50Hz		
Heating (*)			
Capacity [kW]	6.0	10.0	16.0
Power Input [kW]	1.43	2.28	3.72
Running Current (MAX.) [A]	6.3 (11.2)	10.1 (17.5)	16.3 (25.3)
COP	4.20	4.39	4.30
Cooling (*)			
Capacity [kW]	5.0	8.0	16.0
Power Input [kW]	1.28	2.28	4.10
Running Current (MAX.) [A]	5.6 (8.1)	10.0 (11.6)	17.8 (23.0)
EER	3.91	3.51	3.90
Max. Pressure [MPa]	4.2	4.2	4.2
Refrigerant (R32) [kg]	0.8	1.55	2.99

Fig. 19
Chofu Heat Pump specs

G - RETROFITTED COURTYARD

Fig. 20
Retrofitted courtyard heating and cooling energy demand results

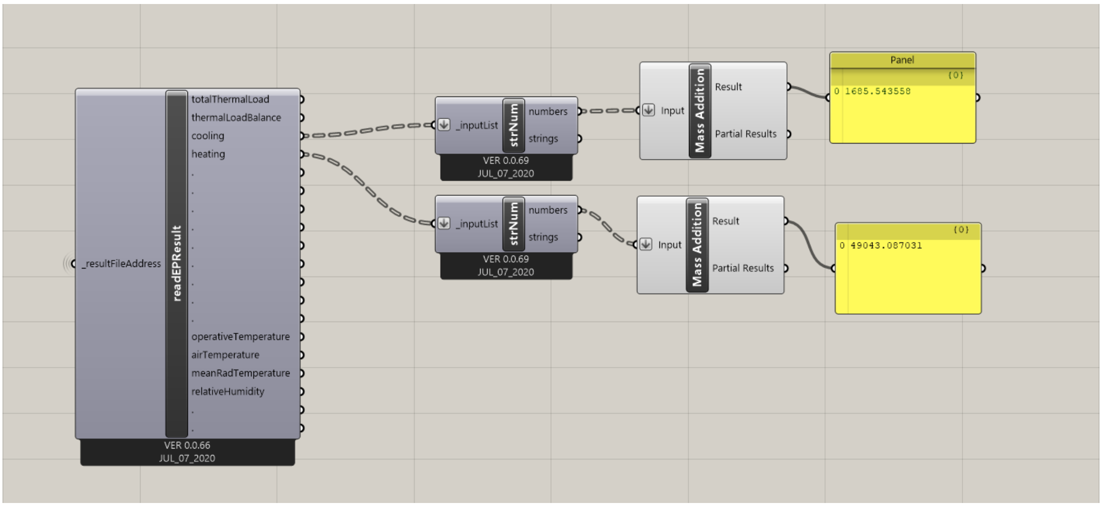

Fig. 21
Aria Next Heat pump specs

	40 M LINK
Riferimento	3069556
Potenza termica (Ta -7°C, Tw 35/30°C – EN 14511) riscaldamento	1,0 / 4,1 / 4,6 kW (Min / Nom / Max)
COP (Ta -7°C, Tw 35/30°C – EN 14511) riscaldamento	3,3
Potenza termica (Ta 7°C, Tw 35/30°C – EN 14511) riscaldamento	1,5 / 3,5 / 5,7 kW (Min / Nom / Max)
COP (Ta 7°C, Tw 35/30°C – EN 14511) riscaldamento	5,1
Potenza termica (Ta 35°C, Tw 7/12°C – EN 14511) raffrescamento	1,1 / 4,0 / 4,8 kW (Min / Nom / Max)
EER (Ta 35°C, Tw 7/12°C – EN 14511) raffrescamento	3,4
Potenza termica (Ta 35°C, Tw 18/23°C – EN 14511) raffrescamento	1,6 / 4,8 / 6,9 kW (Min / Nom / Max)
EER (Ta 35°C, Tw 18/23°C – EN 14511) raffrescamento	5,4

RETScreen® Energy Model - Photovoltaic Project

Training & Support

Site Conditions		Estimate	Notes/Range
Project name		**Restaurant**	See Online Manual
Project location		**Fenhuang Town, China**	
Nearest location for weather data	-		Complete SR&SL sheet
Latitude of project location	°N	34.1	-90.0 to 90.0
Annual solar radiation (tilted surface)	MWh/m²	2.02	
Annual average temperature	°C	12.8	-20.0 to 30.0

