POLITECNICO DI TORINO

Dipartimento di Architettura e Design

Corso di Laurea Magistrale
in Architettura per il progetto sostenibile

Tesi di Laurea Magistrale

Design of energy efficient pilot buildings in the Hou Ji Village, Pingyao, China

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July 2019

ABSTRACT

The main topic of the thesis concerns the project development of an area located inside the Hou Ji village, about 5 kilometers southwest of the Ancient City of Pingyao (that is the nearest big urban agglomeration), in the Shanxi region, central-east part of China.

Hou Ji village (or Houjicun in the local language) is the perfect example of the internal contrast that China has been experiencing in recent decades, due to which there is a strong dualism between modernity, represented by the advancement and development of the cities, as in this case Pingyao, and the maintenance of historical memory that is likely to be lost, represented by the historical buildings and villages, as in this case Hou Ji. In fact the village is located in a kind of *boundary* position, placed between a high speed train line (on the north) and a highway (on the south), and being situated at the edge of what will be the future urban expansion of the city of Pingyao, as stated in the Pingyao's Master Planning for years 2013-2030. The local administration is moving rapidly in this direction, having already accomplished the main arteries of the new area, in anticipation of the building development of the next few years.

In addition Houjicun besides being very close both to the Ancient City of Pingyao and Shuanglin Temple, which are on the UNESCO Heritage List and consequently can guarantee a significant influx of tourists to the surrounding areas, it is an important example of a typical Chinese rural village, witness of the Chinese cultural and architectural tradition and of the region in where it is, the Shanxi.

Starting from these considerations, the concrete project objective focused on the design of new energy efficient buildings based on one pilot building typology, able to be replicated with small modifications, in rural contexts similar to that of Houjicun.

The project started from the analysis carried out on the Hou Ji village thanks to the collaboration between South East University (SEU) of Nanjing, China and the NTNU, Norwegian University of Science and Technology (NTNU) of Trondheim, Norway, focusing at the same time on the guidelines dictated by the Chinese design, the vernacular architecture and the use of local materials. The aforementioned were then combined with a modern, integrated design, which foreseen the use of efficient and intelligent energy systems combined with passive strategies in order to reach the comfort conditions with the

least possible consumption of resources.
In relation to this last observation, elements of anthropic nature, such as the orientation of buildings, the design of performing and sustainable enclosures, etc. and natural elements, such as solar radiation, soil energy, rainwater collection and reuse, etc. are extremely important to achieve the best possible result.

The use of an integrated approach to the design, that considered at the same time the building itself and the natural elements through the use of passive strategies suited on the local climate, allowed the creation of buildings that had very low energy consumption.
The passive strategies, identified in the use of shading systems (fixed and movable), walls and roofs with a high thermal mass and performing assemblies, low heat losses, wider windows on the sunnier sides and an adequate arrangement of the functions of the buildings have made it possible to greatly reduce the energy systems loads, and therefore the emissions associated with them. One of the key strategies for the project layout was to use green roofs and green courtyards, which made it possible to obtain significant positive results.
The design of the energy systems was directed towards the use of innovative technologies, which could be coupled adequately with all the bio-climatic strategies put in place: the heart of the system is the geothermal heat pump, combined with a radiant floor system that provides both the heating and cooling part and a Controlled Mechanical Ventilation system, which monitors the indoor air a quality and starts to heat and cool only in the most critical moments.
Lastly, the use of systems for renewable energy sources, including photovoltaic and solar thermal panels and the water harvesting, has made it possible to further reduce the building's needs, as well as making it as independent as possible from the external supply.

The results obtained show that by correctly combining historical, urban and climatic analysis with passive and active strategies suited on the local climate and performing construction, it is possible to obtain very low consumption in line with those of the nZEB buildings; despite the possible initial cost that could be higher compared to the use of conventional technologies, the amortization that occurs in the following years makes it possible to greatly reduce the pay back time.

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INTRODUCTION

Luis Barragàn said in 1965 "*Before the machine age, even in the centre of cities, nature was a trusted companion, partner of the baker, the ironsmith, the carpenter... Nowadays, this situation has been turned around: man can not find nature, not even when he leaves the city to enjoy it. Locked in his shiny automobile, man is within nature a foreign body. A billboard is enough to erase the call of nature. Then nature becomes a fragment of man. The promised dialogue between man and nature becomes a hysterical, monotonous human monologue."* (Smith C., 1967)

Nowadays, the construction sector is facing a complicated situation, after decades of wild development and excessive consumption of resources; the sector is in fact starting to direct towards a much more sustainable building design, both as regards the construction process, and in terms of energy consumption and exploitation of renewable energy sources.
In the western states this process started decades ago, while in China, it started concretely from a few years, after decades of uncontrolled building, coincided with the rapid and impressive economic growth. The latter went hand in hand with a strong increase in population, which led China to exceed 1.4 billion in 2019. But China's economic boom and urbanization are closely linked to a phenomenon that has greatly changed China's social structure in recent decades, i.e. internal migration.
The migration phenomenon has led to a continuous increase in the urban population, which after exceeding the rural one between 2010 and 2011, reached in 2018 a percentage equal to about 58% of the total, with more of 810 million individuals; it is estimated that by 2035 70% of the population, around one billion, will live in the city.
In fact, those who have paid the most for this situation have been the rural villages, which in addition to being in some cases incorporated by the expansion of the cities, in others have seen their population shrink very much, with consequent lack of maintenance of historic and non-historical buildings, that for centuries were evidence of the Chinese culture, which slowly risk to be lost. Just in 2018, according to the Chinese National Bureau of Statistics (NBS), the number of rural labourers working in China's urban areas increased by 1.8 million.
The relationship between cities and villages is changed: while once the countryside was the livelihood mean of cities, producing food and resources to the latter, which were seen as places mainly of commerce, now this vision has been reversed: the cities have assumed a prevalent role, becoming the place where it is necessary to move for having higher incomes and wealth.
So, what were once traditional villages, a material representation of Chinese history and culture, slowly began to lose importance, in many cases leading them to be completely dispossessed and destroyed to make room for the cities expansion. A process of replacing historic buildings has therefore occurred throughout China, inside the villages not incorporated by the cities

by the construction of buildings in concrete blocks and tiles to replace the vernacular dwellings.
Lastly, according to the Rural Development Institute of the Chinese Academy of Social Sciences, due to the emigration today 25 millions of rural houses, which make up 10.7% of all Chinese housing stock, are abandoned.
Instead, talking about the energetic situation of China, and all the related emissions caused by buildings' energy consumption, nowadays it's facing a situation in which it's at same time the most polluting and the biggest producer of green energy in the world. The challenge that the country will face in the next years will be to decrease much more the use of fossil fuel in favour of clean energy, designing and building in the most sustainable way possible

All this constituted a starting point for the project developed in this thesis, which was made possible thanks to the willingness of the professor Luca Finocchiaro (Associate Professor at the Department of Architecture and Technology of the NTNU, Norwegian University of Science and Technology of Trondheim, Norway), wanting to realize with a new project, the theoretical studies carried out previously on a case study in particular, the Hou Ji village, which is located about 5 km southwest of the Ancient City of Pingyao (that is the nearest big urban agglomeration), Shanxi region, in north-eastern China.
The project developed in this thesis is proposed as a continuation of studies and researches carried out since 2013 by the collaboration between South East University (SEU) of Nanjing, Faculty of Architecture, and the NTNU of Trondheim, on the Hou Ji's historical buildings, in provision of their renovation, upgrading energy performance and in some cases of repairing non-structural elements. The research and studies, divided into three Work Packages, as well as the inspections carried out, have highlighted the high historical value of the village and the need to develop projects that recover it and encourage the increase of tourism and interest in the area, thanks also to its strategic position, being located near UNESCO sites, and in an area adjacent to the future expansion of Pingyao.
The theme of this thesis is to design energy-efficient buildings, whose design combines the main features of the local architecture with a modern design using at the same time passive strategies, performing active energy systems and renewables sources, combining everything to integration of greenery and agriculture, which is an identifying element of the area.
To adequately develop the project, the first part, related to historical research, analysis and building design, according to local architecture and use of passive strategies, was carried out at the NTNU of Trondheim, so as to more easily access the data and work with the staff that worked on the previous projects; the second part, on the other hand, for defining the active energy systems, use of renewables sources and the energy analysis, as well as the integration of the project as a whole, was carried out at the Polytechnic of Turin.

Chapter 1

The World context

In this chapter it is analysed the situation at global level in terms of resource consumption, pollution, overpopulation in relation to the building sector, which clearly represents the focus of this thesis; at the same time the issue of environmental sustainability in the building sector is discussed, with particular attention to low energy buildings. At the same time legislative guidelines are provided, with particular attention to the European and Italian regulatory framework. The goal is to give a general introduction of the global framework in which the design of new buildings is located in the contemporary era.

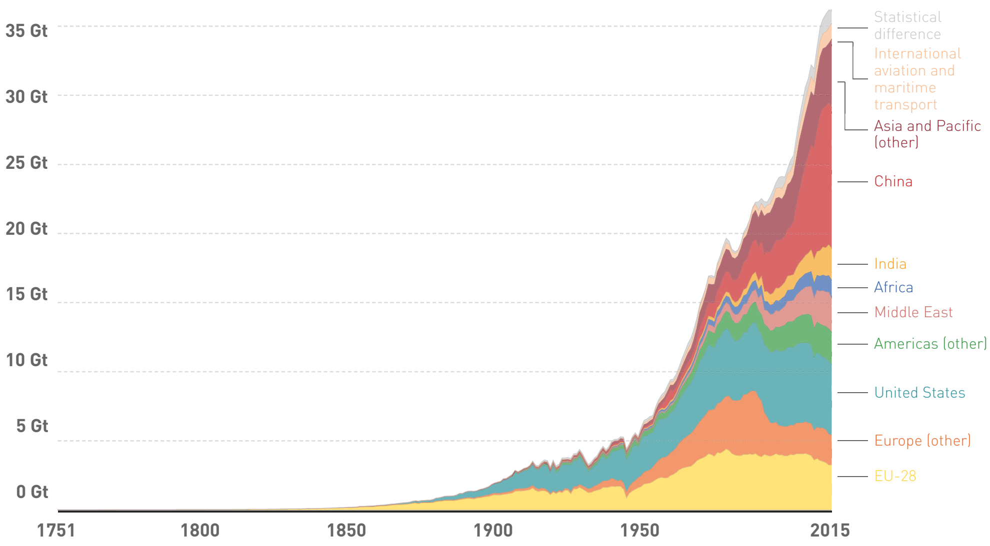
1.1 The global context between pollution and overpopulation

To date, considerations relating to climate change and its causes, as well as its future repercussions, are taking on an increasingly important role in the international context in every field. Over the years there's been a growing interest in the topic, with numerous initiatives and stances taken at a global level with the aim of stopping, or at least slowing down a phenomenon, that today seems unstoppable, in a relatively short time horizon.
However, it must be emphasized that the international context has moved very slowly on the subject, after gradually setting out from the end of the 19th century onwards, a model of economic growth that did not take into consideration the issue of environmental sustainability; a model that is so rooted in human vision, that changing its fundamental parameters seems almost impossible, as it would involve having to make a radical change in society as we know it today.

This growth model, as mentioned above, originated with the so called *Second Industrial Revolution*, also known as the *Technological Revolution*, which is conventionally started from 1870 with the introduction of electricity, chemicals and oil.
From that period onwards there has been a constant increase in greenhouse gas emissions, caused initially by the use of coal and subsequently by the use of fossil fuels, combined, as mentioned, with a slow but progressive increase in the consumption of natural resources; therefore, although the terrestrial ecosystem is able to absorb excessive gas emissions, through the process of plant photosynthesis and through the absorption operated by the oceans, and regenerate the flora and fauna, the speed with which these changes of an anthropic nature occurred (and are occurring), has not allowed to maintain stable the equilibrium of the planet.
This balance, which has taken millions of years to settle, is tied with a double wire at a temperature range of a few degrees, and any variation, even if minimal, of it brings with it consequences of enormous importance. This theme has never been so current: for some decades continuous and inexorable variations in global temperature have been taking place (or to call it with another name the global warming phenomenon), with drastic consequences for the climate and for living conditions.
They are caused largely by the so-called "greenhouse effect". It is an atmospheric-climatic phenomenon, always existed on the Earth, necessary to reach an optimal temperature level such as to make life prosper: this is made possible thanks to the presence in the air of so-called greenhouse gases, among which carbon dioxide, methane, ozone and water vapour, which allow short-wave solar rays to pass through the atmosphere, blocking harmful ones; at the same time these gases block the portion of solar radiation, the infrared radiation, reflected from the earth's surface. All this allows the earth to warm up.
The current problem is the fact that the continuous increase in the concentration

of greenhouse gases, caused by human activities, blocks the irradiation of heat from the Earth into space; in this way most of the irradiation is reflected back towards the Earth, heating the air near the ground and increasing the temperatures.
As mentioned, in recent decades the phenomenon has intensified considerably as the emissions of gases in the atmosphere have increased exponentially: the main ones are methane, nitrous oxide and carbon dioxide, generated mainly by industrial development, emissions from transport vehicles and urbanization; deforestation is another fundamental cause, since plants help to improve air quality, helping to keep oxygen and carbon dioxide levels in balance. It is necessary to highlight how carbon dioxide has an average duration in the atmosphere of about one hundred years, therefore even drastically reducing emissions, it is not possible to reduce its presence in the atmosphere in a short time.
Therefore it is easy to understand how the global situation is highly complicated, and that its resolution requires an enormous global effort in every field.
For the reasons listed above, the average surface temperature of the planet has increased by about 1.1 ° C compared to the end of the 19th century. To date, 2018 has been the fourth warmest year ever, after the years 2016, 2017 and 2015 respectively; and 18 of the 19 hottest occurred since 2001.
According to the report entitled "Global Warming of 1.5 ºC" published in October 2018 by the Intergovernmental Panel on Climate Change, IPCC, which is one of the most important scientific bodies dedicated to research on how the Earth's climate is changing, at the current pace by 2030 the increase in the global average temperature will be higher than 1.5 ° C considered the maximum safety threshold to have contained and manageable effects, albeit with large expenses of money and resources. But looking at the trend on a global scale, this threshold around 2030 could be overcome: in order for this to happen it would require enormous investments and enormous changes in lifestyles and in the ways in which food is produced, starting from farming and agriculture, which today don't seem to be possible, despite the various agreements between the States carried out to date.
The report estimates that the investments needed to stay below 1.5 ° C should amount to around 2 trillion euros between 2016 and 2035, only with regard to energy systems; to this should be added the costs of reducing carbon dioxide in the air, improving the existing building sector, which consumes a lot of energy in all its processes, etc.
The effects expected in the event of exceeding the 1.5 °C threshold are, to say the least, disturbing, and foreseen: a global sea level rise of 10 centimeters due to the ice melting; oceans that could increase their acidity, with very serious consequences for marine flora and fauna, including the coral reef that could disappear; unpredictable seasons, with much hotter summers and greater frequency of extreme weather events such as hurricanes or torrential rains that would make the cultivation of many agricultural products much more difficult and expensive.

Looking at the graph relating to the trend of emissions of pollutants in the

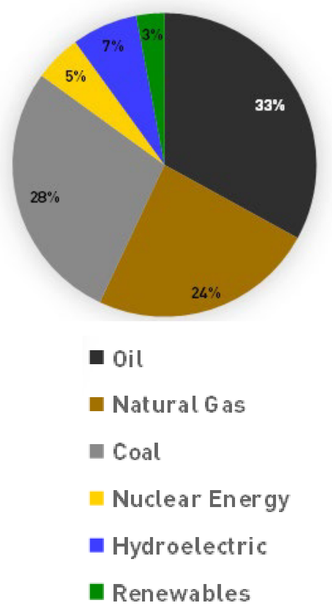


◀ Fig. 1.1
Annual CO2 emissions by world region measaured in billion tonnes (Gt) per year. Source: Boden, T. A. and Andres, R. J.: Global, Regional, and National Fossil-Fuel CO2 Emissions. Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tenn., USA (2016)

atmosphere related to the last century, it can be seen how serious the situation is. From the graph it can be noted that the western regions, including Europe, United States and Americas, up to the 80s and 90s have greatly increased their emissions, to then begin a decrement that goes on until nowadays; Middle East, Africa and India have a similar profile, albeit more limited; the eastern regions, on the other hand, have made the reverse journey, having contained emissions until the 1980s, to then have a sudden increase that continues to this day, particularly regarding Asia and Pacific and China areas.

To date, the global energy consumption is constantly growing, and does not seem to be showing signs of diminishing, in particular regarding the States that have had or are having a remarkable economic growth, such as China and India.
Global energy demand grew by 2.3 % in 2018 compared to 2017, mainly due to world economic growth, despite the slowdown in China, and an increased energy demand for heating and cooling in many regions of the world due to atypical climatic phenomena, which means that the greatest increase in the last decade has occurred, according to what was declared by the International Energy Agency.
By increasing energy demand, the use of fossil fuels has increased at the same pace, despite the growth in the use of energy from renewable sources; it is estimated that today 70% of energy consumption is covered by fossil fuels, whether it is coal, oil or methane. Referring to coal, although it is established that its application pollutes a lot and is not sustainable at all, to meet the increase in energy consumption, particularly in Asia, there has been a growth in its use, with about 10 gigatons (Gt) used for electricity production; currently coal makes up 28 % of global energy production, ranking second in the scale of the energy sources. As regards the other components, on the other hand: 33%, that is the largest share, is composed of oil and 24% of natural gas; this means that 85% of global energy consumption is made up by fossil fuels. Nuclear energy instead composes 5% of the total, while renewable energy such as solar, geothermal, wind and biomass make up 3% of the total; lastly the hydropower has a share equal to 7% of the total. So the total energy

▼ Fig. 1.2
Global primary energy consumption source in 2017.



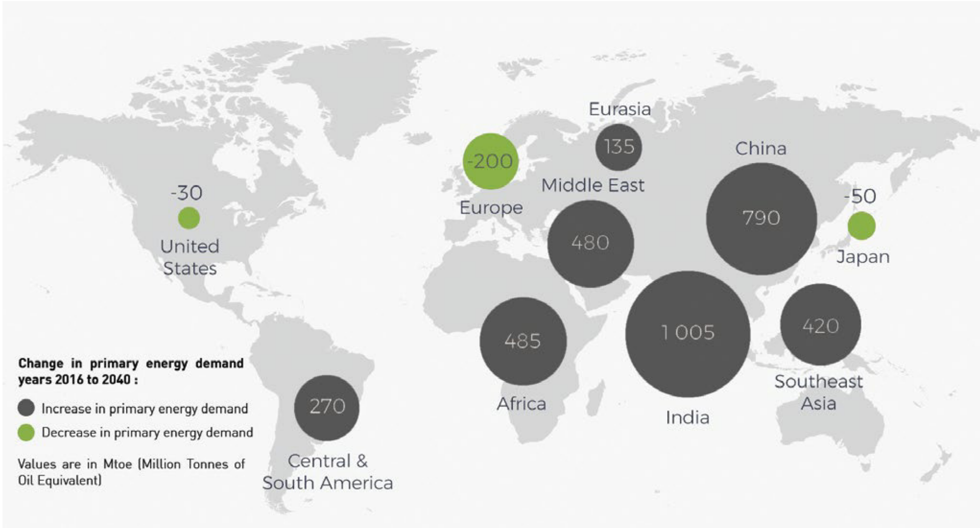


Fig. 1.3 ▶
Change in primary energy demand, 2016 to 2040.
Source: IEA, World Energy Outlook 2017

covered by renewable sources stands at 10%, which is starting to be a good percentage compared to 2010, for example, in which the renewables share was 1.3%; however, it is still too little and it is increasing at a slow rate to concretely implement policies to reduce polluting emissions.
In this sense, global carbon dioxide emissions linked to energy increased by 1.7% to 33 gigatons (Gt) in 2018.
In the New Policies Scenario, global energy needs rise more slowly than in the past but still expand by 30% between today and 2040. This is the equivalent of adding another China and India to today's global demand. (IEA, 2017) The largest contribution to demand growth, almost 30%, comes from India, whose share of global energy use rises to 11% by 2040. Southeast Asia is another rising heavyweight in global energy, with demand growing at twice the pace of China. Overall, developing countries in Asia account for two-thirds of global energy growth, with the rest coming mainly from the Middle East, Africa and Latin America. (IEA, 2017).
Translating in numbers, in the scenario outlined by the World Energy Outlook 2017, China and India will increase their primary energy consumption by 790 and 1005 Mtoe respectively, while Africa, Middle East and Southeast Asia will increase by 485, 480 and 420 Mtoe respectively. The most advanced economies will reduce consumption instead, with the largest drop expected in Europe with -200 Mtoe.
In this situation, electricity consumption is undergoing a phase of full growth and expansion: thanks to the digital economy and advances in electric mobility, according to the forecasts of the World Energy Outlook 2018, an overall 90% increase in overall electricity demand could be achieved by 2040.
Looking at these forecasts it is necessary that the global energy policy moves towards a total and complete drive to the use of renewable energy, since, if these data will be verified, in case of continuous use of fossil fuels at current levels it will mean that the global emissions will continue to grow instead of decreasing; as pointed out above, if such a scenario should occur, it will mean that global climate changes will be irreversible.

Consistently with the awareness of the increase in energy consumption and polluting emissions during the last century, the debate about energy savings started to grow, to be precise after the first oil crisis of the 70s. At that time the main concern was its rapid exhaustion, as well as the high dependence of the industrialized countries on the Middle Eastern producing states. Today the problem is different, as the oil supply is on average constant and there are numerous deposits; what worries the most are the emissions deriving from the use of fossil fuels, from which 80% of the final energy is produced.

Reducing energy consumption means reducing emissions and increasing environmental sustainability. There are two strategies to reduce emissions: energy savings and the promotion of technologies that use renewable energy sources such as the sun, water and biomass. One of the sectors in which more energy can be saved is certainly the building sector. At present the buildings are real energy devourers that consume more than 40% of energy for heating, cooling and lighting and hot water production.

The first concrete initiatives were seen in the early 1990s, when the awareness of having to move world economies towards a more sustainable development model began to take hold.

On a global scale the most important agreements implemented were:

• Kyoto Protocol, signed on 11th December 1997 during the COP3 Conference of the parties of Kyoto, subject to the voluntary acceptance of the individual states, forecasted a quantitative reduction of greenhouse gas emissions compared to 1990 emission levels; to do this, the signatory states would have had to create a national system for monitoring the emissions and absorption of greenhouse gases, defining at the same time measures to reduce them. The validity of the protocol ended with the end of 2012, forecasting by that date that the states should have reduced the emissions by an average of 5 %, depending on the individual economies, obtaining positive data for some states, while others do not: Italy for example had a target of -6.5% and reached -4.6%.

• United Nations Agenda 2030 for Sustainable Development, is an action program for people, the planet and prosperity signed in September 2015 by the governments of the 193 UN member countries. It encompasses 17 Sustainable Development Goals, SDGs - in a major program of action for a total of 169 "targets" or targets. The official launch of the Goals for Sustainable Development coincided with the beginning of 2016, guiding the world on the road ahead over the next 15 years: the countries, in fact, have committed themselves to reach them by 2030 (UN/RIC, 2015).

• Paris Agreement 2015 (COP 21), it is the first universal and legally binding agreement for all states on the world climate; the agreement includes elements for a progressive reduction of global greenhouse gas emissions to maintain the global temperature increase below 2 ° C compared to pre-industrial levels, with the aim of limiting it to 1.5 ° C. According to the agreement this is to be achieved as soon as possible and to monitor individual progress the states will have to present and comment every five years at international level a national emission reduction target, to Nationally Determined Contribution NDC.

The EU on the basis of the provisions mentioned above, is taking three main routes:

• Compliance with international agreements on climate change, the main one is the United Nations Framework Convention on Climate Change, UNFCCC of 1992, from which the COPs, Conference of the Parties, which gave rise to the Kyoto Protocol and the Paris Agreement.

• The development of the 2030 climate and energy framework, which foreseen different measures and objectives to be achieved based on an improvement in the European economy and energy system, so as to make them more sustainable, safe and competitive.

• The use of EU ETS, i.e. the EU emissions trading system that limits the quantities of greenhouse gases that can be emitted by certain industrial sectors

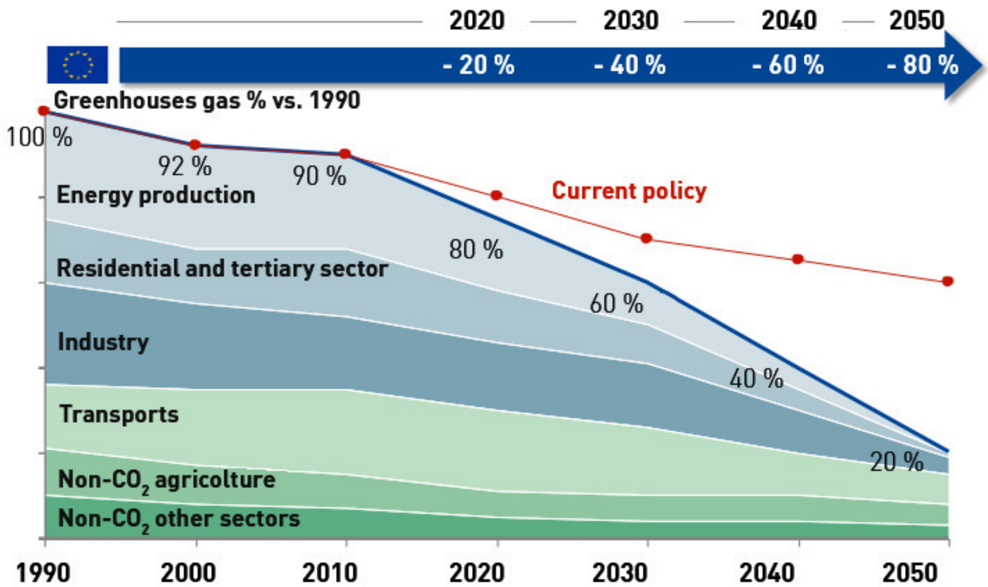
In the EU, among other things, in line with the commitments made in Kyoto and ahead of the COP 21 in Paris, but also with the aim of guaranteeing competitiveness and economic growth during the energy transition, the leaders of the Member States have ratified in 2011 of the European Commission Communication on the De-carbonisation Roadmap to reduce at least 80 % of greenhouse gas emissions by 2050 compared to 1990 levels (NES National Energy Strategy 2017, 10/11/2017). However with the current policies the polluting emissions will probably be reduced by 30 - 40%, that is half of what has been set, unless there are particular accelerations in the matter, which, as is happening on a global scale, shows how difficult it will be to maintain emissions and temperature increase within acceptable levels.

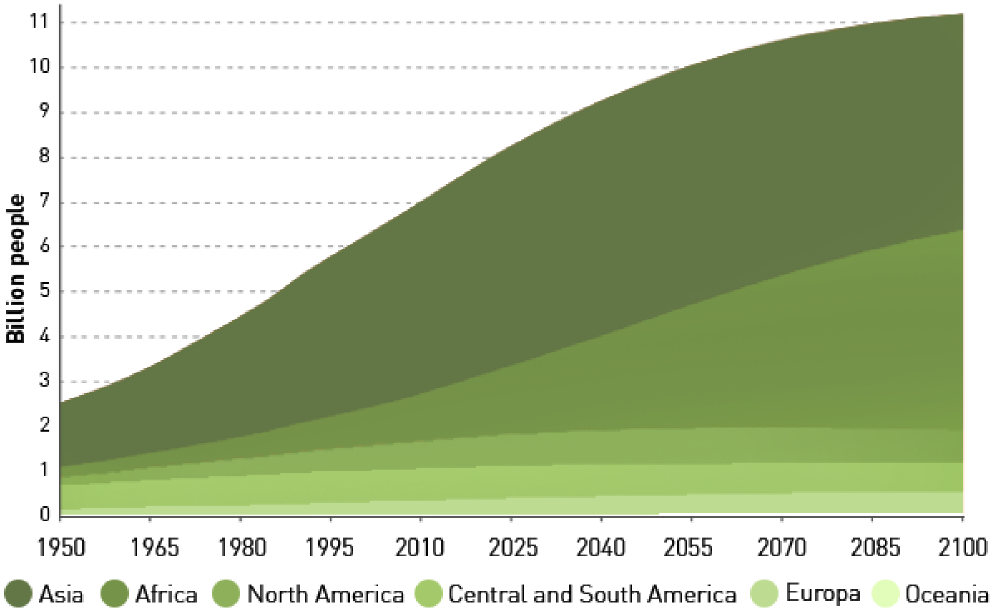
Despite all the agreements and the "good intentions", the pollutants emissions continue to grow, and the USA, which are among the main polluting states, will probably come off the Paris Agreement if they follow the current policy. The problem is that the environment is almost never part of economic and political decisions, which look only to the immediate response of the investments, without a long-term vision: only by implementing strategies that involve all the sectors and raising the climate issue at the center could be

Fig. 1.4 ▶

EU de-carbonisation roadmap to 2050.

Source: Comunication of CE COM (2011) 112 final





◀ Fig. 1.5
World population growth from 1950 to 2100, divided by continents
Source: UN-DESA, World Population Prospects 2017.

possible to have positive effects.
As well as the pollution rate, the world population continues to increase, without giving signs of slowing down. This phenomenon from the first and especially the second industrial revolution onwards has continued to grow as it has never happened before in human history, which, in the long term future, will bring problems for the sustainability of this growth and for the planet's resources necessary to maintain it.
To date the global situation is very varied: in many Western countries, which are those with the best quality of life, there is close to zero growth, or worse, as in Italy there are fewer deaths than births; in many poor countries, on the other hand, the ratio is reversed, with births much higher than deaths, with nations like China and India where the billion inhabitants are abundantly exceeded.
As mentioned above, he world population has grown dramatically, in particular since 1950, registering a + 195%, going from about 2.5 billion to the current almost 7.5 billion, with a peak in the period 1960-1990, and an average annual variation of just under + 2%, to then decrease to + 1.5% in 1995 and + 1.2% in 2015. The future projections instead show how a strong deceleration will occur in this century, for which by 2050 the average annual growth of the population is expected to be reduced to + 0.5%.
The segment of the population that shows the highest growth rates is the one referred to people older than 64: between 1950 and 2015 the variation was + 440% and, unlike the population as a whole, in the coming decades it is expected a strong acceleration, which should lead to the overcoming of a billion individuals in 2035. This is mainly due to longer life expectancy and the progressive reduction of births.
Asia, as can be seen from the graph, is the most populous continent, in which today around 60% of the earth's inhabitants live, with China and India which together exceed 2.7 billion individuals. But looking at the forecast period it can be seen that it is expected that Africa will have exponential population growth, reaching a level similar to the Asian population in 2100: today about one sixth

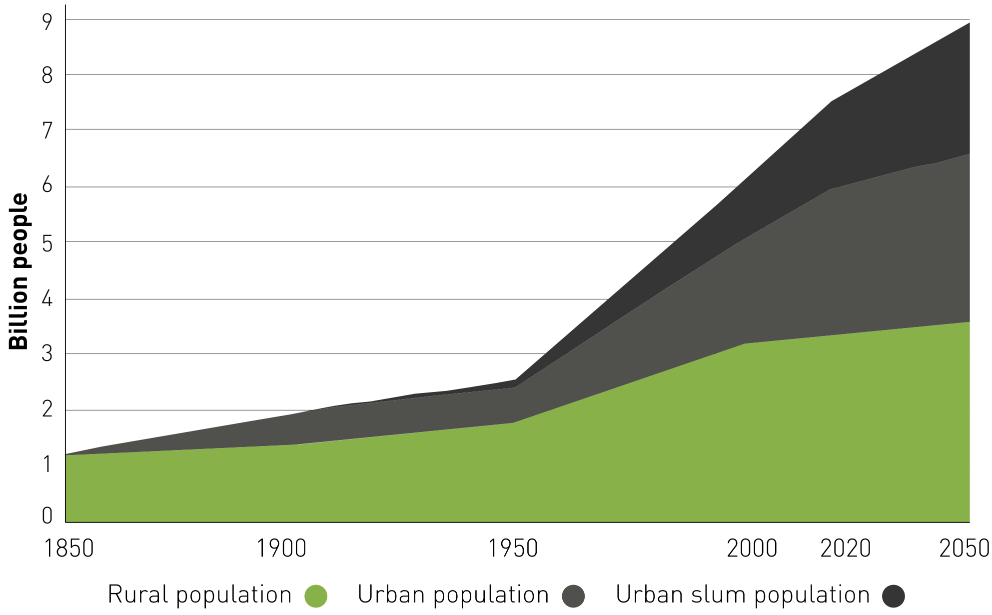


Fig. 1.6 ▶
World population from 1850 to 2050
Source: UN-HABITAT, Global Urban Observatory + Author's elaboration

of the world population lives in Africa, in 2050 the quota will be a quarter and around 2100, one inhabitant out of three in the world will be African. Together, India, China and Nigeria will account for 35% of the projected growth of the world's urban population between 2018 and 2050.

The populations of North America and Europe, on the other hand, are expected to be at levels similar to the current ones, with Europe even expecting to experience negative variations starting from 2030.

The most alarming figure, as can be seen in the graph above, is, if possible, the increase in people living in urban areas or worse in urban slum; this means that in the coming decades the population will be faced with an increasing number of poor people, with the risk of huge social crises.

The urban population of the world has grown rapidly from 751 million in 1950 to 4.2 billion in 2018. Asia, despite its relatively lower level of urbanization, is home to 54% of the world's urban population, followed by Europe and Africa with 13% each (UN/DESA, 2018).

In 1950, about 30 % of the world's population lived in urban areas, a proportion that grew to 55 % by 2018. The global urbanization rate masks important differences in urbanization levels across geographic regions: Northern America is the most urbanized region, with 82 % of its population residing in urban areas, whereas Asia is approximately 50 % urban, and Africa remains mostly rural with 43 % of its population living in urban areas in 2018 (United Nations, 2018).

By 2030, the world is projected to have 43 megacities with more than 10 million inhabitants, most of them in developing regions. However, some of the fastest-growing urban agglomerations are cities with fewer than 1 million inhabitants, many of them located in Asia and Africa. While one in eight people live in 33 megacities worldwide, close to half of the world's urban dwellers reside in much smaller settlements with fewer than 500,000 inhabitants (UN/DESA, 2018).

From the data related to the global population growth it can easily be deduced that is occurring, and will occur, a growing increase in the surface area of cities on a global scale.

To date only 71 % of Earth's land surface is defined as habitable. Humans use half of global habitable area for agricultural production; of the remainder, 37 % is forested, 11 % shrubbery, and only 1% is utilised as urban, where the latter seems not so much, but its global impact is enormous. More than three-quarters of the agricultural land is used for the rearing of livestock through a combination of grazing land and land used for animal feed production

The growth in number and size of large urban aggregates, particularly in Asia and Africa, brings with it numerous consequences: in these aggregates live populations with above-average consumption, more waste is produced and more greenhouse gases are emitted, soil is consumed with twice the rate of population growth. In the less developed countries, almost a third of the population lives in slums or in informal settlements, with rudimentary services, precarious access to safe water sources, poor hygiene, subject to environmental risks, often without a permanent dwelling and therefore at risk of expulsion. In theory, urban areas should take advantage of the economies of scale generated by their size, however the lack of adequate planning and adequate rules has prevented almost everywhere from having these theoretical benefits of scale.

As the world continues to urbanize, sustainable development depends increasingly on the successful management of urban growth, especially in low-income and lower-middle-income countries where the pace of urbanization is projected to be the fastest. Many countries will face challenges in meeting the needs of their growing urban populations, including for housing, transportation, energy systems and other infrastructure, as well as for employment and basic services such as education and health care (UN/DESA, 2018).

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To date, among the 20 most populous metropolitan areas in the world, only two, London and Moscow, are European and only two are African; the others are divided between America,5 , and, above all, Asia with 11.

Currently over 70% of current CO_2 emissions are the result of direct emissions from cities or related needs. It is estimated that CO_2 emissions from urban areas have increased from 15 billion tons in 1990 to 25 in 2010, to reach 36.5 billion tons by 2030, assuming the current levels of growth. The problem is that this rate of growth is not sustainable, neither at a social level, nor above all at the environmental level, given the size of the impact.

The same applies to the consumption of soil that the expansion of urban centers brings with it.

Today, urban areas around the world are expanding on average twice as fast than their populations. Although urban land cover is a relatively small fraction of the total Earth surface, urban areas drive global environmental

change. Urban expansion and associated land cover change drives habitat loss, threatens biodiversity, and results in the loss of terrestrial carbon stored in vegetation biomass (Seto K. C. et al, 2012).
Globally, more than 5.87 million km^2 of land have a positive probability (>0%) of being converted to urban areas by 2030, and 20% of this, 1.2 million km^2, have high probabilities (>75%) of urban expansion; the last datum corresponds approximately to the surface of South Africa. If all areas with high probability (>75%) undergo urban land conversion, there will be a 185% increase in the global urban extent from 2000 (Seto K. C. et al, 2012).
Given the long life and near irreversibility of infrastructure investments, it will be critical for current urbanization-related policies to consider their lasting impacts. Another significant problem is that the continuous urbanization has, and will have, serious repercussions on global biodiversity, therefore on fauna and forests, with the latter being the planet's oxygen reserve; the highest rates of urban growth are forecasted to take place in regions that were relatively undisturbed by urban development in 2000: the Eastern Afromontane, the Guinean Forests of West Africa, and the Western Ghats and Sri Lanka (Seto K. C. et al, 2012).
Land-cover change could lead to the loss of up to 40% of the species in some of the most biologically diverse areas around the world, and as of 2000, 88% of the global primary vegetation land cover had been destroyed in "biodiversity hotspots" (Seto K. C. et al, 2012).
Therefore it is understandable that these events are anything but negligible; given the imminence of these phenomena it is necessary to implement policies related to urban expansion and building in general, which bind to total environmental respect, limiting the consumption of land as much as possible. At the same time, many more funds must be invested and consideration must be increased much more in the recovery of green areas and the creation of new ones, so as to reverse the current trend that focuses on the economic side only.

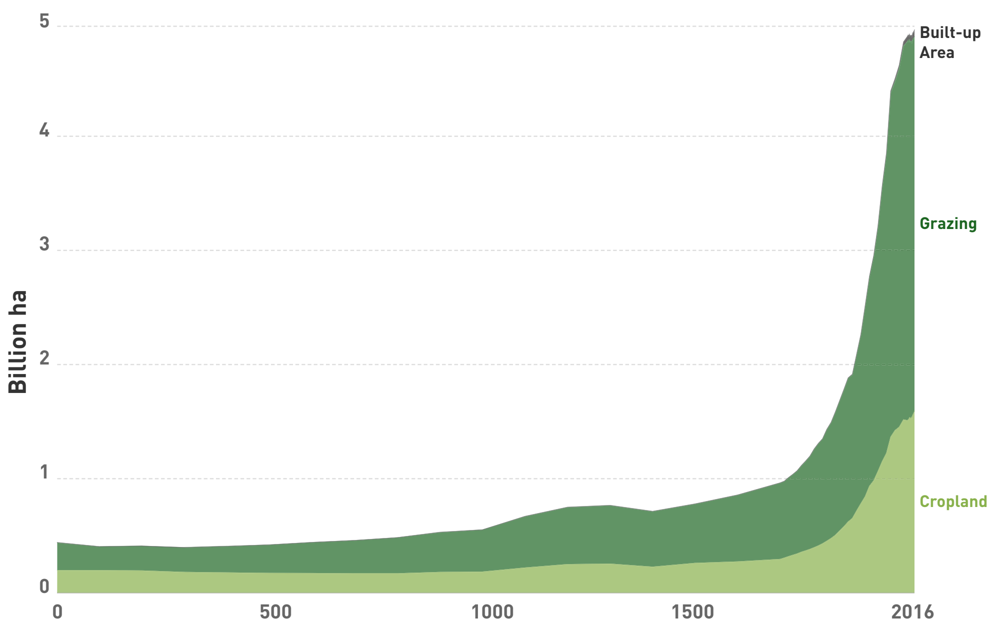
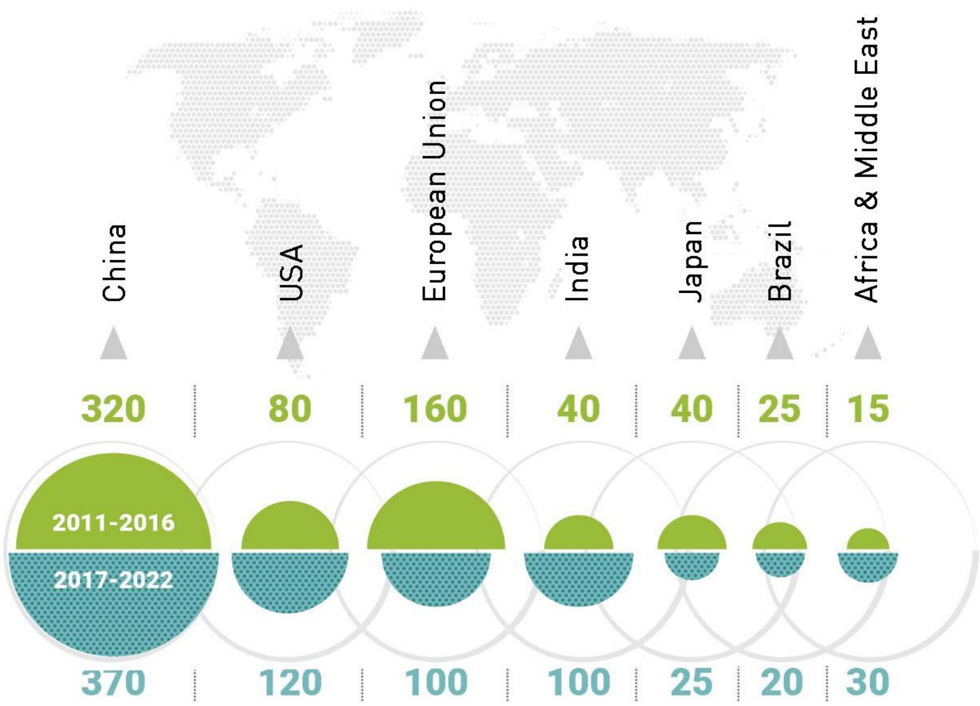


Fig. 1.7 ▶
Total land area used for cropland, grazing land and built-up areas.
Source: Klein Goldewijk et al., 20xx History Database of the Global Environment (HYDE) + Author's re-elaboration

1.2 Global trend in sustainability

As described in the previous section, energy consumption is moving, albeit more slowly than expected, towards an increasing use of renewable energy. In a global situation that seems increasingly aggravated, this still represents a positive element.
In recent years the cost of technologies related to renewable energy has dropped a lot, bringing with it numerous changes in the energy system on a global scale.
Because of the reduction in costs, which make renewable energy the least cost source between the energy plant types, according to International Energy Agency forecasts, two thirds of the investments put in place by 2040 will be for the creation of hydroelectric, wind or photovoltaic power plants.
Unfortunately, however, in 2018 the installed renewable energy capacity has reached the same levels of 2017 without having significant increases, registering the first stall since the beginning of the 2000s; turning into numbers, in 2018 the energy produced from renewable sources has increased by around 180 GW, when it is estimated that 300 GW of increase per year up to 2030 is required to stay within the parameters set by the Paris Agreement. This is reflected to what was mentioned in section 1.1, i.e. that in 2018 the emissions grew by 1.7% compared to the previous year.
Among all, solar energy is the one that increased the most in 2018, offsetting the slower increases in wind and hydroelectric energy, reaching 97 GW of installed power in the world.
Rapid deployment of solar photovoltaics (PV), led by China and India, helps solar become the largest source of low-carbon capacity by 2040, by which time the share of all renewables in total power generation reaches 40% (IEA, 2017).



◀ Fig. 1.8
The growth of energy produced from renewable sources by country / region in GigaWatt.
Source: International Energy Agency, 2016.

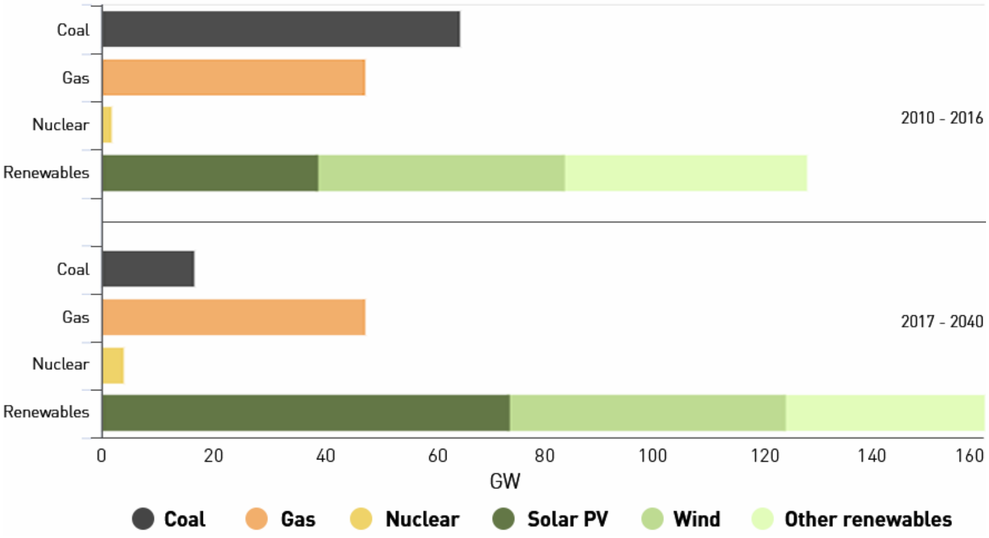


Fig. 1.9 ▶
Global average annual net capacity additions by fuel.
Source: WEO, IEA 2017

However, solar energy, due to the decrease in incentives guaranteed by the Chinese state for the installation of new plants due to the shift of investments in the growth and improvement of the electricity grid on a national scale, suffered a slowdown in 2018. The forecasts given by the International Energy Agency, however, predict that in the five years between 2017-2022, the three states that emit the most pollutants, namely China, the USA, and India will greatly increase the energy produced with renewable sources: for China it is expected an increase of 370 GW, for the USA of 120 GW and for India of 100 GW. For the European Union, on the other hand, a 60 GW decrease is expected compared to the 2011-2016 five-year period, reaching a growth of 100 GW.
In any case, to date in the Western coutries, there is an ever increasing orientation and awareness taking on the need to reduce waste and energy consumption, which were reflected in strong increases in investments, after decades in which these concepts were in the background. Even in the eastern states this trend seems to occur, although due to the exponential increase in energy demand due to the number of people (China and India will reach the 3 billion population within a few years), the effects of the use of renewable energies could be seen very much less.
As it can be seen from the graph above, for the period between 2017-2040 are planned annual global average net capacity additions of renewables of about 160 GW, including about 75 GW of solar PV, 50 GW of wind plants and about 40 GW of all other renewables together. At the same time, a strong increase in the installation of energy production using natural gas is expected, for around 40 GW per year. Regarding the coal instead, although it is now an outdated source in the Western countries, with the exception of the USA, it will continue to increase its use, albeit at a much slower pace, mainly to satisfy the energy demand in Asian countries, with an increase of about 17 GW per year.
For 2019, on the other hand, a constant decrease in the costs of renewable electricity and energy storage is expected, with a huge impact on global investments in energy production. Even in emerging economies, as mentioned above, where the environmental impact remains a secondary concern compared to the economic advantages, wind and solar energy have surpassed fossil fuels by adding new capacity in production.