System Characteristics		Estimate	Notes/Range
Application type	-	**On-grid**	
Grid type	-	Central-grid	
PV energy absorption rate	%	100.0%	
PV Array			
PV module type	-	User-defined	
PV module manufacturer / model #		Suntegra Shingles	See Product Database
Nominal PV module efficiency	%	17.2%	4.0% to 15.0%
NOCT	°C	57	40 to 55
PV temperature coefficient	% / °C	-0.40%	0.10% to 0.50%
Miscellaneous PV array losses	%	-2.0%	0.0% to 20.0%
Nominal PV array power	kWp	**5.00**	
PV array area	m²	29.1	
Power Conditioning			
Average inverter efficiency	%	98%	80% to 95%
Suggested inverter (DC to AC) capacity	kW (AC)	4.9	
Inverter capacity	kW (AC)	72.0	
Miscellaneous power conditioning losses	%	0%	0% to 10%

Annual Energy Production (12.00 months analysed)		Estimate	Notes/Range
Specific yield	kWh/m²	370.5	
Overall PV system efficiency	%	18.4%	
PV system capacity factor	%	24.6%	
Renewable energy collected	MWh	10.991	
Renewable energy delivered	MWh	**10.771**	
	kWh	10'771	
Excess RE available	MWh	**0.000**	
			Complete Cost Analysis sheet

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Fig. 22
PV3 - retrofitted building

Fig. 23
SWH - domestic hot water estimation

Water Heating Load Calculation		Estimate	Notes/Range
Application type	-	Service hot water	
System configuration	-	With storage	
Building or load type	-	House	
Number of units	Occupant	5	
Rate of occupancy	%	100%	50% to 100%
Estimated hot water use (at ~60 °C)	L/d	300	
Hot water use	L/d	300	
Desired water temperature	°C	60	
Days per week system is used	d	7	1 to 7
Cold water temperature	-	Auto	
Minimum	°C	8.1	1.0 to 10.0
Maximum	°C	17.0	5.0 to 15.0
Months SWH system in use	month	12.00	
Energy demand for months analysed	MWh	6.03	
	GJ	21.71	
			Return to Energy Model sheet

System Characteristics		Estimate	Notes/Range
Application type		Service hot water (with storage)	
Base Case Water Heating System			
Heating fuel type	-	**Electricity**	
Water heating system seasonal efficiency	%	250%	50% to 190%
Solar Collector			
Collector type	-	Glazed	*See Technical Note 1*
Solar water heating collector manufacturer		Alternate Energy Technologies	*See Product Database*
Solar water heating collector model		Alternate Energy AE-21	
Gross area of one collector	m^2	1.93	1.00 to 5.00
Aperture area of one collector	m^2	1.78	1.00 to 5.00
Fr (tau alpha) coefficient	-	0.71	0.50 to 0.90
Fr UL coefficient	$(W/m^2)/°C$	4.91	1.50 to 8.00
Temperature coefficient for Fr UL	$(W/(m \cdot °C)^2)$	0.00	0.000 to 0.010
Suggested number of collectors		3	
Number of collectors		5	
Total gross collector area	m^2	9.7	
Storage			
Ratio of storage capacity to coll. area	L/m^2	45.9	37.5 to 100.0
Storage capacity	L	409	
Balance of System			
Heat exchanger/antifreeze protection	yes/no	Yes	
Heat exchanger effectiveness	%	95%	50% to 85%
Suggested pipe diameter	mm	10	8 to 25 or PVC 35 to 50
Pipe diameter	mm	38	8 to 25 or PVC 35 to 50
Pumping power per collector area	W/m^2	0	3 to 22, or 0
Piping and solar tank losses	%	1%	1% to 10%
Losses due to snow and/or dirt	%	3%	2% to 10%
Horz. dist. from mech. room to collector	m	5	5 to 20
# of floors from mech. room to collector	-	2	0 to 20

Annual Energy Production (12.00 months analysed)		Estimate	Notes/Range
SWH system capacity	kW_{th}	6	
	MWth	0.006	
Pumping energy (electricity)	MWh	**0.00**	
Specific yield	kWh/m^2	453	
System efficiency	%	28%	
Solar fraction	%	72%	
Renewable energy delivered	MWh	**4.37**	
	GJ	15.73	
			Complete Cost Analysis sheet

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Fig. 24
SWH - solar collector energy production estimation