1.3 Global trend in building sector and building sustainability

In the last decade alone, more than 50 billion m^2 of new concrete surfaces have been built on Earth, making just as many ground surfaces sterile. And this is a trend destined to continue according to current forecasts that foresee 230 billion m^2 of new buildings within the next forty years, which will be added to the approximately 235 billion m^2 existing. To give an idea it has been estimated that the equivalent of a city as large as Paris every five days is born in the world. Added to this is the relative increase in energy consumption due to the creation of new buildings.
It is easily to understand that at this rate it is impossible to reach the qualitative standards of energy efficiency that nations have established with the 2015 Paris Agreement, unless that in the next decade zero-emission and near-zero energy constructions become regularity.

To date, the global construction sector, in terms of energy consumption and resources between existing buildings and the construction of new ones, has a significant impact on global pollution for a total of about 39% of the total.
Therefore, due to their high energy usage, buildings are a key element of sustainable global energy policies all over the world.
According to surveys by the International Energy Agency (IEA), in addition to the aforementioned final global consumption of primary energy attributable to buildings, the building construction process uses around 10% of energy and 12% of drinking water, in addition to around three billion tons of raw materials for the manufacture of building products and components. With reference to the latter figure, the use of raw materials for the building alone accounts for about 40/50% of the total world economy. Furthermore, the construction sector has environmental repercussions thanks to a massive use of materials containing high incorporated energy, the consumption of soil, the production of liquid and solid waste.
Most of the energy consumed by buildings is used for temperature control, around 66% for the residential sector and 39% for the services sector. The rest of the energy is used for the production of domestic hot water (14%), domestic appliances (9%), domestic consumption (5%) and lighting (3%) (IEA, 2013).
In 2018 final energy use in buildings has reached the value of 3060 Mtoe (million tonnes of oil equivalent) compared to 2820 Mtoe in 2010. Consequently direct emissions from buildings increased to just over 3 $GtCO_2$ (Gigatonnes of CO_2) in 2018, a slight rebound from just under 3 $GtCO_2$ in previous years (Dulac J. et al., 2019).
When indirect emissions from upstream power generation are considered, buildings were responsible for 28% of global energy-related CO2 emissions in 2018. In absolute terms, buildings-related CO2 emissions rose for the second year in a row to an all-time high of 9.6 GtCO2 (Dulac J. et al., 2019).
The problem related to the renewed increase in energy consumption in the construction sector is due to a series of similar factors between the different

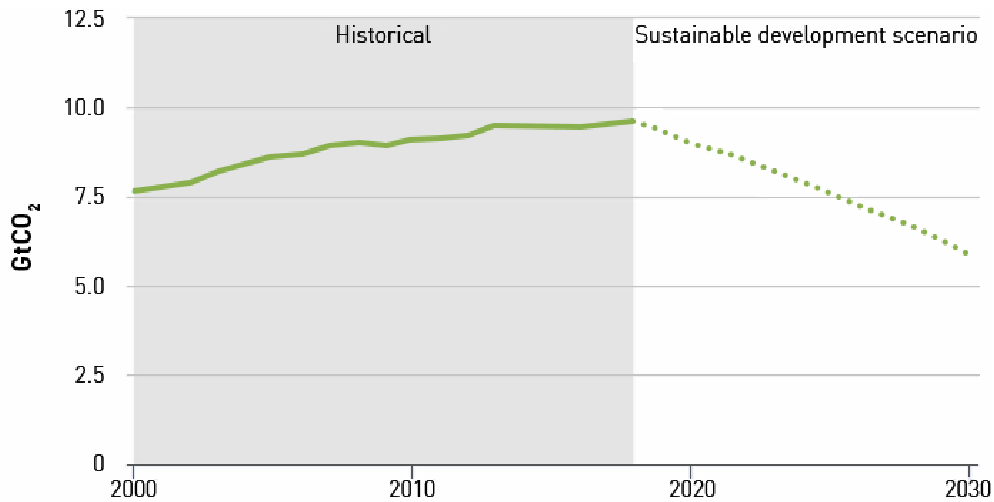
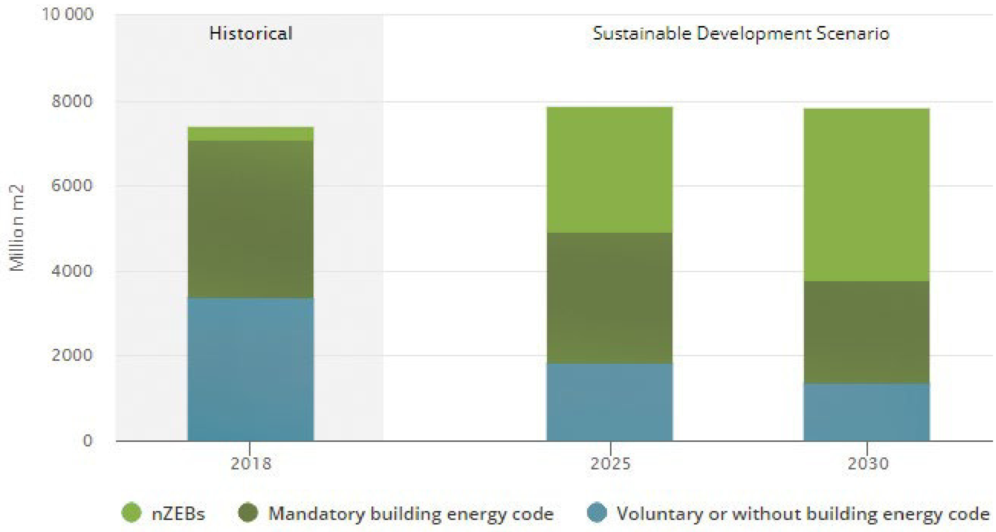


Fig. 1.10 ▶
Global average annual net capacity additions by fuel.
Source: WEO, IEA 2017

areas of the world: firstly, the increase in electricity consumption, particularly in countries with strong economic growth like China, wasn't coupled with an equal if not higher growth of energy production from renewable sources; this is because the growth in demand is moving at an unsustainable pace. Added to this are the already evident signs of climate change, which have led to unusual temperatures far above average due to heat waves or lack of rain, in many parts of the planet: for this reason, energy use for air conditioning it has grown out of all proportion. The same argument, on the other hand, applies to heating, with areas of the planet where, due to very cold winter temperatures, the energy demand for heating has increased considerably.
Another decisive factor is the lack of coherent global policies that are valid for all nations: in 2018 approximately 40% of all existing buildings were covered by energy efficiency policies, with a very slow increase in the percentage of global coverage by about 2% compared to 2017.
In this sense, currently two thirds of the world's states do not have mandatory energy codes, which means that only in 2018, 3 billion m^2 were built without being adequately regulated by legislation. For example, in India only in 2018 approved the first building energy code that aims to regulate residential buildings; also Nigeria, which is expected to be one of the countries with the highest population growth in the coming decades, has issued its first building energy code in 2017. To be in line with the SDS, Sustainable Development Scenario, by 2030 all countries need to move towards mandatory building energy codes, high-performance new construction needs to increase from 250 million m^2 to 4 billion m^2, and deep energy efficiency renovation of existing stock needs to double to at least a 30-50% energy intensity improvement (Dulac J. et al., 2019).
Unsurprisingly, given the lack of major policy progress and clear market signals, investments in sustainable buildings are insufficient: although largest energy efficiency expenditures are still in buildings, growth in incremental energy efficiency investments decreased by 3% in 2018, to USD 138 billion.
Lastly, it is added the fact that a large part of the building stock has a high age and therefore uses outdated technologies and types of construction, which leads to a noticeable increase in consumption, due to heat losses, lack of insulation, etc.



◀ Fig. 1.11
Estimated global buildings construction to 2030, dividing in nZEB and building regulated or not by energy codes.
Source: International Energy Agency, 2018.

In the EU for example, where buildings are responsible for approximately 40% of energy consumption and 36% of CO2 emissions, currently, about 35% of the buildings are over 50 years old and almost 75% of the building stock is energy inefficient, while only 0.4-1.2% (depending on the country) of the building stock is renovated each year. Therefore, as it can be guessed, more renovation of existing buildings has the potential to lead to significant energy savings: potentially reducing the EU's total energy consumption by 5-6% and lowering CO_2 emissions by about 5%.

Currently, global state policies should all be directed towards the incentive to build all new buildings according to a main construction standard, that is the creation of high energy efficiency buildings, combined with the energy renovation of the building stock, which however moves at a pace equal to 1-2% a year.

Currently the most suitable solution is the design of nZEB buildings, i.e. near-zero energy buildings, in which, as the name implies, the balance between energy consumed and produced is close to zero, having at the same time minimum consumption for heating, cooling, air-conditioning, lighting, ventilation and domestic hot water. For their design an integrated approach is needed, using together passive strategies, building design and energy systems. To date, nZEBs make up less than 5% of the building stock worldwide and their large-scale reproduction is moving slowly; however, what is happening in Europe, gives good signals: according to current regulations, from 2021 the obligation to build only nZEB in private building will come into force, after the obligation for public buildings had started in 2018.

What is happening in Europe, shows how to address changes in the building sector, setting clear objectives, regulated by laws, which have a long-term vision, is possible, but only through the implementation of agreed common policies, which bind the individual nations to respect them. To do this, energy codes and mandatory performance standards to enable and encourage uptake of key energy technology solutions for buildings are needed, speeding up the transition to the use of energy from renewable sources.

1.4 The future in building construction: the nZEB buildings

Buildings with low energy consumption, i.e. nearly zero energy buildings (nZEB), as they are understood today, were hypothesized for the first time following the energy crisis of the 1970s, but only recently concrete actions have been developed and promoted towards this objective, with numerous initiatives taken in function of an increasingly rapid transition towards the construction of this new building typology, hand in hand with the redevelopment of those already existing.
In legislative and regulatory terms, actually the European framework (and also the Italian) is one of the most advanced; for this reason, given its importance in the design process developed in this thesis, will be defined in more detail in the following sections, as well as the Chinese one.
First of all, however, it is important to mention the European Directive that has clearly defined the design of low environmental impact buildings, the EPBD, Energy Performance Building Directive, recast.
The EPBD recast 2010/31/EU, whose most important specifications will be defined in the section related to the European legislative framework, introduces for the first time the concept of nZEB, or nearly Zero Energy Building, defined as a high-performance building energy, whose requirement, very low or almost zero, should be covered to a very significant extent by energy from renewable sources (European Parliament and Council, 18/05/2010).
In this sense, the European Union provides the guidelines for the design, but does not specify which are the exact parameters required by a building so that it can be considered a nZEB, nor does it clarify to what extent renewable sources must contribute to meeting its energy needs, since the task of putting into practice the definition of nearly zero-energy buildings in detail is attributed to each Member State.
According to the objectives, the new buildings or the energy-renovated ones must have better performances than the standard ones established by the decrees of the single States. Nevertheless the first important observation that can come is that nowadays if a designer takes care only of the overall

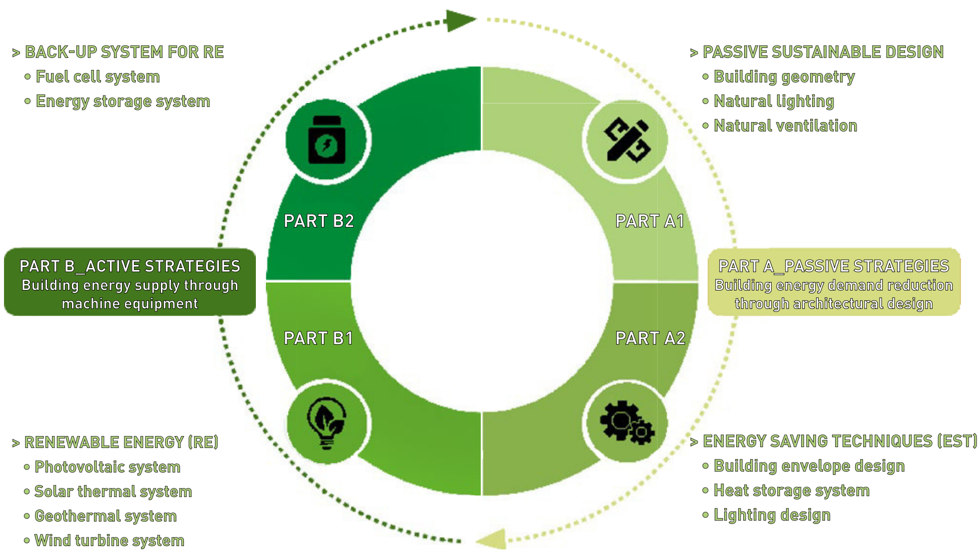


Fig. 1.12 ▶
Strategies to be used in nZEB building design, from energy systems to design to renewable sources

performance index of the building, as required for the nZEB building in many countries is reduced to designing buildings that do not exceed the energy class B, which corresponds to the performance class of the reference building used by the regulations. Therefore it is necessary a step further for reaching the best possible results.

As mentioned before, the nZEB design must consider many elements during the design process; when it comes to the topic of global energy performance it must be taken into account that different fundamental components are involved in the design of the building: heating, cooling, DHW i.e. Domestic Hot Water production, air-conditioning, which means ensuring a suitable indoor air quality, natural ventilation and lighting, which means also having a good shading system and adequate access to natural light.

It is therefore clear that a high energy performance building must take care of all the installations, making sure that an imbalance is not created towards one of the services listed above: designing a building paying attention mainly to heating, for example, can create difficulties in meeting the parameters required for cooling or ventilation services.

The design of a nZEB building therefore requires a complete balance, in order to have the lowest possible energy requirement: it could be necessary for example to sacrifice a level of performance that is too high in winter to favour the removal of the heat that accumulates inside in summer; or to reduce the solar gain due to the glazed elements in order to avoid the summer overheating of the building.

Although, as mentioned, the European directives do not indicate specific parameters relating to the energy needs of a nZEB, the meaning of what an almost zero energy requirement is, can be derived from two of the most stringent certifications present today: PassivHaus and CasaClima.

The PassivHaus certification, conceived by the *Passivhaus-Institut*[1], German institute dedicated to the design of buildings with very high energy performance, requires for a passive house an annual heating requirement of less than 15 kWh/m^{2}year.

The CasaClima certification instead, created by the Italian *Agenzia CasaClima*[2], which is an independent public certifying body, consists of three levels, the highest, the Gold one, requires lower consumption than 10 kWh/m^{2}year, while level A <30 kWh/m^{2}year and level B <50 kWh/m^{2}year.

In both cases, these values are significantly lower than the average for standard buildings, which generally varies from 150 to 250 kWh/m^{2}year in the case of non-insulated buildings, and between 80 and 120 kWh/m^{2}year for standard buildings built in the 1990s.

In this sense, buildings designed to be NZEB tend to have consumption from 30-40 kWh/m^{2}year or lower,as close as possible to 0.

▲ Fig. 1.13
Symbols of CasaClima and Passivhaus agencies

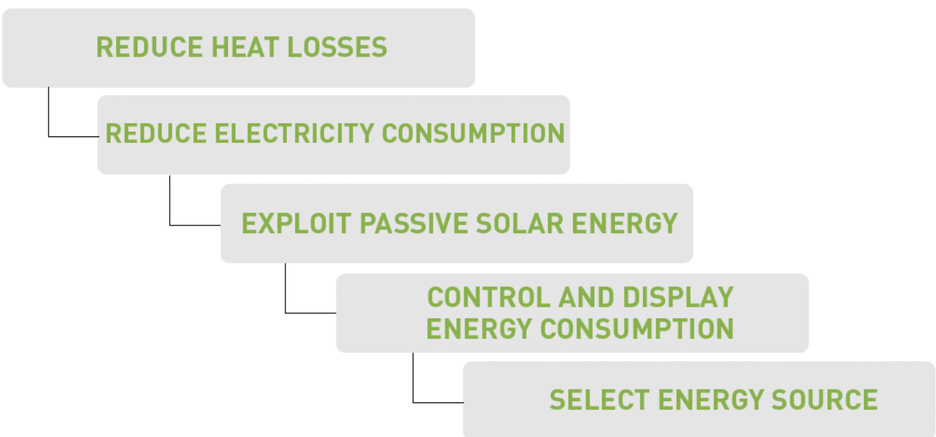
1.1 The Passivhaus-Institut was founded as an independent research institute in 1996 by Prof. Wolfgang Feist, and is based and active in Darmstadt, Germany.

1.2 The Agenzia CasaClima, credited as an independent public certifier, was created by Norbert Lantschner in 2002 for the Regional Agency for Environmental Protection of the Bolzano Province in Italy.

A valid starting point, useful for explaining the result to be achieved with a low energy consumption building design, are the guidelines defined to obtain a building that is considered Passive House. They in fact provide very stringent parameters to be respected once realized the building.
First of all it is necessary to respect the limit for the space heating energy demand, which must not exceed 15 kWh/m^{2}year; this value refers to the net area of the building, that is the habitable floor area, excluding non-air conditioned areas.
In the same way the space cooling energy demand must not exceed 15 kWh/m^{2}year, referred to net habitable floor area.
Then the primary energy demand related to all the house services, i.e. heating, domestic hot water, auxiliary and household electricity, must not exceed 120 kWh/m2year, referred to net habitable floor area.
The building envelope must have a good value of air tightness, that means it must have a maximum of 0.6 air changes per hour at 50 Pascals pressure (ACH50), obtainable after a pressurization test result after the building completion.
The thermal comfort must be assured along the winter in all the living areas, taking as a reference the limit of 20 ° C, without exceeding the abovementioned amount of energy; the same applies in the summer, in which the amount of time in which internal temperatures above 25 ° C can occur is defined in 10% of the total hours.
To comply with the above mentioned criteria, however, it is necessary, in addition to having used an integrated approach to the design, to foresee the presence of some technological solutions necessary to achieve the required standards.
The building insulation must be designed appropriately according to the local climate, isolating the opaque components very well, until it reaches, in the case of colder climates, a maximum value of thermal transmittance U-value = 0.15 W/m^{2}K. The same concept applies to windows, which are the most dispersing part of buildings; therefore the window frames must be well-insulated while the window must be at least double-glazed, with one of the surfaces covered by a low-emissivity layer. The gap between the glass must therefore be filled with a gas, among which argon or krypton are the best performing, to further limit the heat losses. In this case, for colder climates the thermal transmittance limit is equivalent to a U-value = 0.80 W/m^{2}K, with a solar transmittance value, that is the proportion of the solar energy available for the room, g-value = 50 %.
Another important element is the use of an efficient heat recovery ventilation, which has the function of recovering energy from the exhausted air, keeping the indoor air quality under control. The limit set for a Passive House is that at least 75 % of the heat is recovered before expelling air.
Then, as mentioned above, the uncontrolled leakages of the building must be reduced to a minimum, respecting a value of 0.6 h^{-1}.
Lastly, there must be no thermal bridges inside the building, so the design must focus very well on the preventive actions to avoid them, excluding, if possible, overhangs and reducing at the same time the building volume.

1.5 nZEB definition guidelines

As explained in the previous section, the nZEB building design must follow well-defined guidelines, taking as a reference a set of limit parameters regarding energy consumption. The primary objective is clearly the achievement of a high energy efficiency, finding the right compromise between best energy performance and cost ratio.
However, before planning, it is necessary to clearly define the steps to follow and use to carry out the most reasoned and effective planning possible; it is therefore possible to summarize a design strategy divided into five steps, aimed at having cost effective energy buildings.
• First it is fundamental to orient and set the building plan and its functions to use as much as possible the passive solar gains, which are fundamental in the winter period both to reduce the heating consumption and to increase the values of internal daylight.
• Secondly it is important to use design strategies that allow to reduce the building's heat losses, therefore using opaque and transparent performing envelopes becomes very important, in order to have good airtightness values. In this way it is possible to reduce heating and cooling consumption throughout the year.
• Then it is important to reduce the electric consumptions,which today is one of the elements that has the greatest impact on the building balance sheet; using electrical systems, latest-generation appliances that have low consumption, as well as reducing waste, becomes crucial for having a building that is nZEB.
• Once the architectural, bio-climatic and system components have been adequately thought on these bases, there must be a dynamic control of the energy use, to ensure that the design strategies are respected, as well as that there are no anomalies in the use of the systems.
• Lastly, it is necessary to cover the building's energy needs as much as possible, staying in the pre-established cost schemes, using renewable energy sources, also evaluating which are the best on-site or nearby, through an in-depth climate analysis. For example it becomes important to use photovoltaic or wind power plants in some cases, for covering the electrical



◀ Fig. 1.14
Five step strategy for designing a correct nZEB design.

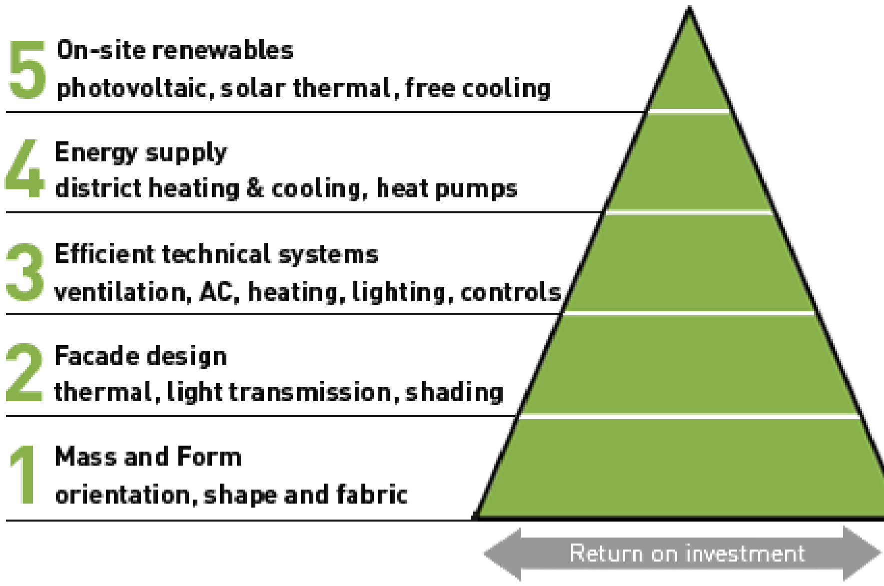


Fig. 1.15 ▶
Return on investment and cost pyramid for nZEB buildings.

energy demand of light, equipment and systems, or solar thermal systems for covering the domestic hot water demand; alternatively, active systems based on heat pumps can be used.

In architectural design, as mentioned above, since energy efficiency is the main component from the earliest stages, it is important that decisions are taken with care, as any corrections during construction can lead to high costs or inability to improve the energy use: a typical example of disregard of the energetic part in the design is the lack of the predisposition for technical systems or the wrong orientation of some internal spaces, rather than of some fixtures.

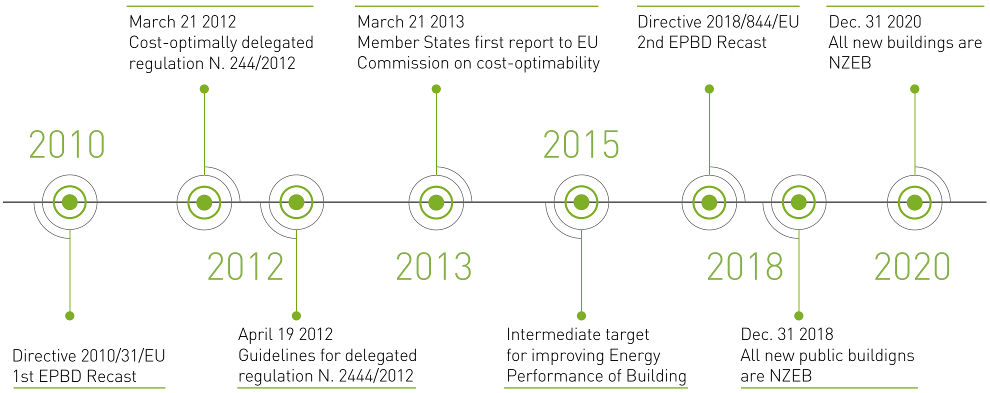
In the design process, another important factor is to design of shadings, daylight and fenestration together to create an efficient integrated system; therefore it is important to design energy systems such as HVAC (Heating, Ventilation, Air Conditioning) so that they are as flexible as possible while still achieving the pre-established energy efficiency criteria, as changes in the internal layout of the building can always occur during construction.

As can be seen from the image above, which shows a pyramid referring to the components cost of a nZEB building compared with the return of the investments made for them, it illustrates how important is to make the right choices during the design process, with particular attention to the categories positioned in the lower part, as they could have the highest energy saving potential demonstrating a good economic return on the investments. What is most important is placed at the base and refers to the mass, shape and orientation of the buildings; however, they require less investment than the upper components.

Then the design of the façades is the second most important element in terms of cost, with everything that refers to envelope insulation and the transparent component. The upper parts of the pyramid represent choices that are more expensive and have low return of investment potential: in the third slot there is the installation of efficient energy systems, in the second the type of energy generation, such as district heating or heat pumps, and lastly the choice of on-site renewable technologies.

1.6 European legislative framework for building sustainability

The European Union has always been at the forefront in terms of energy efficiency and reduction of polluting emissions, by the states that compose it, in the construction sector. In recent decades have in fact been carried out various reforms and initiatives with the aim of increasingly improving the building heritage, in order to achieve a standard that leads to having only NZEB buildings by 2050 on European soil.
But the directives issued so far contain the definition of NZEB, but leave each state the freedom to identify which features define such a construction and how it is to be realized. In this way it was allowed to take into consideration the traditions and specificities of each European nation, allowing each member state to transpose the directives, issuing regulations that govern the subject.



◀ Fig. 1.16
Pathway to nZEBs for European countries after EPBD Recast.
Source: Author's elaboration

The first important directive in terms of environmental sustainability relating to buildings issued by the European Union was Directive 2002/91/EC, better known as EPBD, or Energy Performance Building Directive.
The directive concerned the residential and tertiary sectors (offices, public buildings, etc.), dealing with all aspects of the energy efficiency of buildings, to establish an effectively integrated approach during their design, requiring each member States to strengthen their building regulations, and to introduce the energy certification of buildings.
Following the previous directive, the EU's commitment to sustainability in the building sector has been widely implemented with the Directive 2010/31/EU or EPBD Recast. This measure took on great importance in the design process, as it required that the buildings constructed from 2018 onwards should be nearly Zero-Energy Buildings (nZEBs) and that the existing building stock be retrained, starting from the buildings of the Public Administration. To be precise, the legislation established that the new private buildings and those of the public administrations must all be nZEB respectively from 31st December 2018 and 31st December 2020.
In this case it is important to give a brief definition of what nZEB means, as defined within the article 2 of EPBD Recast: "a nZEB is a building that has a very high energy performance with the nearly zero or very low amount of energy required covered to a very significant extent by energy from renewable

sources, including energy from renewable sources produced on-site or nearby" (European Parliament and Council, 18/05/2010).
At the same time, with the EPBD Recast, States were required to identify a common methodology for calculating and certifying the energy performance of a building and to set minimum energy performance requirements for buildings, and the methods of inspection and maintenance of air conditioning and hot water production systems. (European Parliament and Council, 18/05/2010)
Following the two regulations described, the Directive 2012/27/UE Energy Efficiency Directive was therefore approved, which took over the criteria in Directive 2010/31/EU: this directive underlined the strategic role of energy efficiency in the civil sector, asking Member States to save energy by setting national indicative energy efficiency targets. At the same time, it has also introduced the obligation to carry out the energy audit for large companies and to promote it for small and medium-sized enterprises, while at the same time asking for financing instruments to be developed to promote energy efficiency measures.
With reference again to public buildings it was also established that the member States should implement a series of actions and interventions, including from 10 January 2014 the redevelopment for each subsequent year of 3% of buildings with an area exceeding 500 m^2 owned by the central government and occupied by it, to at least respect the minimum energy performance requirements, with a lowering of the threshold to 250 m^2 starting from 9 July 2015.(European Parliament and Council, 14/11/2012)
The Directive currently in force instead, issued on 9 July 2018, is the Directive 2018/844/EU, or 2nd EPDB recast, which has amended the existing Directive 2010/31/EU and Directive 2012/27/EU on energy efficiency.
The Directive 2018/844/EU has introduced targeted amendments to Directive 2010/31/EU, aimed at accelerating the cost-effective renovation of existing buildings, with the vision of a de-carbonised building stock by 2050 and the mobilisation of investments. The revision also supported electro-mobility infrastructure deployment in buildings' car parks and introduced new provisions to enhance smart technologies and technical building systems, including automation. (European Parliament and Council, 30/05/2018)

Together with the directives and regulations issued, the European Union carried and is carrying out projects aimed at increasing the use of renewable energies and the construction of low energy consumption buildings.
In fact, a European economy and society can be sustainable if based on renewable energy and energy efficiency. For the housing sector this means the large-scale deployment of low energy buildings (almost zero nZEB energy buildings). In fact, European legislation on the energy performance of EPBD buildings makes nZEB a standard by 2020. The technology is already available and tested, but the large-scale adoption of nearly zero-energy buildings will still be a great challenge for all operators of the building market.
The ZEBRA2020 project funded by the European Union, launched towards the end of April 2014 in Vienna, was created with the aim of monitoring the

development of the nearly zero energy building market in Europe, in order to gather concrete data useful to the Member States governments in evaluating and calibrating virtuous and efficient decisions in the building sector; the purpose of this study was to create an observatory on nZEB, based on market studies and various tools for data collection. The project joined and based on the already existing different databases that collect data on the energy efficiency of the European real estate stock, among which for example ENTRANZE data tool[3], ODYSSEE (Enerdata)[4], Mure[5].
ZEBRA2020 involved 17 European countries: Austria, Belgium, Czech Republic, Denmark, France, Germany, Italy, the Netherlands, Norway, Poland, Lithuania, Luxembourg, Romania, Slovakia, Spain, Sweden and the United Kingdom; together they form around 89% of the European building stock and population.
One of the aims of the ZEBRA2020 project, as well as helping EU and Member State policy makers, energy agencies and all stakeholders in the European construction industry to develop efficient strategies to accelerate the building market to energy almost zero, was to contribute actively to the achievement of 100% of new nZEB buildings starting from 2020, combined with a high level of redevelopment of existing buildings, setting the same energy saving targets.

Another important project is the AZEB, or Affordable Zero Energy Buildings, begun in June 2017 and slated for completion in the year 2020; eight partners from Member States, Italy, Spain, Bulgaria, Germany, France and The Netherlands are part of it.
The project is part of the European Horizon 2020 program (H2020) and aims to achieve significant construction and lifecycle cost reductions of new nearly zero energy buildings (NZEB's) through integral process optimization in all project phases. Optimizing these processes to fully integrate available solutions in the areas of process, technology and contracting is seen as the largest potential in life-cycle cost reduction. The project will create a common methodology for the development cost effective NZEBs.[6]
The project will pave the way for the process and organizational innovation in construction, to enable significant cost reduction and solid market acceptance of NZEB's.

1.3 Entranze data tool is a tool for mapping buildings, which provides data on the thermal quality of buildings, size, age, type, structure, heating and cooling systems, final energy consumption

1.4 ODYSSEEis a database on energy efficiency indicators in Europe

1.5 Mure is a database that provides information on energy efficiency policies and measures that have been carried out in the EU. The information is differentiated by housing, tertiary sector, industry, transport. It allows the simulation of the impact of energy efficiency measures at national level.

1.6 https://azeb.eu /more-about-azeb/

1.7 Italian legislative framework for building sustainability

Italy, transposing the European directives, is moving at great pace towards a transition to buildings with higher energy efficiency, such as nZEB, NZEB or passive houses. In this sense, to implement the EU guidelines issued by the European Union in terms of environmental sustainability in the building argued in the previous section, Italy has initiated several processes, both legislative and operational.
In this context it is therefore important to define the regulatory framework and the actions undertaken in the field of sustainability by Italy, since, although the project developed in this thesis is located in China, they have greatly influenced the considerations and design choices. This happened because the European and Italian regulatory framework, in addition to being easier to access in all its sections, currently appears to be more accurate and stringent than the Chinese one.
Among the sectors that are most affected by the initiatives mentioned, the building sector is certainly one of the most important, contributing to a large extent within the Italian energy balance; this is due to the fact that the national building park is composed for the most part of buildings constructed with non-modern criteria, consequently having very high consumption. Suffice it to say that around 70% of the buildings were built before 1990.
Currently, the most important plan that the Italian government has enacted is the 2017 National Energy Strategy (NES), which provides the objectives that the Italian government aims to achieve by 2030 in terms of environmental sustainability and energy consumption for buildings.
But before defining the NES it is necessary at the same time to cite the most important decrees and provisions issued by the Italian State regarding high energy efficiency buildings that preceded it.

In Italy the issue of energy efficiency was introduced by Legislative Decree 192/2005, then amended by Legislative Decree 63 of 4 June 2013, which became L. 90/2013 to integrate some aspects required by the EPBD Recast that were still missing . This law dealt with energy efficiency and integration into the site of renewable sources for energy production, and introduced in Italy the concept of almost zero energy building, NZEB, which, as mentioned, consists of a very high energy performance building with low energy demand and prevailing supply of energy from self-produced renewable sources.

Subsequently, with Legislative Decree (D.lgs) 102/2014 and the Energy Efficiency Action Plan (PAEE), Italy has implemented Directive 2012/27/EU, establishing a framework of measures for the promotion and efficiency improvement aimed at achieving the national energy saving targets defined in 2020. For that purpose, the Decree outlined a series of actions aimed at overcoming the obstacles and market failures that hampered the efficiency of the supply and in the final uses of energy.
For improving energy performance of buildings, both public and private,

Legislative Decree 102/2014 provided sectoral plans for energy efficiency:

• the Strategy for Energy Regeneration of the National Real Estate Park (STREPIN), aimed at mobilizing investments in the restructuring of the national building stock.

• the Action Plan for Nearly Zero Energy Buildings (PANZEB), which, since the new buildings will have to be almost zero-energy since 2021, outlined the national guidelines and development lines to increase their number by regulation measures and incentive plans available.

• the Plan for Energy Re-qualification of Central Public Administrations (PREPAC), which provided that, annually, starting from the year 2014 and until 2020, the Ministries of Economic Development and the Environment and the Protection of the Territory and the Sea should prepare, by November 30th of each year, a program of annual energy redevelopment projects in the buildings of Public Administration, relating to at least 3% per annum of the covered air-conditioned useful surface. (Government of the Italian Republic, 18/07/2014)

But a final regulatory intervention was needed for a more complete approach to the topic, which saw the entry into force of the Interministerial Decree (DI) of June 26, 2015 "Application of energy performance calculation methods and definition of minimum requirements and requirements of buildings", which was issued to complete the transposition of Directive 2010/31/EU, which took place with Legislative Decree 4 June 2013 n. 63. (Ministry of Economic Development, 06/26/2015)
The decree defined the characteristics that a building must meet, such as minimum performance requirements, to be a NZEB. In this sense, the DI consisted of three separate decrees:

• "Application of energy performance calculation methods and definition of minimum building requirements and requirements", which defined the energy performance calculation methods and the new minimum building requirements.

• "Schemes and reference methods for compiling the technical project report for the purpose of applying the requirements and minimum energy performance requirements in buildings" which defined the layouts of the technical project reports.

• "Adaptation of the national guidelines for the energy certification of buildings" which defined the new national guidelines for the Energy Performance Certificate (APE). In this Decree are also reported, in addition to the guidelines, the instruments of connection, consultation and cooperation between the State and the Italian Regions. The Information System on Energy Performance Certificates (SIAPE) is also established, for the management of a national register of APEs and thermal plants. (Ministry of Economic

Development, 06/26/2015)

After the previous Decree, with the Interministerial Decree of 16 September 2016, the following topics were defined:
• the procedures for implementing the action program for improving the energy performance of Public Administration buildings, indicating the methods of financing;
• the methods and criteria for identifying and selecting the interventions admitted to financing;
• the presentation of the intervention proposals and the approval of the intervention program;
• the necessary information and technical assistance activities;
• coordination, data collection and monitoring necessary to verify the progress of the program. (Ministry of Economic Development, 09/11/2016)

Lastly, as regards the NES, National Energetic Strategy, in summary, the document provides that all coal-fired power plants, which currently produce about 8 GW of power, are excluded from national energy supply by 2025; that at least 28% of energy consumption from renewable sources is covered; that at least 55% of the electricity consumed is produced from renewable sources. At the same time, in terms of energy efficiency, the NES forecasts a 30% reduction in consumption by 2030, with a reduction in final energy consumption from 118 to 108 Mtoe, with a saving of around 10 Mtoe.
The objectives also include strengthening security of supply, reducing energy price gaps and promoting public mobility and sustainable fuels. A path that by 2050 envisages, in line with the European strategy, the reduction of at least 80% of emissions compared to 1990, to combat climate change.
For all this, the NES 2030 provides a total investment of 175 billion euros: of these 30 billion will be allocated to networks and infrastructure, 35 will go to renewable sources and the rest will serve to support energy efficiency, especially in the residential sector and in the transport sector. (Ministry of Economic Development, 10/11/2017)

Chapter 2

The Chinese context

The purpose of the following chapter is to define the contemporary Chinese situation, with particular attention to energy condition, building sector and the related urbanization, as well as the new Chinese policies for energy efficient buildings.
At the same time, in the contextualization of the Chinese situation, it is necessary to define the social context, currently characterized by great disparities, in particular as regards the division between the inhabitants of cities and rural areas, and by the phenomenon of great emigration to the large inhabited centers .

2.1 China's condition and development

China, or the People's Republic of China, is the most populated world nation today, with the current share exceeding 1.4 billion people, composing alone about 18% of the world population, even if the exponential growth rate that has allowed the Chinese nation to double its population from the 60s to today is slowing down.
China has been a country under dictatorial regime for much of the twentieth century, and by many it is still considered such, although defining the Chinese political structure in a precise category is not very simple: for over two thousand years the nation has been governed by an imperial centralist monarchy, to then have a series of authoritarian and nationalist governments until the first Chinese revolution of 1912; today China, controlled in every field by the Chinese Communist Party, is slowly transforming its political/economic system into a capitalist system.
The large population has allowed China to become one of the world's leading economies, thanks to the amount of labour force it could have. The Chinese economy since 1978 and in particular from 1990 onwards, has registered very high growth rates, higher than the average world-wide ones, while in recent years it has experienced a slowdown, finding itself today to traverse a trajectory that will lead it to converge towards the income levels of industrialized countries. This economic boom that has allowed China to become one of the world's leading powers, has also been possible thanks to globalization, which allowed in turn to attract a huge number of companies and industries from all over the world in search of cheap workforce to China, as well as to grow the domestic industry. According to data from the Chinese government in 2018 the Chinese economy grew by 6.6%, recording the lowest growth rate of the last 25 years, after having reached the highest point with almost 12% in 2007, with a further contraction expected for 2019 around 6%. Current forecasts foresee a constant slowdown in the Chinese economy over the next ten-fifteen years, with the risk even in the worst case scenario, of recession, after decades of continuous growth; therefore one of the main challenges for China in the near future will be managing to cope with this decline, without compromising the domestic economy.
As regards the domestic demand, there is also a continuous growth, given by the enrichment of the Chinese population: despite having still large parts of the population below the poverty line, in these years economic growth has allowed to increase the standard of living of good part of the Chinese. In this sense, officially in urban areas unemployment is at 4%, even if according to non-governmental sources it could be 10% or higher. Although according to estimates by the International Monetary Fund, China has become one of the most unequal regions in the world, with 43 million people living on less than 95 cents a day, the poverty threshold set by the Chinese government.

For the years to come, the Chinese government has, however, foreseen an impressive infrastructure development plan that plans further expansions

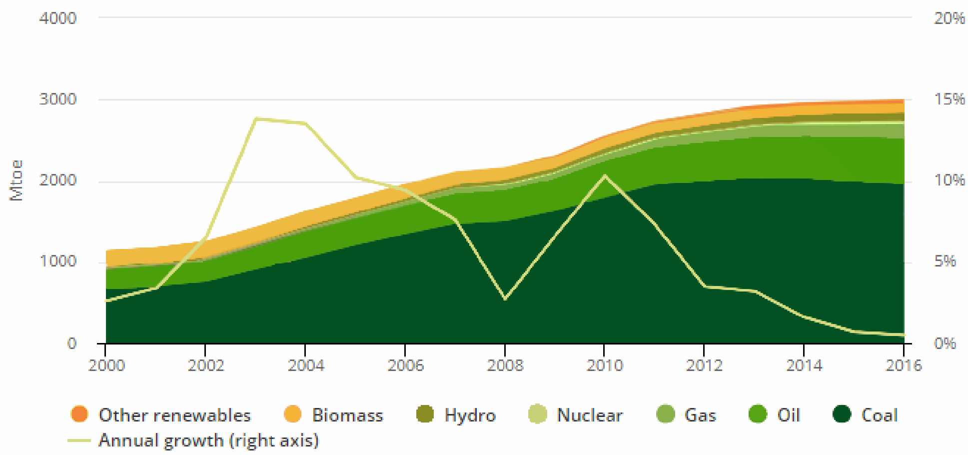
for airports, railway network and urbanization with the target of reaching 60% of the resident population. The government foresees a simultaneous efficiency improvement of companies and industrial plant and an increase in the standards of living and income per capita by 2020: this because China aims at a qualitative improvement of its system.
Among the most important projects that China is carrying out, there is "One Belt, One Road" promoted by the current President Xi Jinping: China (in cooperation with other nations, including Italy) is realizing a new connection between East and West that retraces the ancient Silk Road and the Maritime Silk Road. This project will facilitate and promote trade between the more than 60 states that it will cross, as well as increase the income of the Chinese economy, which in this way will greatly speed up the passage of goods towards Europe.
However, having a dense population and a perennially growing economy bring a series of negative consequences; China nowadays has well-known environmental problems, among which the main ones are severe droughts to satisfy the ever-increasing water consumption, a pollution, above all in the urban areas, among the highest on the planet, with heavy consequences on the health of the inhabitants, devastating floods and significant increase in sea level, which are putting many rural villages and many coastal cities at risk, such as Guangdong, Shanghai, Tianjin, and Hong Kong.
Talking about the actual emissions of carbon dioxide in Asia, they are 17.4 $GtCO_2$, and China account for more than one half, with 9.10 $GtCO_2$ (IEA, 2016)
Many Chinese cities are among the most polluted in the world, due to factors such as huge vehicular traffic and industries, which bring smog levels to levels that are very harmful to human health. To counteract this phenomenon the Chinese government in recent years has been carrying out numerous policies, which are leading to reductions in the levels of PM[1] with the objective of achieve the pollution-free status by 2020, which, however, today seems impossible. The standard average of $PM_{2.5}$ on the Chinese territory it is 35 micrograms, therefore much above the maximum imposed by the World Health Organization of 10 micrograms to avoid damage to health.
Currently the Chinese government has stated that thanks to the initiatives taken in 338 cities the level of $PM_{2.5}$ has dropped by 9% in 2018, compared to 2017; however it must be underlined that in the winter period, particularly in the cities in the north where there are very low temperatures, there are continuous increases; the worst city was the city of Linfen in the province of Shanxi, the same region where the thesis project site is located, which reached 174 micrograms of $PM_{2.5}$ (Guo G., 2019).
As a matter of fact, the country seems to be backsliding on its earlier efforts, as shown by the move to revise pollution targets for the October-March period to 3 percent, down from the 5 percent reduction asserted in earlier plans. (Guo G., 2019). It is clear that the road taken by China is right but greater efforts and investments are needed to improve a situation that is still critical today.

2.1 Particulate Matter, identifies the mixture of pollutant solid particles and liquid droplets found in the air; the most harmful are the PM10 and PM2.5.

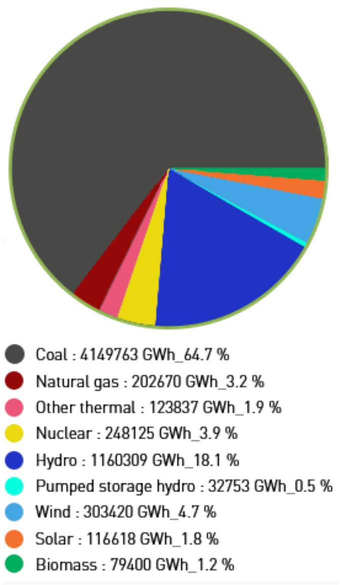
2.2 Chinese energy condition

Talking about the energetic situation of China, nowadays it's facing a situation in which it's at same time the most polluting and the biggest producer of green energy in the world. The challenge that the country will face in the next years will be to decrease much more the use of fossil fuel in favour of clean energy, like hydroelectric, wind, thermal, solar and nuclear power.
In dwellings and houses, in the past, China's inhabitants depended mostly on coal and wood as main sources for heat production and on fossil fuel in the modern economy, for producing electricity (that in turn it also serves for heating and cooling purposes).
It's important to consider that heat in China is considered a potentially available and cheap public good, especially in the northern part of the country, which needs heating up to six months a year, due the colder temperatures. On an annual basis, the polluting emissions of coal-based district heating represent between 3% and 5% of the total pollutants related to energy at national level. But the northern cities are much more affected, as the heating pollution is concentrated there.
The problem is that the district energy systems are fed mainly with coal: in 2016, 33% of the total was heated by coal-fired boilers for the production of commercial heat and co-generation accounted for 51%, the rest comes from gas and other sources (Benazaref D., 2017).

But China's composition of energy sources depends very much on the geographical location. To date, as said above, part of the Chinese population still lives in rural areas where coal and wood are the main energy sources, in particular for heating; while places like Guangdong region, in the south-east, mainly utilize gas, and economically more developed areas such as Shanghai primarily employ electricity. At the same time, in the rural areas, for cooking wood is the most used material, although some economically developed rural areas employ natural gas. A consequence of this is a sharp increase in polluting emissions and a deterioration in the quality of life, since the combustion of wood and coal poses severe threat to the environment and rural residents' health.



◀ Fig. 2.1
Primary energy demand by fuel in China.
Source: IEA, 2017.



▲ Fig. 2.2
China's electricity generation by source in 2017.

On a national level, an impressive increase of the electricity consumption is taking place: between 2010 and 2018 it grew from about 4200 TWh (TeraWatthour) to 6840 TWh. To satisfy the continuous increases, coal was used as the main fuel, which fortunately has partially stopped its growth thanks to the advent of renewable energies also on the Chinese market. In 2017 coal made up 64.7 % of the electric generation, natural gas 3.2 %, and other thermal sources 1.9 %. Nuclear energy instead covered 3.9 %, while renewable energy is divided as follows: hydro 18.1 %, pumped storage hydro 0.5 %, wind 4.7 %, solar 1.8 % and biomass 1.2 %.
The two main sources are coal and hydropower: in fact, China is the third nation in the world for coal reserves, located mainly in the northern and north east regions, as well as having large water resources, mainly located in the south west. China has the largest hydroelectric power plant in the world by installed capacity, the *Three Gorges Dam*, with 22.5 GW.
In 2019, however, according to current forecasts, after having reached about 1900 GW in 2018, China will reach an installed power generation capacity of about 2000 GW, of which 1040 GW came from coal-fired power plants.
However, after years of substantial increases, the growth in Chinese energy demand is slowing down, until it will reach a value around 1% per year according to the New Policies Scenario (NPS): this is mainly due to demographic changes, the implementation of new energy efficiency policies and the use of renewable energy and the economic changes that the nation is facing. According to forecasts, the total energy demand growth to 2040 will be roughly the same experienced between 2008-2016.
In 2019, instead, an installation of a new power capacity equal to 110 GW is planned, of which 62 GW of energy from renewable sources.

What is more positive is the growth of the share of renewable energies, which according to the IEA forecasts, in the NPS will reach about 2040 GW in 2040. What is less positive is that although the use of coal will not grow, its share will remain constant, in the order of 1000 GW, with all the environmental costs connected, since coal is one of the most polluting fossil fuels.
The only way to improve this situation for the Chinese government is to increase investments, with measures to improve the income level of residents, and with measures that increase research and installation of the renewable

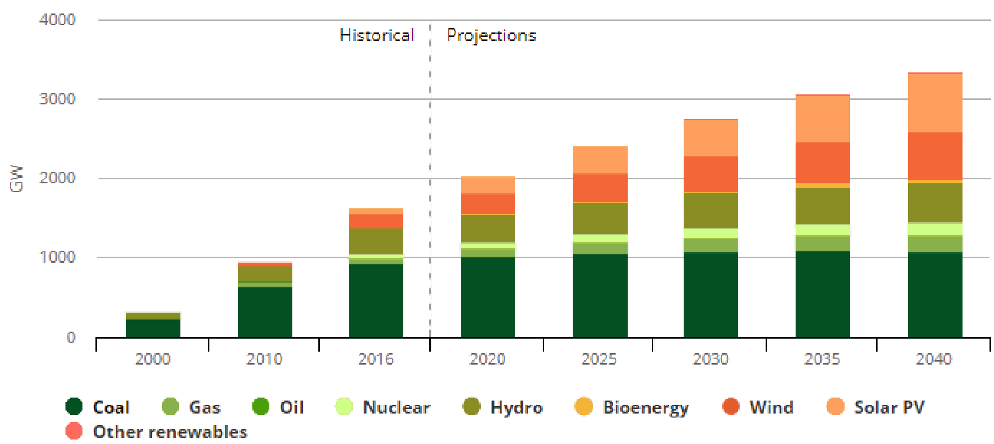


Fig. 2.3 ▶
Installed capacity in China in the New Policies Scenario.
Source: IEA, 2017.

energy as well as measures to upgrade energy infrastructure, weakening the use of coal.

Investments of the Chinese government in the renewable energy market are planned to reach 360 billion dollars by 2020. Thanks to this, China overtook the United States and Germany, becoming a leader in solar energy production while the installed wind power, that is about 150 GW, is the largest in the world. It isn't a coincidence that China is largely responsible for the trend in the global price of solar modules, which has fallen by as much as 80 % since 2009; and the trend towards higher production and lower costs is set to continue. The Chinese government expects the country to reach at least 200 GW of solar power and 250 GW of wind power by 2020, with an annual cost reduction target of 2 % for solar and 3-5 % for wind power[2].
But China is also investing heavily in hydroelectric, geothermal and biomass generation capacity. Overall, these developments should help the government achieve its goal of increasing the share of non-fossil energy consumed by the current 11 % to 20 % by 2030.
The main reason for this huge expansion is that renewable energy represents energy security, which is accompanied by the important factor represented by the decrease in air pollution. Unlike oil, coal and gas, whose reserves are finite and subject to geopolitical tensions, systems based on renewable energy can be built wherever there is water, wind and sun.
The results of massive investments in renewable energy and government support are starting to be evident: the use of renewable energy in China in 2017 covered 26.4% of total power generation. To meet its Copenhagen commitment (result of the 2009 United Nations Conference on Climate Change) of reaching 15 % by 2020, and keep up to 20 % by 2030, as required by the Paris agreements, a recent government directive requires regional distribution companies to buy from the 3 and 5 % of its electricity from renewable non-hydroelectric sources by 2020.
Hence, renewable energies such as geothermal and biomass also have room for further development: currently renewable sources contribute only around 1% of district heating, compared to 28% in the European Union (Ballocchi A., 22/01/2018). The road taken by the Chinese government is for sure good and is a perfect example of what can be done in all the country, especially in rural areas that for years have been forgotten in favour of economic expansion and development of urban agglomerations.
In fact, in the rural areas where energetic systems in dwellings are still mostly related to old practices there's still a lot to do; another important fact is that rural building heating constitutes 25% of total energy consumption in China (Zhuang, Z., Li, Y., & Chen, B., 2009).

Installed low-carbon capacity, led by hydropower, wind and solar PV, is projected to grow rapidly and make up 60% of total capacity by 2040. Average

2.2 A.A., "China sets out to conquer renewable energy challenge", 17/01/2018, https://www.webuildvalue.com/en/global-economy-sustainability/china-sets-out-to-conquer-renewable-energy-challenge.html

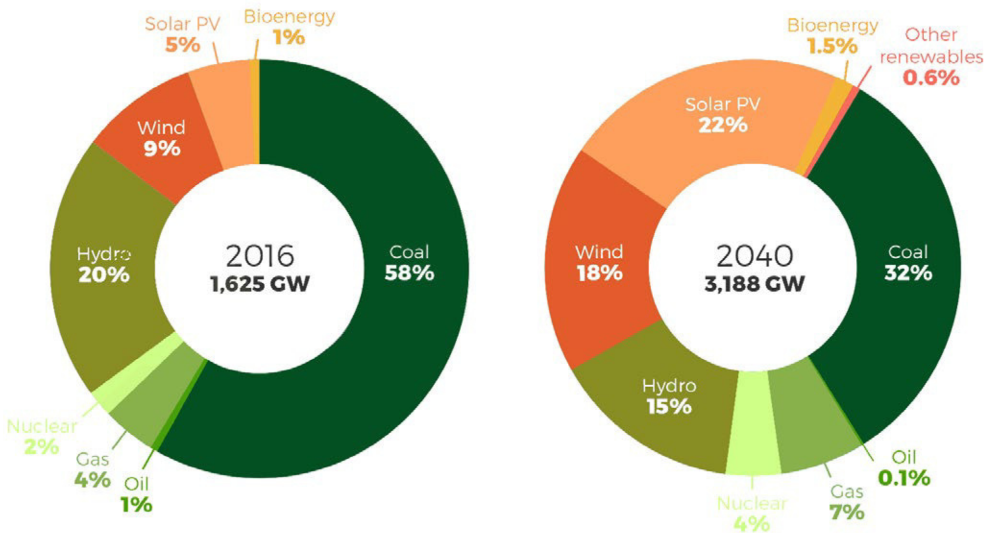
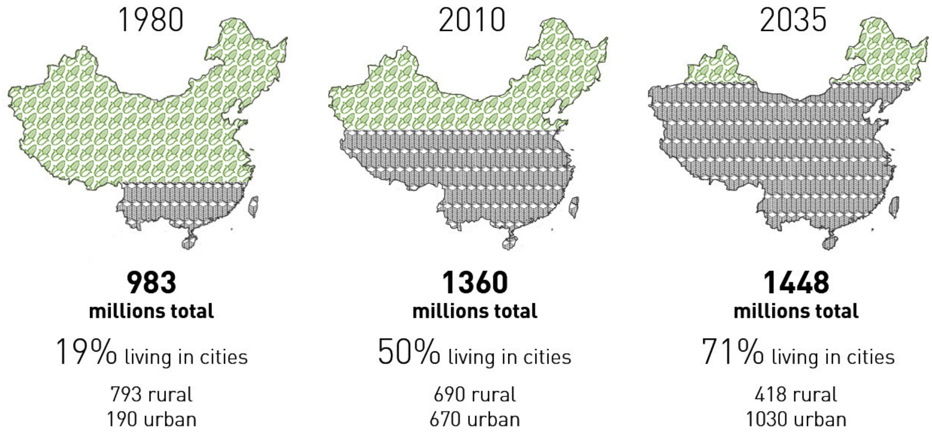


Fig. 2.4 ▶
Installed capacity in China in the New Policies Scenario.
Source: IEA, 2017.

solar PV projects in China become cheaper than both new and existing gas-fired power plants around 2020 and cheaper than new coal-fired capacity and onshore wind by 2030 (IEA, 2017).
According to current forecasts, by 2040, the costs of solar power plants for electricity production will be much lower than the costs of running coal-fired plants. But what is also necessary is major power market reforms and a strengthening of the network to integrate a higher share of variable wind and solar PV output (IEA, 2017).
Already today, about 15% of China's wind and solar PV generation is being curtailed because it cannot be accommodated by the existing power system: a major investment in new power transmission lines eases these constraints, enabling China's inland renewable potential to bring cheaper power to demand centres closer to the coast (IEA, 2017).
However, in 2018 there was a lower growth of solar energy: the main reason was a sudden change in China's photovoltaic incentives to contain costs and face the challenges of network integration: China added 44 GW of energy solar in 2018, compared to 53 GW in 2017.
Regarding the wind energy, the Chinese government has invested 18 billion dollars for the development of 24 offshore wind plants that will increase the overall share of renewables.
Hand in hand with renewable energies, a great increase in the use of methane gas is expected in the coming years, which despite being a fossil gas has a lower environmental cost compared to coal and oil, with a share of the total that should not exceed the 10%. Lastly, the nuclear power will continue to be a source of energy used, despite the associated risks, with China that around 2030 will become global leader in nuclear-based electricity generation, surpassing the European Union and the United States.
The road taken by the Chinese government is the right one, even if the data show a slow development of renewables, with strong deployment and policy support continue to bring costs down for renewables, and with solar PV plants that became China's cheapest form of electricity generation, but what still needs to be improved is the decrease in the use of fossil fuels which today still cover an important part of China's primary energy.

2.3 Between migration and hukou: the Chinese social situation

Internal Chinese migration in recent decades has been one of the largest in history, leading to the displacement of hundreds of millions of people from rural areas to cities, which in many cases have become mega-cities.
The floating population has increased from six million in 1979 to 211 million in 2009; it is expected that it'll continue to rise until 2050, dropping however from six to three million per year, when China will have reached a migrant population of 350 million (UNHABITAT, 2017).
Just in 2018, according to the Chinese National Bureau of Statistics (NBS), the number of rural labourers working in China's urban areas increased by 1.8 million.



◀ Fig. 2.5
Evolution of migration in China from the countryside to the cities since 1980, with a forecast for 2035.

According to NBS estimates, in 2018 there were 288 million migrant workers from the vast rural hinterlands, which constitute more than a third of the total workforce, capable, as mentioned in the previous section, of providing the necessary thrust to the impressive economic growth of the last three decades.
Rural migrant workers are those who have a rural household registration, i.e. the rural hukou, but work and live in urban areas, even if within this category there are also those who do not come from rural areas: they were born in the city but they were also son of migrants, so due to the Chinese household registration system they don't have the same rights.
Since the 1980s, the cities that have benefited most have been the major coastal cities, which have seen their population grow exponentially, such as for example Guangzhou, in the south-east of China, that grew from 3 million in 1990 to 13 millions in 2019. But currently migrants stand out in two types, permanent and temporary: the number of permanent migrants is limited, since they are only a privileged minority, usually being richer and highly educated; the great majority of the migrants can't access to the local household registration status and they are therefore excluded from urban citizenship treatment in their adopted city of domicile (Li et al, 2009), not to mention that they are considered as outsiders by the local population.
Currently, due to unbalanced migration in different regions of China, the Chinese government has launched a series of projects and funding to increase employment opportunities in many inland regions, while cities like

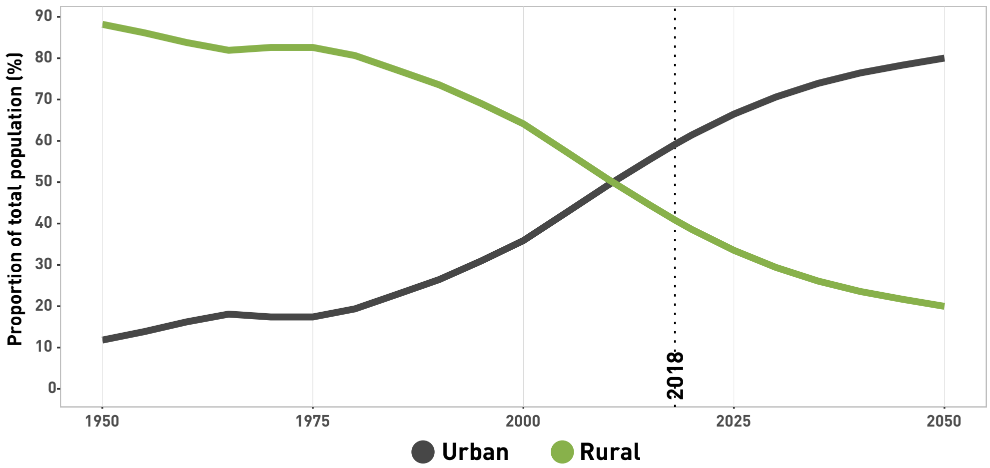


Fig. 2.6 ▶
Percentage of people living in rural and urban areas in China.
Source: United Nations, DESA, Population Division, 2018 + Author's elaboration

Beijing and Shanghai, which have now abundantly exceeded twenty million inhabitants, impose high restrictions on migrant workers.
The migration phenomenon has led to disproportionate urbanization, with a continuous increase in the urban population, which after exceeding the rural one between 2010 and 2011, reached in 2018 a percentage equal to about 58% of the total, with more of 810 million individuals; it is estimated that by 2035 70% of the population, around one billion, will live in the city. For this reason, China currently has six mega cities, which exceed 10 million people, and 10 major cities, between 5 and 10 million. This difference in population is also reflected at the economic level, with the cities that attract investment and industries, increasing the income of their inhabitants: it is estimated that today the income of those living in rural areas and those living in the city is 1:3, particularly in the coastal regions, which are the richest.

But, as said, the Chinese migration situation, brings with it very important social consequences, including the type of use of the before-mentioned *hukou* system, or better to say the household registration.
Hukou, also called *huji*, with origins in ancient imperial China, is a residence certification system, which, in addition to registering the area of residence of a person, includes identifying information and personal data on it and, being released for family units , it is also used as a family register in various administrative areas.
The hukou was established in 1958 and its purpose was to distinguish the rural Chinese population from the urban one and therefore the workers of the agricultural communities from those of the city (*danwei*). Originally it did not have a discriminatory purpose, but the goal was to impose a strict control on the movements of the population, avoiding a chaotic and excessive urbanization, as could happen in the period of its creation.
In practice nowadays, since the social insurance, social welfare and social assistance programs are financed locally, the hukou establishes different rights for citizens from different geographical areas; in this way, for example, those who from the countryside move to a metropolis are not guaranteed public services, such as health and education. It is clear how in recent decades due to the enormous phenomenon of emigration to the cities, great social disparities have been created, as well as problems relating to housing people

in the big cities; on the one hand, many workers travel from the countryside to the cities only for work and then return to the villages, but many, moving from one region to another or moving to the coast from within have settled in the big metropolises.
Nowadays, among the various attempts to regulate the system, almost always on a local basis, residency cards and even points systems have been created, the latter accumulated thanks to factors such as obtaining a degree in time or purchase a house while they are removed for committing violations of the law, like having more than one child. In this situation the black market, as well as the real estate market that is currently experiencing a particular moment in China, is increasingly involved in the issue of the hukou.
During the last few years, the interest in the issue has increased a lot, so much that in 2009, at first the former premier Wen Jiaobao started a policy of reforming the system, then the Central Economic Work Conference released a statement pledging "to push for urbanization in an active and steady manner and to solve the hukou problem of migrant workers" (Yao Y., 2009). This initiative was followed by an announcement to implement a study and formulate a new policy by the National Development and Reform Commission (Yao Y., 2009). But this change in view of the Chinese government may not have been linked to a more equitable policy, but rather to a merely economic factor: a resident in the city consumes many more products than one who lives in the countryside, about 1.6 times, and in the same way the greater housing demand in the cities brought with it a greater demand for services and infrastructures which in turn brought more investments; after the 2009 crisis this was of fundamental importance to help China to overcome the economic crisis.

At the same time the emigration combined with the increase in the average age of the Chinese population is rapidly bringing the pension services of some provinces to be short of funds, with the first provincial jurisdictions that today are unable to meet the one-year pension requirements. This is due, as said, to the aging of society and to irregular economic development in different parts of China, which has brought the overall contributions to the national pension fund rose by 19.5 %, or 571 billion yuan (US$ 86.19 billion) last year, but payments grew by 23.4 %, or 604 billion yuan, according to a report made by the Chinese Ministry of Human Resources and Social Security.[3]
The fact is that it was the fifth consecutive year that the growth in spending had outpaced the expansion of funds. The differences in prosperity levels from one region to another means that the system is unbalanced: for example the Guangdong province in 2017 had enough funds to cover five years unlike the Heilongjiang province, where the elderly grew and the workforce decreased due to emigration, which failed to cover an entire year.
But generally the whole Chinese population is rapidly aging: in 2011 for each pensioner there were 3.1 workers, while at the end of 2016 the ratio fell to 2.8, with forecasts of further reduction until reaching 1.3 in 2050.

2.3 https://www.scmp.com/news/china/policies-politics/article/2123703/chinas-rapidly-greying-population-leaves-provincial

2.4 Chinese urbanization and energy standards

The great internal migration and the population growth that has reached 1.4 billion people, has led to an imposing urban development, given the ever-growing housing need, considerably spreading the surface area of most Chinese cities.
The building sector in China, since President Deng Xiaoping[4] opened China to the world in 1978, it has grown, and is still growing, at an exponential rate, building about 1.8 billion m^2 per year; this means that only China is building more than a third of the total new buildings in the world. To give an idea, between 2009 and 2011, according to estimates by the National Bureau of Statistics of China, the country would have used 5.5 billion tons of cement, while the US throughout the twentieth century used 4.6 billion. Urban areas in China only, from '78 onwards, increased by 513%, taking the place of many rural areas (Chen M., 2016).
Due to the conformation of the Chinese territory, which for about 60% is composed of mountains and plateaus, in particular in the central and western areas, most of the urbanization has developed in the eastern and south-eastern areas, among which three main centers stand out: Shanghai, Beijing and Guangzhou-Shenzen.
It should be emphasized that most of the buildings constructed are part of residential housing addressed to the burgeoning middle class, thus having low construction costs and lowering construction qualities: the new buildings, not being designed with high energy efficiency criteria, increase the electricity demand and fossil fuels consumption for producing the energy needed. In this sense, it is easy to understand that the Chinese government, national and local, has given, and gives, more importance to the quantity of urbanization, rather than its quality.
This led to an excessive push of the construction market and real estate sector generating a large amount of housing, higher than the demand: for this reason, over the years, entire uninhabited neighbourhoods or, worse, the so-called "ghost town" have been formed, which remained empty also due to the rapid growth of prices that affected large urban areas.
This is connected to another critical factor, which concerns local authorities budget: during the government of former president Deng Xiaoping, the process of fiscal decentralization launched by the reforms, together with other reforms that favoured speculative dynamics in the sale of land use rights, as well as the rapid growth of the real estate market, has led local governments to use the urban development as a mean to generate wealth and increase tax revenues. In this way the local authorities became heavily indebted, offering the same unsold properties to the banks, which are under state control, as a "guarantee". For this reason, a deflation of the housing bubble has worried

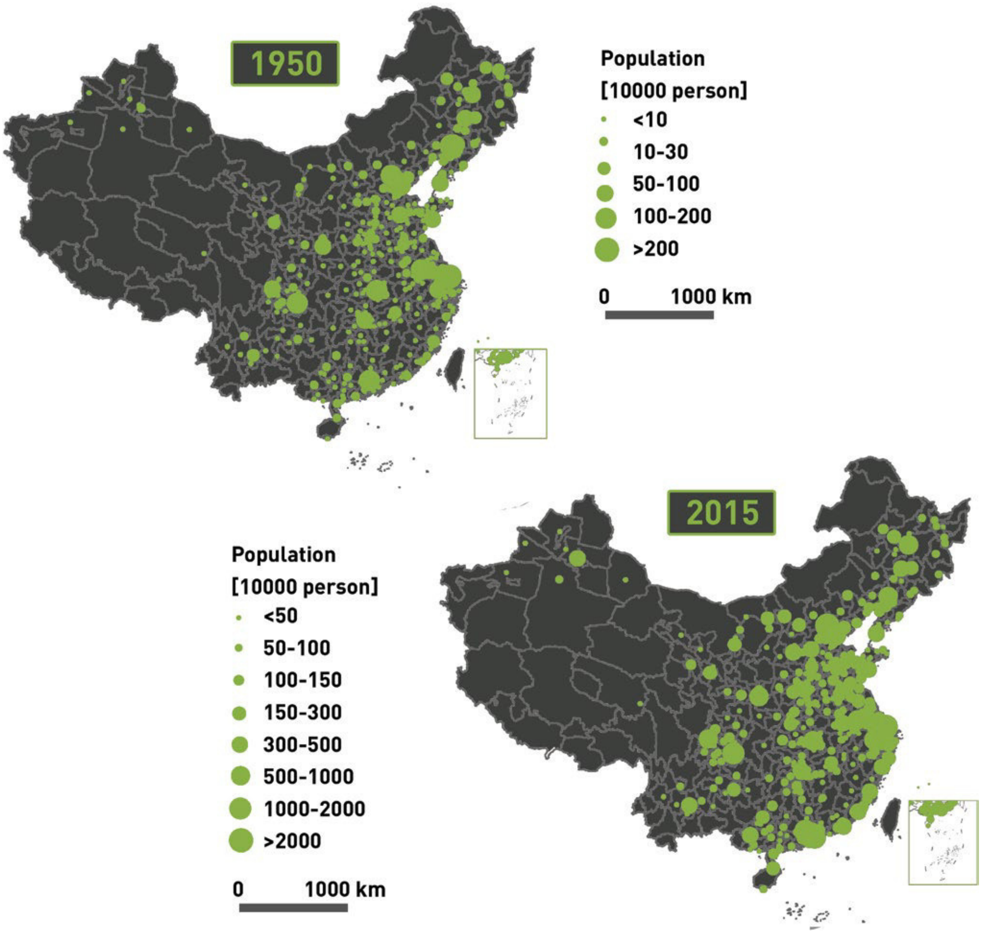
2.4 Deng Xiaoping is proclaimed the supreme leader of the Chinese Communist Party in 1976, introducing for the first time in Chinese history the concept of "open door policy", opening up the Chinese economy to trade and foreign companies, while giving much more freedom to the population, ending most of the Maoist policies.

the entire banking system and led the government in 2015 to put a cap on the debt of local authorities to build new homes.

▲ Fig. 2.7
View of a Chengzhongcun.

The great urbanization has also brought important social consequences, with the construction of neighbourhood composed by morphologically similar high buildings, leading to the decline of community and identity links that for centuries have been one of the founding pillars of Chinese culture. In fact the new areas built in many cases have become sort of "dormitories", with the inhabitants working all day and then returning in the evening, not actually creating social interaction.
Another discriminating social factor in the Chinese urban development, in addition to the hukou system described in section 2.3, was the creation of the *Chengzhongcun*, that in Chinese means "urban village": during the expansion of the cities, the governments expropriate the rural lands to build new buildings; when they cannot relocate the owners or pay them, instead of providing a new home, the rural settlement is left to avoid compensation cost, thus creating urban landscapes in which there are villages surrounded by buildings, totally disconnected from the urban fabric (Lang, W. et al., 2015).

Social problems are then compounded by the enormous environmental damage caused by the overbuilding and the destruction of entire landscapes that a wild urbanization brings with it. Increased population means increased consumption of resources, so greater demand for food and increasing water



◀ Fig. 2.8
Change of urban spatial patterns in China between 1950 and 2015.

withdrawals and increasing pollution, caused by vehicular growth and the loss of green areas (McGranahan G., 2014). Not to mention that much of the population growth has been concentrated in coastal areas vulnerable to the effects of climate change, such as the increase in the average sea level and the greater frequency and intensity of extreme weather and climate events. The urban expansion has also brought with it a heavy loss of arable land, which in the long run could represent a major problem for the livelihood of the Chinese population.

In 2014, as a consequence of the awareness of all these issues related to urbanization, the "National Plan for new urbanization (2014-2020)" was issued, drafted by the Central Committee of the Chinese Communist Party and the Council of State. It has attempted to respond to the problems that have arisen in the population regarding environmental, social and economic problems, trying to integrate as much as possible the mentioned sectors: it is the first macro-planning document of China dedicated to urban development. According to the plan, urban development had to be guided by technological and productive innovation, attention to the preservation of nature, energy efficiency and mobility, while at the same time taking better care of the interests of disadvantaged classes. Incentives have been allocated to move migration from the eastern coasts to small and medium-sized cities to internal areas, in order to balance the current disparities between different regions. Another important topic in the document is the reduction of the city-countryside gap, with particular reference to the hukou system, both in terms of greater social inclusion of newly urbanized populations, and in terms of investments necessary to integrate the urban and rural productive fabric.
In order to implement all these policies, the initiatives to be carried out should have as a first goal to decrease as much as possible the urban expansion by firmly placing at the center of every discussion the theme of the environment and its protection, as well as a responsible use of resources. In the same way it is necessary to increase the integration of economic migrants as well as to greatly weaken the social discriminations that the houkou system has exacerbated in recent decades, through investments in education and widening access to social services. Another necessary move is to reduce as much as possible the difference in importance between rural and urban areas, promoting projects that help to enhance rural areas and at the same time promote sustainable development in urban centers. Hand in hand with the latest one, it is necessary to strengthen and further improve the process of redistribution of economic migrants to the central areas of China, in order to reduce the social pressure that has been created in the eastern part of China, with a consequent worsening of conditions of life quality.
However, in practice, although more emphasis has been placed on environmental sustainability issues, the economic sphere prevails: the central point continues to be economic growth instead of limit the resource exploitation and increase environmental protection. The latter becomes really relevant when it can be exploited for economic purposes, therefore for example increasing the tourist flow.

During the initial analysis of the Chinese context, it was also examined in depth the legislative framework referred to the construction sector, in order to understand which regulatory system, whether European/Italian or Chinese, was more suitable for the design objectives. China, as mentioned, found itself, in the last decades, in a situation of increasing energy consumption in the building sector, mainly due to the change in the standard of living of the Chinese population as well as to the strong emigration to the cities and the consequent continuous need for new spaces for housing.

The China Ministry of Construction (MoC) has been formulating Energy Standards for building construction since the early 1980's, but the first mandatory national building energy code, was adopted in 1986 for new residential buildings located in cold and severe cold regions. After further revisions, a targeted energy saving rate of 50%, based on total space heating and space cooling consumption, took effect in July 1996 (Hogan et al., 2001).
In 2000-2001, an Energy Code was developed for residential buildings in the "Hot-Summer/Cold-Winter" Zone along the Yangtze River. The Compiling Team consisted of representatives from key cities within the region (Chongqing, Shanghai, Wuhan, Nanjing and Chengdu). International support was provided by the Energy Foundation, the Natural Resources Defense Council, and the Lawrence Berkeley Laboratory (Hogan, J. et al., 2001).
After these, China's building codes have significantly evolved during the past two decades, having set out mandatory and voluntary energy efficiency measures for both commercial and residential buildings, with some of these codes tailored to specific climate zones.
Nowadays, China's building energy codes and laws, defined by the Ministry of Housing and Urban-Rural Development of P. R. of China (MOUHRD), establish minimum standards for the energy efficiency of building components such as envelope, heating, ventilation, and air conditioning (HVAC), and the power system. These codes are mandatory for residential and commercial buildings in urban areas, while compliance with rural residential building codes is promoted through incentives. Recent research has found that these building codes could drive significant reductions in China's building energy use (between 13 and 22%) and CO_2 emissions (14-20%) from a business-as-usual scenario by the end of this century, depending on their stringency and coverage (Yu S., Eom J., Evans M., Clarke L., 2014).
In China, Energy Codes & Standards, regarding everything related to energy systems in buildings, are divided according to different characteristics:

- Region, that can be North - Central - South of China

- Building Classification, divided in:
    - Residential Building, like house, kindergarten, dormitory, apartment, etc.
    - Public Building, like office building, finance building, Hotel, etc.
    - Buildings for education, science, culture and public health services
    - Buildings for communication, post and broadcasting
    - Buildings for transportation, as airport, train station, etc.

Starting from this classification, the energy codes and standards for residential buildings are then based on the climate zone. For example, for 'Hot Summer, Cold Winter' zone, it's used the standard JGJ 134 - 2001, for 'Hot Summer & Warm Winter' zone the JGJ 75-2003, for 'Cold & Severe Cold' zone the JGJ 26-2010[5].

Fig. 2.9 ▶
China's climate classification.

The public buildings are indeed regulated by the GB standards, like the GB 50189-2005.
In this thesis, the project area, as will be detailed in Chapter 3, is located in the village of Hou Ji, near to the city of Ping Yao, laying in the 'Cold' climate zone.

Climate sub-zone		Division Criterion
Severe cold zone (Zone 1)	Severe cold (A) zone	6000 ≤ HDD18
	Severe cold (B) zone	5000 ≤ HDD18 < 6000
	Severe cold (C) zone	3800 ≤ HDD18 < 5000
Cold zone (Zone 2)	Cold (A) zone	2000 ≤ HDD18 < 3800, CDD26 ≤ 90
	Cold (B) zone	2000 ≤ HDD18 < 3800, CDD26 > 90

Tab 2.1.1 ▶
Climate division criterion according to JGJ 26-2010

According to the range of different heating degree day (HDD 18) and cooling degree day (CDD 26), the severe cold and cold zones can be divided into 5 climate sub-zones indicated in the table.
The HDD18 and CDD26 of the project area are respectively 3100 and 109; the calculation was possible thanks to the online software BizEE Degree Days[6].
Then PingYao is located in the "Cold B Zone", since the HDD are included between 2000 and 3800 and the CDD are higher than 90.

2.5 JGJ 18th March 2010, n. 26, Design Standard for Energy Efficiency of Residential Buildings in Severe Cold and Cold Zones.

2.6 http://www.degreedays.net

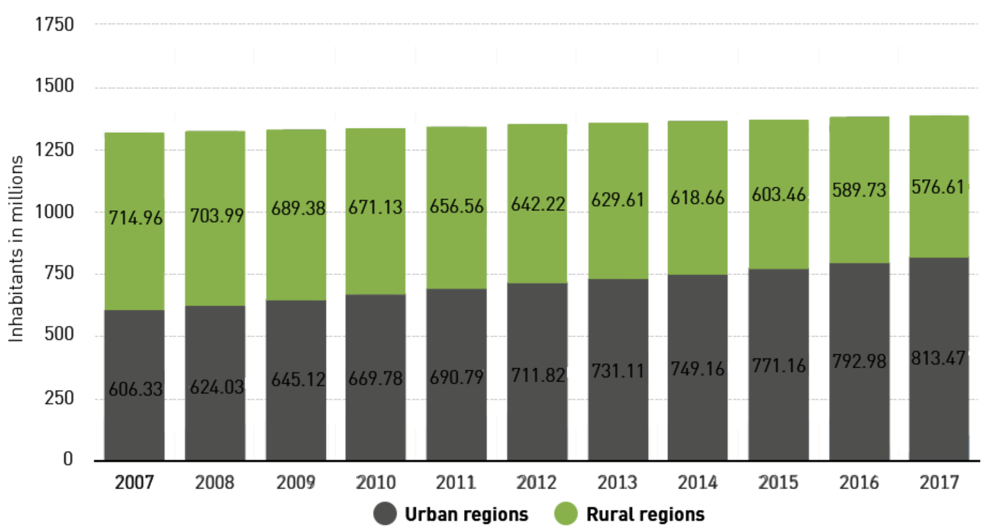
2.5 Condition of rural villages in China

In China nowadays, less than 600 millions of people live in rural areas. They are usually characterized as being ''confronted with economic poverty, with heavy reliance on biomass, leading to damage to ecological environment, etc.'' (Zhang et al., 2009).

Since China began to have a rapid economic growth combined with a strong increase in population and emigration, the landscape of urban settlements has not changed drastically; those who have paid the most have been the rural villages, which in addition to being in some cases incorporated by the expansion of the cities, in others have seen their population shrink very much, with consequent lack of maintenance of historic and non-historical buildings, which slowly risk to be lost.

According to some estimates of about ten years ago, the number of rural villages on the mainland decreased from 3.6 million at the beginning of the years 2000 to 2.7 million in 2010; nowadays there are no reliable data, but the forecast tells that the number have declined again.

The fast urbanization that happened after the Chinese opening to world, has changed the relationships between cities and villages: while once the countryside was the livelihood mean of cities, producing food and providing resources to the latter, which were seen as places mainly of commerce, since the election of Deng Xiaoping onwards this vision has been reversed; the cities have assumed a prevalent role, becoming the place where it was necessary to move because it could offer higher incomes and wealth. So, what were once traditional villages, a material representation of Chinese history and culture, slowly began to lose importance, in many cases leading them to be completely dispossessed and destroyed to make room for the cities expansion. A process of replacing historic buildings has therefore occurred throughout China, inside the villages not incorporated by the cities: the construction of buildings in concrete blocks and tiles to replace the vernacular dwellings that characterized each area of China in different ways depending on the climate or local traditions began to become normal. Suffice it to say that in the years



◀ Fig. 2.10
Urban and rural population of China from 2007 to 2017.
Source: National Bureau of Statistics of China, 2017

Fig. 2.11 ▶
Example of more recent buildings built in concrete blocks in the Hou Ji village.
Photo by Ingrid T. Ødegård

following 1978, houses built in rural areas were up to five times larger than those built in the city, as those who went to work in the cities sent money to relatives who remained in rural areas.
This sudden renewal process was seen by villagers, even though they lived in poverty, as a way to improve their social status by imitating in small ways what was happening in large urban centers. Most of the villagers in fact believed that a concrete house was synonymous with well-being and modernity, even if in practice the effect was inverse, leading to a rampant loss of historical memory in favour of homologated buildings without an identity; not to mention that the building quality, being the buildings the same everywhere, was of very poor quality: the new houses did not take into account the climatic and morphological conditions of the different Chinese regions, resulting in fact being worse than traditional houses.
The loss of identity of the villages has completely disconnected the cultures, as well as the inhabitants, from millennia of previous history in favour of a forced modernization, not taking advantage of an excellent opportunity to set in motion processes of hybrid integration between local history/culture, modernity and also agriculture. The latter was a fundamental part in the history of the villages, shaping rural life but also traditional architecture, whose interior spaces have adapted to the functions that agricultural work entails. Today, however, contemporary agriculture is designed to exploit the environment as much as possible and make the highest possible profit, heavily polluting and artificialising the natural environment, in complete contradiction with what happened in the past.

At the same time those who moved from the villages but left no relatives in their homes, ended up leaving their houses uninhabited for long periods or permanently: according to the Rural Development Institute of the Chinese Academy of Social Sciences, due to this phenomenon today 25 millions of rural houses, which make up 10.7% of all Chinese housing stock, are abandoned. Added to this are the bad initiatives of local governments that have banned the private sale of homes in rural areas while they have encouraged the purchase of those in urban areas, to reduce ghost towns and populate entire city neighbourhoods that were still uninhabited.

◀ Fig. 2.12
Example of fast modernization occurring near the Hou Ji village during the construction of a section of the high-speed train rail station. Photo by Ingrid T. Ødegård

Lastly the increase in tourists, willing to visit the places of historical China, has transformed many villages and the rural landscape even more. In fact local governments, to increase economic revenues, have used monuments, villages, natural places, etc. while implementing new infrastructures such as accommodation facilities, road, rail, etc. to get as many people as possible. An indicative example is what happened after the discovery of the *terracotta army*[7] (now part of UNESCO World Heritage), located in the Lintong County, Shaanxi region in central China. After the discovery by a local farmer and after the government understood the immense historical value of the place, over the years what was once a rural area characterized by a classic agricultural landscape has been completely transformed: over the years a disproportionate building development has arisen around the site, which has seen the expansion of the village, the creation of many accommodation facilities, infrastructures and sales points.

On the other hand, in the last decade the interest in the conservation of villages by government and population has greatly increased in China. Among the most interesting initiatives, in 2012 646 ancient villages have been designated as having special cultural significance, a first step towards slowing the pace of their destruction in the drive towards development.

The villages were selected by an expert panel from nearly 12000, nominated by the central and regional governments, and were mostly located in remote and less developed regions. The panel of experts that selected the villages was commissioned by agencies including the Housing Ministry and State Administration of Cultural Heritage.

Although the designation would not in itself provide additional protection, it gave the villages priority access to funding. Conservationists said that was a milestone in the effort to stop the villages' destruction, which has been wiping out irreplaceable links to China's past.

2.7 The terracotta army is a collection of statues that represent a symbolic army destined to serve the first Chinese emperor Qin Shi Huang (260 BC - 210 BC) in the afterlife. Since1987 the area in which is located is included in the list of UNESCO World Heritage Sites.

2.6 Towards sustainable constructions: nZEB buildings in China

China, like many nations today, until a few years ago did not have mandatory legislation regulating new buildings in terms of energy efficiency. In fact, the first nZEB buildings in China are starting to be seen since 2011, with the first initiatives in this regard.

Despite China's building energy conservation work started in the late 1980s, in the following decades the weight on total energy consumption by buildings rose from 10% in 1978 to the current 30%, with signs of continuous increase. Therefore in the new Chinese policies the building sector will be one of the fundamental components of the analysis aimed at energy efficiency and consumption reduction.

The Chinese authorities firstly introduced new construction standards at national level, and the nZEB building type with the 12th Five-Year Plans (2011-2015) which represents a series of economic and social development initiatives issued by the Chinese government every five years since 1953, where they have required 5 provinces and 8 cities to include green building standards in their regional five-year plans. To facilitate the achievement of these standards, the authorities subsidized and provided tax breaks to developers.

Together with the above-mentioned provinces and cities also other cities took tha Plan as a reference for new energy-efficiency standards, for developing new plans for green buildings, eco-cities and sustainable construction, in accordance with the framework adopted at a central level.

The 12th Plan aimed to build nearly 20% of the total floor space constructed during that period, but they succeeded in part, having high growth mainly in public buildings, and in the eastern coastal cities.

Consequently to the13th Five Year Plan (2016-2020), on 6 January 2017, the China State Council issued the "*13th Five Year Comprehensive Work Plan for Energy Conservation and Emission Reduction*" (the "Work Plan") which while setting forth implementation guidelines for energy conservation and

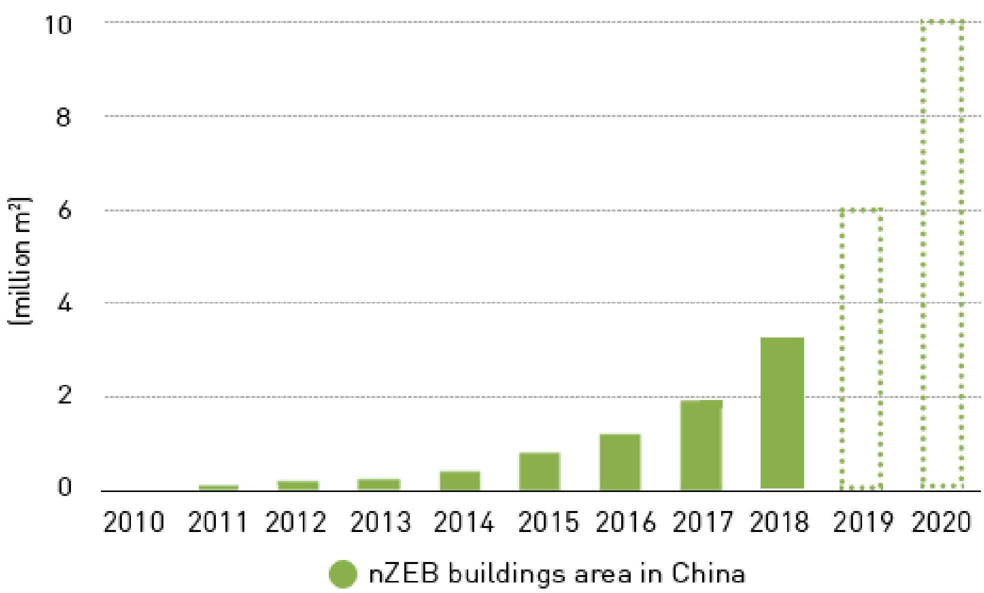


Fig. 2.13 ▶
Total nZEB building area in China until 2018 and forecasts for 2019 and 2020

emissions reductions, listed 11 detailed measures to push forward China's energy-saving and emission-reduction work, among which strengthen building energy conservation was highly noted (APEC, 2018). Thanks to this Work Plan many ultra-low energy consumption and nZEB pilot buildings were started to develop.
After the before mentioned "The Work Plan", the Ministry of Housing and Urban-Rural Development of P. R. of China (MOUHRD) issued *The 13th FYP Building Energy Conservation and Green Building Development Subject Plan* (The "Plan") on March 31th, 2017, aimed at promoting ultra-low-energy building and nearly zero-energy building. According to the forecasts, by 2020 over 10 million m^2 of ultra-low-energy buildings and nearly zero-energy buildings will be constructed in China[8]. The Work Plan wanted also to promote supply-side structural reform in urban and rural areas, establishing reference parameters for nZEBs based on the different climatic zones, realizing pilot buildings for the new building type.
Lastly, the MOHURD on 3rd May 2017) issued *The outline of the 13th FYP for housing and urban-rural development* (the "Outline"), aimed to speed the construction of the new building typologies, in order to give full space to the leading role in building parameters for improving energy efficiency, and in the meantime contribute to promoting the development of communities with very low consumption (APEC, 2018).
At the same time in China there is now a non-profit organization called China Passive Building Alliance (CPBA) which aims to carry out initiatives to improve the energy performance of buildings. As the close partner and biggest support of MOHURD, CPBA proposed its *30-30-30 Goal* to respond to the 13th FYP nZEB development goal; it proposed that by the year 2030, 30% of the new building will be nZEB, and 30% of the existing building will be renovated to achieve nZEB (APEC, 2018).
With the Five Year Plan (FYP), China has effectively shaken up the low energy consumption building market, setting clear objectives to be achieved; for example Beijing during the FYP launched *Civil Building Energy Efficiency Plan* which foresees, in the five years of the FYP, to build at least 300000 m^2 of ultra-low-energy demonstration buildings, of which 200,000 are supported by government investment, promoting the large-scale development of similar projects also in cities adjacent to the capital. Among other projects, the Shandong region has created a *Special Fund for Building Energy Efficiency and Green Buildings* which provides incentives for those who build low energy buildings, but with a minimum limit of floor area: 3000 m^2 for residential and 5000 m^2 for public buildings.

Currently in China the MOHURD regulates the entire construction sector, and to make this possible it relies on a network of *Construction Commissions* in the main cities and provinces to supervise the construction sites and the buildings built; these commissions are also responsible for granting building permits as well as verifying the application of the codes that govern the

2.8 MOHURD, The 13th FYP Building Energy Conservation and Green Building Development Subject Plan [EB/OL], http://www.mohurd.gov.cn/wjfb/201703/t20170314_230978.html

construction sector in China. Lastly they provide an important support to the MOHURD thanks to a parallel network of building research institutes.
Regarding the energy parameters to be respected, they are managed by the *Department of Standards and Norms* which is part of the MOHURD; however, the concrete development of the standards is in turn entrusted to the *Department of Science and Technology* which collaborates with university and industry research institutes.
But in the end, however, local governments can decide which energy standards to follow, whether national ones, or use the stringent ones for having buildings with high energy efficiency, but which involves a greater expense.

Regarding the actual parameters to be followed in the design of high energy efficiency buildings in November 2015 the MOHURD issued the *Passive Ultra-low Energy Green Building Technical Guidance* which is referred to residential buildings; it is considered as China's first Ultra-low energy building technical guidance (APEC, 2018).
The main parameters to be respected according to the guidance to realize a nZEB (listed below), must be combined with high-performance insulation, good air tightness, a high-performance air heat recovery system, use renewable sources as much as possible, creating comfortable indoor environments based on the climate in which the building is located.[9]
WDH = Wet bulb degree hours DDH = Dry bulb degree hours

Annual heating and cooling demand kWh/m^{2}year	**Climate zones**	Severe cold	Cold	Hot summer and cold winter	Hot summer and warm winter	Temperature
	Heating demand	≤ 18	≤ 15	≤ 5		
	Cooling demand	≤3.5+2.0×WDH20 +2.2×DDH28				
Primary energy consumption for heating, cooling and lighting	≤ 60 kWh/m^{2}year or 7.4 kgce/ m^{2}year					
Air tightness	N_{50} ≤ 0.6					

Tab 2.1.2 ▶
Parameters to respected to build a residential nZEB in China according to the "Passive Ultra-low energy green building technical guidance"

The first official NZEB standard for China will be published in 2019 and will have as its goal, becoming mandatory from 2035, to cover all the climate zones, to cover both residential and public buildings and to have 70% more energy efficiency than the standards existing.

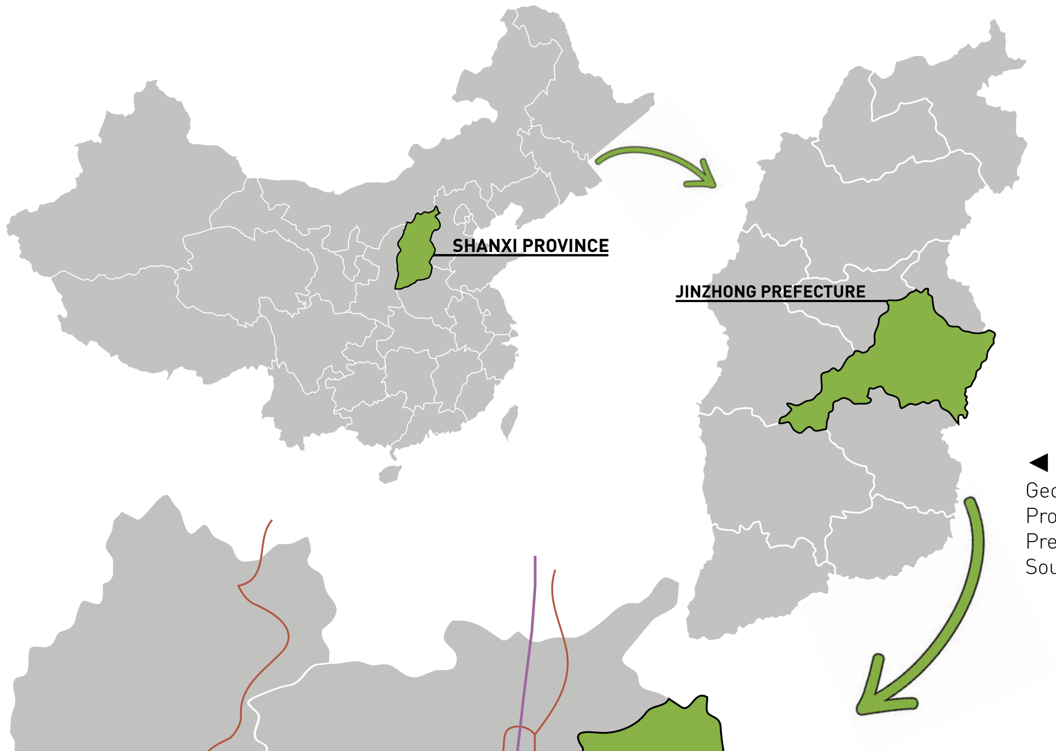
2.9 MOHURD. Passive ultra-low energy consumption Green building technical guidance [EB/OL]. [2018-06-01], http://www.mohurd.gov.cn/wjfb/201511/t20151113_225589.html

Chapter 3

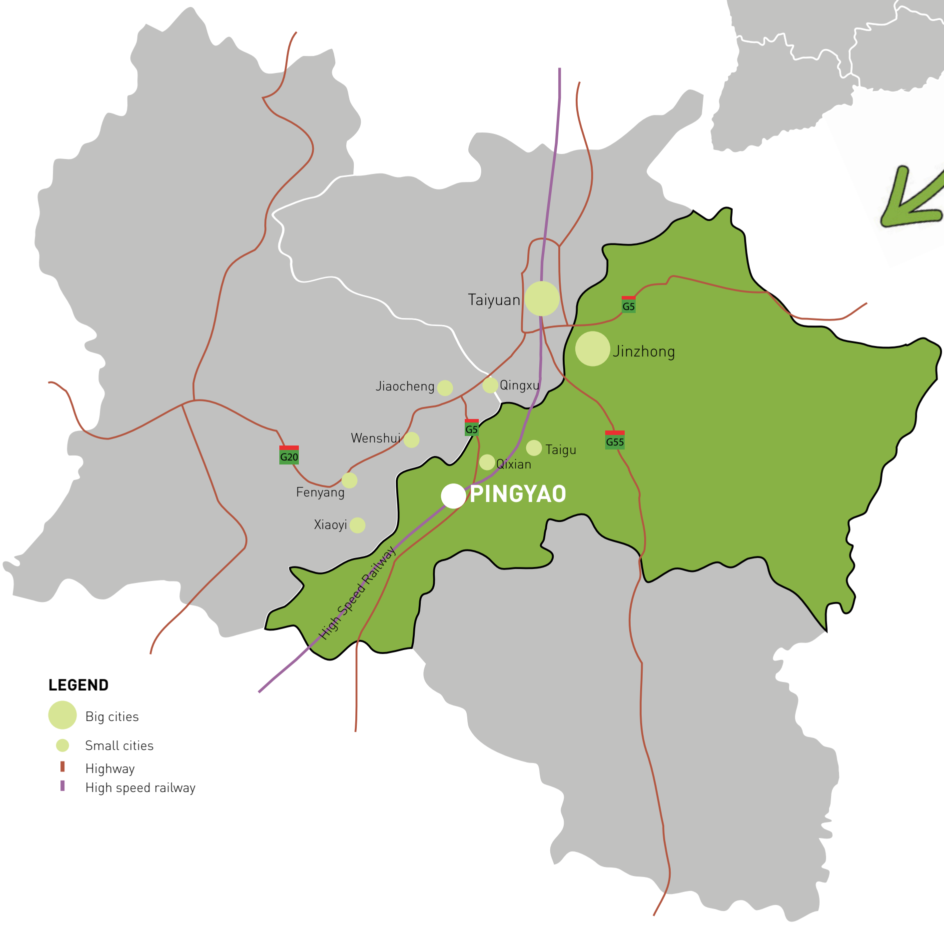
Pingyao and Hou Ji Village

In this chapter, it is defined the general context in which the project site, object of analysis of the thesis, is located. First of all, it was defined the regional context, before analysing the characteristics and strengths of the area in which the village of Hou Ji, i.e. the village of the project site, is located. To do this, every aspect of the city of Pingyao was studied, from its history to its most important monuments and buildings, being the main attraction point closest to the project site. Secondly, it has been thoroughly analysed the situation of the Houji Village, in order to define in detail the historical and social background in which the project will be inserted.

3.1 Pingyao territorial classification



◀ Fig. 3.1 and 3.2
Geographical location of Shanxi Province in China (3.1) and Jinzhong Prefecture in Shanxi Province (3.2).
Source: Author's elaboration



◀ Fig. 3.3
Schematic enlargement of the area of Pingyao, within the highlighted Jinzhong Prefecture.
Source: Author's elaboration

Pingyao, or Ping Yao, formerly known as *Gutao*, is a county located in the central part of Shanxi province, central-east of the People's Republic of China. The Shanxi province has a population of about 37,000,000 inhabitants (2016), spread over an area of about 157,000 km², a territory equal to half of the Italian area, and with an almost equivalent population density index.
The Great Wall forms most of the northern border between Shanxi and Inner Mongolia, while the Yellow River (Huang He) forms the western border with the almost namesake province of Shaanxi.
The Shanxi, has a rather homogeneous territory composed of a high plateau

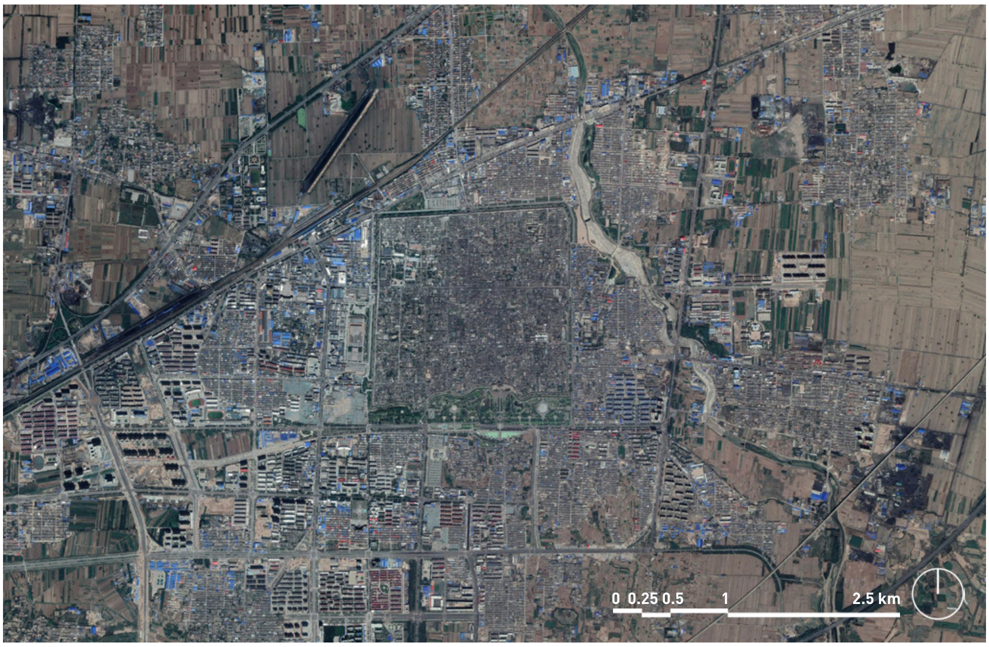
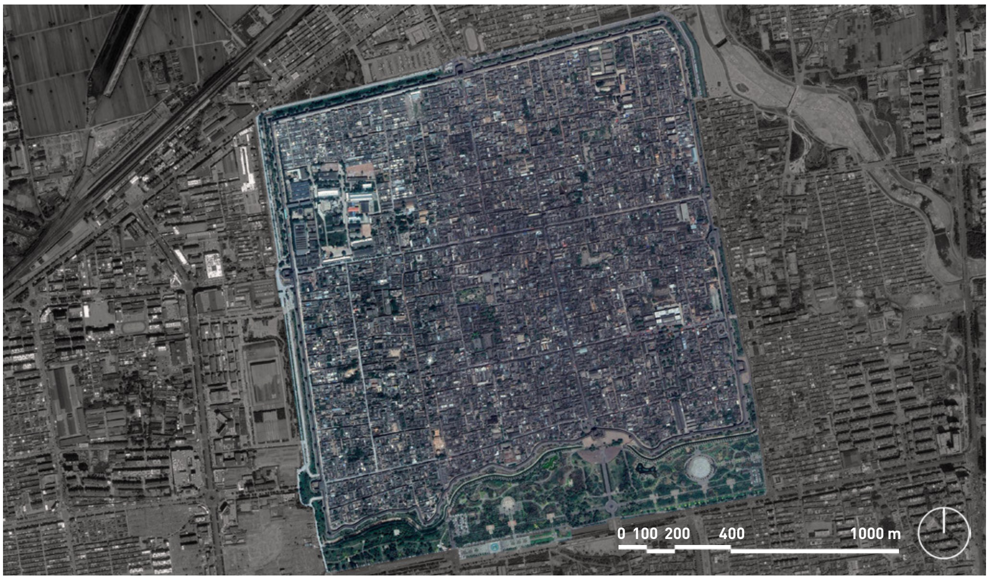


Fig. 3.4 ▶
Pingyao city.
Source: Google Earth Pro + Author's elaboration

between high mountains both in the east (Taihang Mountains) and in the west (Monti Lüliang). This area of China is rather arid and has a continental monsoon climate: average January temperatures are below 0° and summer temperatures are very high, while the average annual rainfall is around 350-700 mm, and 60% of it is concentrated between June and August; but this argument will be well deepen further in the thesis.
Pingyao lies within the Jinzhong prefecture (as can be seen in the images in the left page), which is a prefecture-level city with more than 3 millions inhabitants (2010 census) bordering Hebei province to the east.
At the county level, Pingyao county covers a surface of 1260 square kilometers, having jurisdiction over 5 cities, 9 municipalities, 3 sub-district offices and 273 administrative villages with a total population of 530,000 unit (http://www.pingyao.gov.cn).
The city is bounded by Jiexiu county to south-west, Qi county to north-east, Fenyang and Wenshui Counties to north and north-west (these last two are part of Lüliang prefecture) and Qinyuan, Qin, Wuxiang Counties to south and south-west (these last three are part of Changzhi prefecture).
The city of Pingyao is about 600 kilometers far from Beijing, about 500 kilometers far from the ancient capital of the empire, Xi'an, and 90 from Taiyuan (Capital of Shanxi Province) and Jinzhong, which are the closest big cities, with over 3 million inhabitants each.
Pingyao is located halfway along the Fen River, on the east bank, which runs through the south of the Shanxi Province, on the Shanxi plateau at a height ranging from 750 to 775 meters above sea level, with a slope from south-east to north-west approximate of five units per thousand.
The loyic[1] soil of the Municipality of Pingyao is characterized by deep faults in the ground caused by its alluvial origin of which it is composed. These faults

3.1 The adjective loyic is derived from the word *löss*, more frequently transcribed as *loess* (the word is of German origin) which is a type of very fine wind sediment, like the silt. The löss is an aeolian sediment, that is, it originates from the transport and deposition of particles by the wind.



◀ Fig. 3.5
Ancient City of Pingyao.
Source: Google Earth Pro + Author's re-elaboration

are particularly noticeable in the south-eastern part of the county, where cracks and landslides reach even ten meters in altitude.
In 1990, Pingyao county was divided into two parts, ancient city and new city: the first develops within the high walls of the Ming era built around 1370 AD and focuses on heritage protection; the second is the portion of the city more recently developed outside the walls, which focuses on modern development. As the portion of the city inside the walls, the last datum dates back to 2005, when it had a population of 42,000 units.
The ancient city, enclosed by walls, occupies an area of 2.25 km², with the walls that have an extension of about 6.2 kilometers, with about seventy towers and four turrets, all surrounded by a moat four meters deep and four meters wide.
The urban plan indeed follows what was the standard for old Chinese towns: square shape, orientation along the north-south axis and six gates as entrances, one each in north and south and two each in the east and east walls with a rigid grid of streets inside.
Thus, the streets cross each other horizontally and vertically, while a main street divides the town from north to south into two parts, with the city tower located in the center.
Major constructions are distributed orderly in the left and right parts of the city with the town god's temple in the left city corresponding to the county governmental office in the right, the Confucian temple in the left corresponding to the Guandi Temple worshipping Guan Yu, deified god of war, in the right, and the Qingxu Temple of Taoism in the left corresponding to Buddhist temples in the right[2].

3.2 A.A., Xinhua News Agency, 11/06/2004, https://www.china.org.cn

3.2 The history of Pingyao

Pingyao's history could be traced back to 2700 years ago, according to the historical testimonies that have come down to us; even if first settlements in this area could be older, since traces of settlement from Neolithic times have been found in the region, although unfortunately not in city's area.
Pingyao was founded during the reign of Emperor Zhou Xuanwang (827-782 BC), emperor of the Western Zhou Dynasty[3], for the garrison of one of his generals, named Yin Ji-fu, that was sent there to guard the frontier of Western Zhou's territory; evidences prove that in this period the city was fortified for the first time by earthen ramparts with the aim of defending the outpost.
Afterwards, under the Eastern Zhou Dynasty[4] (722-221 BC), which followed the previous one and is conventionally divided in two periods (Spring and Autumn period and Warring States period), Pingyao belonged to two different States: during the Spring and Autumn period[5] (722-476 BC), period in which the empire was divided in seven states, Jin, Zhao, Wei, Yan Qin, Qi, Chu, the city belonged to the State of Jin, which was one of the most powerful at that time; during the Warring States period[6] (476-221 BC), it was part of the kingdom of Zhao.
Around 221 BC Pingyao, known at that time with the name of *Pingtao*, at the beginning of the Qin Dynasty (221-206 BC), winner-State at the end of the Warring States period, started to be more important in the region, when was implemented the system of prefecture and counties, system that has endured till nowadays: in fact the city became the seat of county administration, role it still covers today.
Afterwards during the Han Dynasty (206 BC - 220 AD) it had the name of *Zhongdu* instead.
Unfortunately no sure infos came to nowadays about the urban layout, the architectural development of the city, etc. therefore no further analysis were made possible about all the periods previous mentioned.

The city started to have a bigger importance during the reign of Hong Wu, emperor of the Ming Dynasty, who in 1370 AD gave order to extend and fortify city's borders: Pingyao was fortified with massive defensive walls in masonry and bricks and changed the urban layout, moving from a chaotic texture to a well organized urban plan, which followed the strict rules of planning of Han

3.3 Western Zhou Dynasty ruled central-eastern China, from XI century until 770 BC and had as capital Haojing, near the city of Xi'an, Shaanxi Province, about 500 km south-west Pingyao.

3.4 Eastern Zhou Dynasty ruled a bigger part of central-eastern and north of China; it is so named due to the displacement of the capital to east, moving from Haojing to Luoyi, known today as Luoyang, Henan Province.

3.5 The Spring and Autumn period (722 BC-476 BC) takes its name from the chronicles of that time, the Annals of springs and autumns, traditionally attributed to Confucius, which narrate the events of the State of Lu from 770 BC to 481 BC.

3.6 The Warring States period (476 BC-221 BC) saw numerous states, Han, Wei, Zhao, Qi, Qin, Yan and Chu, fighting each other for the supremacy of China, till the final victory of Qin state.

◀ Fig. 3.6
Pingyao Ancient City after 1370, historic painting (Undated)

people[7]; in this way the city took the usual Chinese grid layout: the city has two main axis-roads, North-South and East-West, from which develops the rest of the town, following, in most cases, a perpendicular grid scheme.
From the XV century the city of Pingyao, as well as its region of origin, Shanxi, experienced a period of flourishing economic development; this is mainly due to the geographical position, as well as the presence of the Jin merchants[8] , who, born in this area of China, will become the most powerful and important merchants of the empire for several centuries.
On a geographical level, the Shanxi was in a very favourable position: to the north, bordered the northern section of the Great Wall, while the territories surrounding Shanxi in the other directions , were all controlled by the chinese empire; this made Shanxi and its main cities of that time, like Pingyao, into the communication center for commercial trading, both inside and outside the empire.
The region was in fact a transit point for the trade routes that connected the most important cities of the empire, such as Beijing, Xi'an or Luoyang. Among other things, Xi'an, located about 500 km from Pingyao, became the starting point of the Silk Road, establishing a point of contact for trade with Europe and the territories west of the Chinese empire.
To this is added another important factor, namely that starting from the Yuan Dynasty (1271-1368 AD), the transport channels were developed and refined by the Shanxi merchants.
Pingyao then, thanks to these determining factors, became a city of great importance for the Chinese empire, being positioned in the fulcrum of what were the trade routes; just think of a datum: at the beginning of '800, there

3.7 The Han Chinese, Han people or simply Han, are an East Asiatic ethnic group, which constitutes most of China's population.

3.8 Jin merchants, also known as Shanxi merchants, referring to the region from where they came, were the most powerful and prominent merchant guild during the Ming and Qing dynasties.

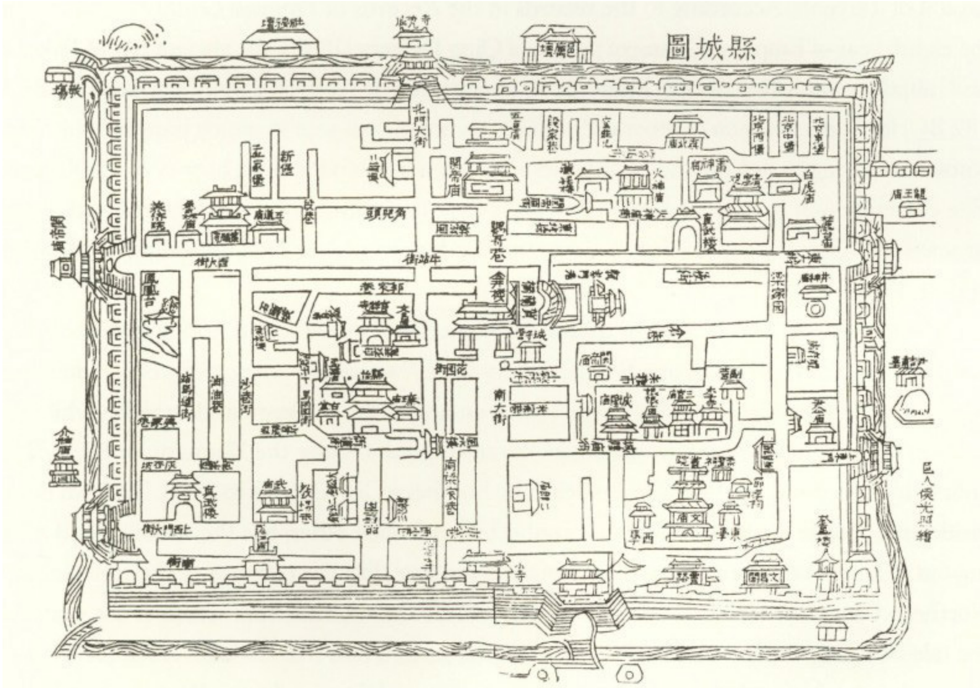
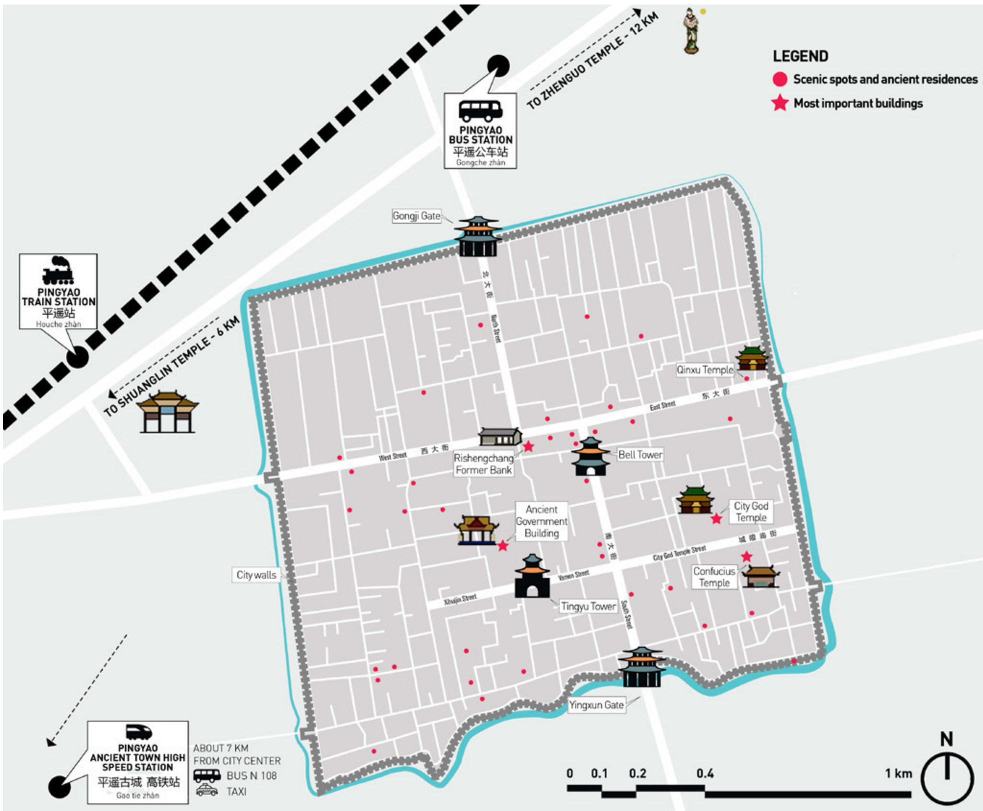


Fig. 3.7 ▶
Sketch map of Pingyao made during the 8th year of Emperor Guangxu of the Qing Dinasty, i.e. 1883.
Taken from architecturalpapers.ch

were more than 700 companies based in the city of Pingyao.
Pingyao reached its golden age during the second half of 19th century when it became a financial center of China and home to many commercially influencing Jin Merchants during Qing Dynasty (1644-1911 AD). Thanks to this, to the flourishing commercial activity of the city, and to the high quantity of money that circulated through the city, in 1823 the first bank of China was founded on Pingyao's West Street, the so called Ri Sheng Chang.
From then it could be said that it was *The Wall Street* in China at that time; in fact the city housed at least 20 financial institutions, more than half of the entire country.
In this period the Ancient City of Pingyao lived its period of maximum splendor: the city and its inhabitants became rich, public buildings, temples and houses were restored, the city expanded.
This continued until the beginning of the twentieth century: from this moment the city experienced a slow and inexorable decline, due to the closure or displacement of its banks, the loss of its centrality in the trade as well as the Japanese invasion during the Second World War.
In this sense, on February 13, 1938, the Japanese army invaded Pingyao, remaining under control until July 13, 1948, when Pingyao was liberated.
Since then the city has not undergone significant changes and became a "normal provincial city", unknown to most and with little relevance at national level. This lasted until the 80s, when the enormous historical importance of the city for China was rediscovered and it was decided to invest extensively on its conservation and promotion of tourism. This led to the UNESCO's recognition in 1997 of the World Heritage Site, thanks to which the city has now become a tourist destination of great importance at national level.

3.3 A living witness of China's history

As it has been said in the previous section, Pingyao represents an extremely important historical resource for China: being one of the four fully protected ancient Chinese cities (the other three are the Ancient Town of Langzhong, the Ancient City of Huizou and the Ancient City of Lijiang), the Ancient City is seen as the *treasure room* of ancient Chinese architecture.
In fact the so called "Ancient City of Pingyao" basically didn't change during the last six hundreds years, bringing till today an amazing painting of China's life, traditions and architecture development throughout all this time.
But Pingyao is almost an exception in this sense, many other cities in recent decades in fact, instead of preserving what history had given them, have carried out processes of demolition and reconstruction; a reconstruction that unfortunately meant to replace with false copies transformed into places of tourist attraction. But this is not only connected to an economic discourse, tearing down old buildings in fact has a long memory in Chinese history. As said by Ruan Yisan, professor of urban planning at Shanghai's Tongji University and a consultant on the preservation of Pingyao: "China is different from Europe in terms of the way it looks at old buildings; throughout history, whenever a new dynasty replaced an old one, everything built by the former dynasty would be destroyed and replaced by new buildings."
Fortunately, this way of seeing in recent years is changing, and the administrations of individual cities, as well as the Chinese government itself, have realized that not only the individual buildings, but the entire urban fabric, can have an important historical value and deserves a investment aimed at



◀ Fig. 3.8
Ancient City of Pingyao main tourist spots.
Source: www.architectureontheroad.com and Author's re-elaboration

its conservation.
Pingyao precisely is a prime example, having succeeded in these years to renew itself as a city while maintaining its history: as said by Wei Mingxi, city's Communist party secretary, "To renew and beautify is Pingyao's motto, but that doesn't mean tearing down old things and building up new things, it means preserving the ancient city with a new creativity."
The numbers in terms of tourism achieved by the city in recent years, have given reason to the strategies adopted over time, currently reaching an annual amount of tourists of about 1.5 million, of which the majority of Chinese origin. However, for the most part it is a one-day-only tourism, meaning that the tourists who come to the city visit it for a few hours and then leave before dusk.
Talking about the architectural heritage the city is mainly famous for its historical courtyard, the so called *siheyuan*, of which, worthy of conservation, it counts a number close to 400 units; among these some can be visited, others are home to hotels and bed and breakfasts, others are private homes. In the image on the left page, it can be seen the most important monuments and buildings in the city, among which it's necessary to mention a few in particular:
• the *Ancient city walls*, which, built in the fourteenth century and about six kilometers long, circumscribe the whole city and are perhaps its most characteristic element;
• the *Town Hall* or *Bell Tower* (*Shi Lou* in Chinese), situated in the middle of the South Street, that, despite its modest height of 18.5 meters, is the tallest building in Pingyao;
• the *Rishengchang former bank*, the first bank founded in Chinese history.
Together with the previous ones it's important to mention also the *Ancient Government building*, the *Tingyu Tower* and three temples, the *City God Temple*, the *Confucius Temple* and the *Qinxu Temple*, along with the main streets, rich in colours and expression of Chinese traditions.
Outside the Ancient City, two very important places are *Zhenguo Temple* and *Shuanglin Temple*, both historical Buddhist temples and both listed in the UNESCO World Heritage List.

Fig. 3.9 ▶
South Street view
Taken from architectureontheroad.com

▲ Fig. 3.10 Ancient City of Pingyao aerial view, seen from the South entrance.

Ancient City of Pingyao aerial view. The bigger road is the South Road, and in the background can be seen the Bell Tower.   Fig. 3.11 ▲

◀ Fig. 3.12
Goshi Tower Pingyao.
Taken from audleytravel.com

◀ Fig. 3.13
Ancient Government building.
Taken from alamy.com

◀ Fig. 3.14
Tingyu Tower.
Taken from wikimedia.org

Fig. 3.15 ▶
Confucius Temple.
Taken from repubblica.it

Fig. 3.16 ▶
City God Temple.
Taken from alamy.com

Fig. 3.17 ▶
Qingxu Temple.
Taken from alamy.com

Being the oldest and largest existing in the nation, the city walls are one of the 6 key national protected relics in Pingyao.
The walls that it can be seen today were built during the reign of Hong Wu, emperor of the Ming Dynasty, who in 1370 AD gave order to extend and fortify city's borders with massive defensive walls, replacing the older ones that were made in adobe.
The city walls are about 6 kilometers long, having quite big dimensions: they are 12 meters high, with a base width that varies from 9 to 12 meters and 3 to 6 meter at the top, allowing, for old time standards, two horse carriages to go side by side.
The total envelope is also composed by 72 smaller watchtowers and more than 3,000 battlements; these precise numbers are supposed to be a reference to the number of Confucius's disciples and students[9].
As entrances, the walls have 6 barbican[10] gates, one each at north and south and two each at east and west, appearing similarly like a shape of a turtle; this is not a case, the turtle in fact for the ancient Chinese is a symbol of longevity. Turrets and moat, the second one measuring 4 meter wide by 4 meter deep, were built sequentially after the gate towers, that were built during the Ming Dynasty.
Originally the walls had also four corner watchtowers, but just one is still standing today, the Great Scholar Tower, while the other three towers fell long time ago[11].

◀ Fig. 3.18
Pingyao city walls on North side.
Taken from ancientchina.org.uk

◀ Fig. 3.19
Great Scholar Tower.
Taken from architectureontheroad.com

◀ Fig. 3.20
Pingyao walls seen from the inside.
Taken from ancientchina.org.uk

3.9 It was traditionally believed that Confucius had three thousand students, but that only 72 mastered what he taught.

3.10 A barbican is a fortified outpost or gateway, such as an outer defence to a city or castle, or any tower situated over a gate or bridge which was used for defensive purposes. In this case, gates in Chinese city walls were often defended by an additional archery tower in front of the main gatehouse, with the two towers connected by walls extending out from the main fortification.

3.11 A.A., "Pingyao Ancient town, the best preserved old chinese city", 12/08/2018, www.architectureontheroad.com

Located in the city center over a surface of 1,300 square meters, the most important architectural work, besides the city walls, is the Ri Sheng Chang Exchange Shop, known also as the first bank in China's history and, for this reason, as the *Father of Chinese Banking*, since it developed a completely new type of trading system.

Established in 1823, differently from what happened before, in this bank was possible to use for business transactions bills instead of gold or silver.

The idea came when the manager of the local dye works, who had a branch in distant Beijing, had difficulty in transferring money between the two; moreover during the Qing Dynasty (1644-1911 AD) China's currency was silver coin, and that represented a big problem for security when he needed to send large sums trough the country.

So he had the idea of replacing the physical transport with a letter of transfer; from that moment the idea developed so much that it had branches in all the major cities of the country, becoming what would have been the first ever bank system in the country. Thus, mainly in the beginning, the system relied on trust: Ri Sheng Chang bank drafts would only be fulfilled if handwritten by the manager of the Pingyao head office, who, as every Ri Sheng Chang manager in the country, needed to be able to spot a forgery.

Thanks to this, as said, it wasn't necessary to transport big amounts of money, since cash deposited at one branch could become payable by means of a bill at another, bringing a great relief to businesses and at the same time contributing to the prosperity of the city.

Ri Sheng Chang, had an enormous influence upon the development of banking in China, until, after 108 years in activity, with the rise of modern banking system, it closes due to bankruptcy.

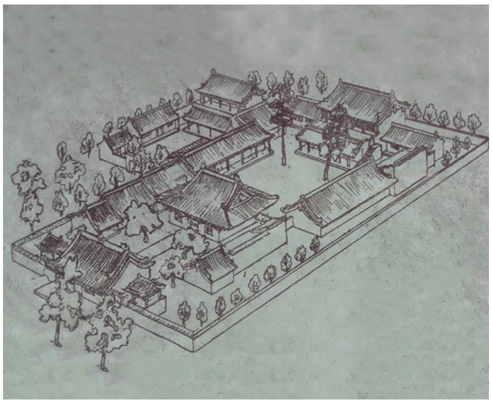
Fig. 3.21 ▶
Ri Sheng Chang inner entrance.
Taken from architectureontheroad.com

Fig. 3.22 ▶
Ri Sheng Chang entrance.
Taken from wikipedia.org

Fig. 3.23 ▶
Ri Sheng Chang internal deposit
Taken from ancientchina.org.uk

Fig. 3.24 ▶
Ri Sheng Chang internal deposit
Taken from ancientchina.org.uk

The Zhenguo Temple, is a Buddhist Temple located about 12 kilometers north-east of Pingyao, is one the two buildings protected by UNESCO situated outside the Ancient City; built during the Five Dynasties period[12] (907-960 AD), its original name was Jingcheng Temple, but it got its present name in the 19th year of emperor Jiajing in the Ming dynasty.
The Temple, which faces south, is made up of two-row courtyard, covering an area of about 10,800 square meters.
The most important part of the complex is the Wan Fo Hall (Hall of Ten Thousand Buddhas), which is the third oldest wooden building in China and houses numerous valuable painted sculptures; the Hall, that has been built in 963 AD, according to a record in the Pingyao prefecture, is a great example of the old Chinese construction tradition, being made completely interlocking and without the use of any nail or fastening element.
But the Hall of Ten Thousand Buddhas now forms part of an elaborate monastery, which is composed by two courtyards, both in front and behind it: in the entrance there is the Hall of the Heavenly Kings, originally built during the Yuan dynasty (1271–1368 AD), but since then rebuilt many times; therefore, surpassing the Wan Fo Hall and the second courtyard, there's the Hall of the Kings of Hell. This Hall was built during the Ming dynasty (1368–1644 AD), and has at its centre a statue of the King of Hell, with two monk-attendants named Ming Gong and Dao Ming. They are outstanding works of the painted sculptures of the Ming Dynasty.



◀ Fig. 3.25
Zhenguo Temple bird view representation

◀ Fig. 3.26
Zhenguo Temple Entrance

◀ Fig. 3.27
Zenghuo Temple, Hall of Ten Thousand Buddhas entrance.

◀ Fig. 3.28
Hall of the Kings of Hell, King of Hell statue.

3.12 The Five Dynasties (and Ten Kingdoms) period, indicates a phase of political fragmentation in Chinese history that lasted from 907 (end of the Tang dynasty) to 979 (reunification by Song dynasty). The north of China saw the succession of five ephemeral life dynasties, while in the south ten kingdoms established themselves.

The Shuanglin Temple, situated in the Qiaotou village, about 5 kilometers south-west of Pingyao, is a Buddhist temple and the second building protected by UNESCO located outside the Ancient City.
Formerly it was known as Zhongdu Temple, which was probably built during the Qi Dynasty (479-502 AD) and rebuilt around 571 AD, as it is suggested by the oldest stone tablet found in the Temple.
It was during the Song Dynasty (960-1279 AD) that it gained its current name, thanks to a legend about Sakyamuni's death[13], which said that the Sakyamuni Buddha died under twin sal trees[14]. Shuangling in fact means *twin trees*.
The complex is distributed along the N-S axis, covers an area of 15,000 square meters and is divided into two sections: western, where Buddhist statues are worshipped and where there are three courtyards with ten halls; eastern, where monks meditate and chant Buddhist sutras. The most important part of the complex is the central Hall, known as the Wanfo Hall, or the Hall of the Ten Thousand Buddhas; this is one of the oldest wood structures buildings in China, having been built in 963, in the Five Dynasties period.
The complex is famous for its Song-era tablets, Ming-era bell, and Temple's ancient buildings and wall paintings, and in particular, for the more than 2000 statues of polychrome clay (the highest reaches 3.5 meters, and the smallest 0.3 meters) which are really valuable historic artifacts, witness of the old Chinese handcraft art; this characteristic has earned the temple the nickname of "Museum of the statues of polychrome clay ".

Fig. 3.29 ▶
Shuanglin Temple Entrance

Fig. 3.30 ▶
Hall of the Ten Thousand Buddhas Entrance

Fig. 3.31 ▶
Polychrome clay sculpture of a temple guardian at Shuanglin.

3.13 Sakyamuni is one of the names with which it is known Gautama Buddha, or simply Buddha, who a was a monk, mendicant and sage, on whose teachings Buddhism was founded.

3.14 The sal tree, latin name shorea robusta, is a tree native to the Indian subcontinent, ranging south of the Himalaya, from Myanmar in the east to Nepal, India and Bangladesh.

3.4 UNESCO World Heritage Site

The city of Pingyao represents nowadays, as mentioned in the previous section, a historical and cultural asset of enormous importance for China, being a living testimony of the last five hundreds years of Chinese history, so much that it obtained by UNESCO in 1997 the World Heritage Site certification. But the path undertook by population and Chinese government to reach this awareness wasn't simple.

After having lived its period of maximum splendor during the '800, from the beginning of the '900 onwards, the city slowly and inevitably fell towards the 'oblivion', becoming a city of secondary importance, important only at the county level that it administers. Because of this, above all, when China faced what would have been its economic boom, it risked to lose almost all the historical heritage of the city, in favour of a wild building development: in 1979 town officials laid plans to demolish the Ancient City and its city walls, in order to rebuild a completely new city to accommodate what was hoped to be a future economic boom and the contradictions it brings with itself.

But many experts in protection of ancient architecture and Chinese historians, firmly opposed this project, presenting a request to province, prefecture and county administrations not to overthrow but to preserve the Ancient City of Pingyao. Fortunately, in the same year, the proposed demolition and reconstruction of the Ancient City was rejected, and the State Administration of Cultural Heritage began to invest in the restoration of the city walls and some buildings. From that moment there was a reversal: first in 1986 the People's Republic of China designated Pingyao as one of the Chinese Historic and Cultural Cities; then, since 1988, the walls of Pingyao, the Shuanglin temple and the Zhenguo temple were listed by the Council of State as the first group of protected national monuments / buildings.

At this point, the idea of the candidacy of the city as a Unesco World Heritage site began to emerge: for the first time the experts of the United Nations Human Settlements Programme[15] (UN-Habitat) visited the ancient city of Pingyao respectively in 1990 and 1992, saying that ancient city was a "world treasure". Then in 1994, after the investigation of national experts, it was proposed to the State Administration of Cultural Heritage to approve the candidacy project of Pingyao Ancient City to be submitted to UNESCO for inclusion in the list of world heritage sites.

In August 1996, Pingyao Ancient City presented to UNESCO the declaration for inclusion in the World Heritage List. After that and after site inspection of UNESCO envoys, on 3rd December 1997, during the 21st General Conference of the World Heritage Committee held in Naples, Italy, the city of Pingyao was listed as UNESCO's World Heritage Site with the consideration that "The Ancient City of Ping Yao is an outstanding example of a Han Chinese city of the Ming and Qing Dynasties (14th- 20th centuries) that has retained all its

3.15 Established in 1978, the United Nations Human Settlements Programme (UN–Habitat) is the United Nations agency for human settlements and sustainable urban development. (UNHABITAT, n.d.)

features to an exceptional degree and in doing so provides a remarkably complete picture of cultural, social, economic, and religious development during one of the most seminal periods of Chinese history" (UNESCO, 1997). Together with the Ancient City, enclosed by the historical walls, the UNESCO certification included also the outlying Zhenguo Temple and Shuanglin Temple.

As written above, the main reason of the cultural and historical importance of the Ancient City of Pingyao is that practically nothing changed from the original architectural and urban layout, style and features that have been developed during Ming and Qing dynasties. As written in the UNESCO report "It shows a lively picture of the cultural, social, economic and religious life of the Han people about 600 to 100 years ago" (UNESCO,1997). Thanks to this it's possible to have a living example for studying the historical development of Chinese politics, economy, culture, military affairs, architectures and art during one of China's most important periods.
In this sense it's important to underline that Pingyao represents the only intact ancient city of Ming (1368-1644) and Qing (1644-1911) Dynasties well preserved in China; even the shops, booths and other buildings bearing the authentic styles of these two dynasties are still well-preserved, traits that, in modern times China, characterized by economic progress at all costs, are almost impossible to find.
Thus it is clear how much this place needs to be preserved, also because it represents a fundamental resource in terms of tourism for the whole surrounding territory and therefore for the whole cluster of villages that 'orbit' around Pingyao, including the village Hou Ji, site in which is located the project area object of discussion in the thesis.

Fig. 3.32 ▶
Pingyao's East Street view.
Taken from architectureontheroad.com

3.5 Hou Ji village, the case study

In the previous sections of this chapter has been introduced the *macro* geographical, historical and cultural context in which the urban agglomeration, where the project area is located, is inserted; a context rich in history and potential, especially in relation to the UNESCO sites present here.
But at the same time the richness of this territory, as well as for all of China, is based for the most part on all those small towns or villages which, despite centuries of history, have witnessed the vertiginous Chinese economic growth, as spectators, covering, as it were, a secondary role.
They represent the backbone of Chinese tradition and history, but this element has not been perceived for a long time; and to further strengthen this situation, as explained in chapter two, has been added the phenomenon of emigration to the cities, which has emptied most of the Chinese villages. In fact for a long time has been favoured the rapid growth and urbanization of cities and metropolis, where traditional districts and buildings have been replaced by modern, urban landscape, that in most cases are completely 'aseptic'.
Luckily in the last decades both to people and Chinese administration, started to realize and gain more interest in this issue
By introducing the list of more than 600 ancient villages of special cultural significance, nominated by an expert panel, including the Housing Ministry and State Administration of Cultural Heritage, China has emphasized the need to curb the loss of rural villages, bearing the essence of traditional Chinese culture, having historic, scientific, artistic, social and economic significance, both tangible and intangible.
In this framework is inserted the village of Hou Ji, in Chinese *Houjicun*, where the project area is situated. *Cun* is the noun describing the village, signifying a community of people, smaller than a town.
Houjicun is located in Zhongdu Countryside, and is under the jurisdiction of

◄ Fig. 3.33
Pingyao and Hou Ji Village geographical location.
Taken from Google Earth Pro + Author's re-elaboration

Pingyao County (Jinzhong City Prefecture, Shanxi Region) about 5 kilometers southwest of the Ancient City of Pingyao, that is the nearest big urban agglomeration. Nowadays, the village, which is mainly made up of older people, has a population of about 2000 units.
Hou Ji village, being in the countryside, is surrounded by other villages: 2 kilometers north-west there is the Ducun Village, around 2.5 kilometers south-east there is the Liangzhao Village, 2 kilometers east there is Tianpu Village, about 2 kilometers south there are Goncun, Jiupu, Xinpu, Jiuxinpu and Nanjia Villages. But mainly it can be said that Hou Ji is bordered by the high-speed railway, on the north side, and by the G5 Jingkun Expy Highway on the south side; these elements are quite new in this landscape, and they changed a lot the old countryside space that lasted for centuries; in fact this stretch of railway was realized in 2016, while the highway was built in 2006. This reflects really well the Chinese villages situation mentioned in the previous page, and in chapter two. i.e. the fact that modernity has completely distorted the spaces like these without thinking too much about the social and environmental consequences that can ensue.
On the other hand, however, these infrastructures have certainly brought significant advantages to the area and the village in terms of accessibility, being quite close: the high-speed railway station, Pingyao Ancient City Station, which refers to the city of Ping Yao, is located two kilometers to the northeast; the exit of the Emeishan-Hanyuan Expressway S66, and the China National Highway G108, are about 8 kilometers far in west direction; and the exit of the Jingkun Expressway G5 (which connects Beijing through Chengdu to Kunming, which is in the Yunnan province, south of China), is situated 9 kilometers to the east. These elements therefore represent a strong point for the project area, since they guarantee a faster and easier communication of the village with the outside.
At the same time Hou Ji is not far from the Ancient City, since it can be reached by a motor vehicle in about fifteen minutes (ten kilometers).

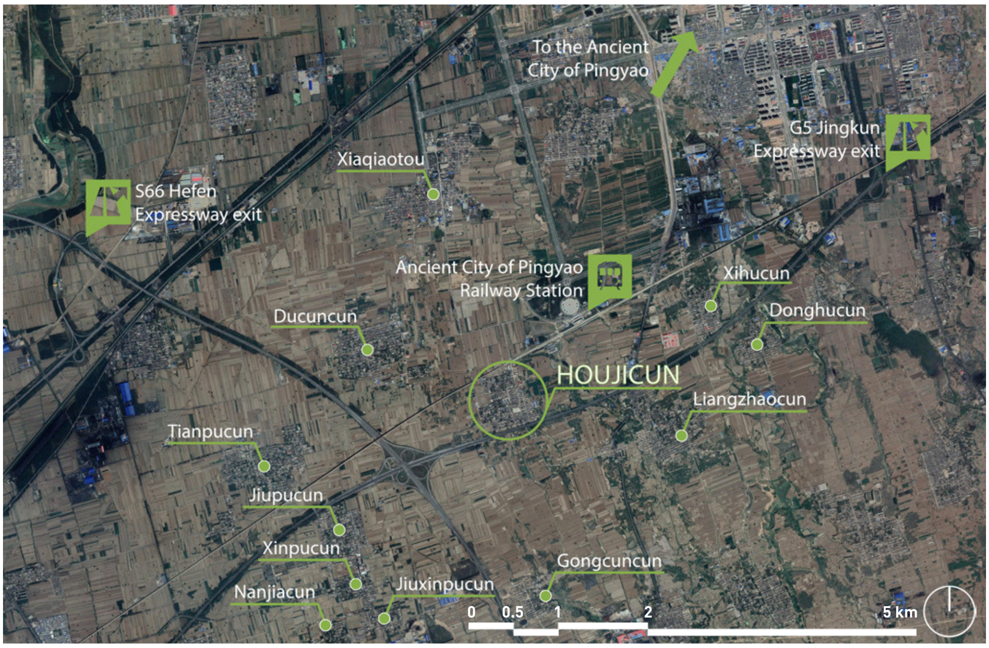


Fig. 3.34 ▶
Location of main villages surrounding Houjicun, railway station and highway exits.
Taken from Google Earth Pro + Author's re-elaboration

▲ Fig. 3.35
Hou Ji village narrow street.
Photo made by Ingrid T. Ødegård

However, despite being facilitated from the point of view of accessibility, the biggest problem related to mobility lies in transport conditions, i.e. in the conditions of village roads and those that connect it with the surrounding ones. In fact the current roads situation is not good, both because many roads are still not asphalted, and because the asphalted roads are poorly maintained; it is therefore normal, during the movements inside the village, to come across continuous holes and a bad road surface.
The narrower streets instead, those that divide the slats of houses with a single courtyard of more recent construction (from the 50s onwards), in many cases have a paved road surface made of terracotta.
Talking about the village's space distribution, substantially it is divided into two parts, completely different from each other: the first, physically divided into two parts, surrounded by earthen walls, is composed of much older buildings, made from the Ming era on, at least 300 years old, and is characterized by an irregular road network; the second one is composed by relatively recent buildings, with areas built in different interventions from 1979 onwards. The areas of recent construction differ from the others for the road network, that is much more regular and faithful to the principles of Han urban design, typical of Chinese cities, and especially for the type of housing: the 'modern' dwellings are all developed following the type of single-family house unit, developed on a single storey and with a single internal courtyard.
Nevertheless the older part, composed by the two forts mentioned above, it's slowly ruining, since the old buildings, although in some cases are still inhabited, are deserted, or worse destroyed by neglect.
As mentioned, the two forts, are surrounded by earthen walls four meters high, in some places reinforced by bricks (the same defense mechanism of the city of Pingyao, but on a small scale), which despite having a high historical value, over time have been demolished to make room for houses or streets or are slowly deteriorating.
Talking about the village's economy, it has agriculture as main source of occupation, which reflects what was, and partly still is, the 'soul' of this part of China; even nowadays, Pingyao County, which has a total population of 530,000 people, has an 'agricultural' population of about 400,000 units.
In this sense Houjicun's economic development mainly rely on agriculture: the main agricultural products are apricots, watermelon and other fruits, including cabbage, broccoli, celery and other vegetables. The village also has a small amount of village-run factories located at the border of the town, working as casting company factories, with others producing sintered brick.
Another sector that could be important for the economy of the village is tourism. In fact, the nearest main tourist spot is the Shuanglin Temple, that is situated in the Xiaqiaotou Village, only 3 km away from Hou Ji on the north-west direction (and about 6km from the Ancient City). Shuanglin Temple, as said in the section 3.3, is an important Buddhist tourist destination in Pingyao County. So that, together with the Ancient City, and with a correct redevelopment of the village, represents another advantage in the definition of the project. In this sense, the creation of a receptive structure, in function of a future greater tourist flow, can be a good choice.

Fig. 3.36 ▶
Hou Ji Village aerial view.
Source: Google Earth Pro


0
50
100
200
500 m

3.6 The history of Hou Ji

At the beginning of this chapter, it was told in detail about the Ancient City of Pingyao; this was made for a reason: in fact the history of Houjicun is closely linked to that of Ping Yao, since in its origins it served as residence area for Pingyao's business men and their families, that at time used to have a dwelling in the countryside. This habit was common in Shanxi, i.e. Hou Ji's region, being the homeland of the powerful Jin merchants, mentioned in section 3.2, which used to set up outside the city, giving rise to new housing compounds.
In this sense, generally these villages developed based on two or three families, each of which built its own dwelling and its own ancestral hall, also known as the family temple, related to the surname of the owner. Then, the people with the same surname used to live in a compact community around their own temple in accordance with the affinity level of the clan. On the other hand, the foreign households that settled in the same area, and that consequently had a different surname, were marginalized and discriminated. The only exception to the common blood of the family members was a strong cohesion aimed at defending itself from the outside.
Then, usually the village name was set based on that of the founding family: in Houjicun, Hou is the surname of the family that firstly settled here and built its own home, which is located in the center of the small fort, positioned in the upper part of the village; nevertheless after some years they sold their property to the wealthy Liu family, which gave their name to the house, that today is known as Liu House.
As mentioned, originally Houji was composed by two parts, that could be called *big fort* and *small fort*, that were enclosed by earthen walls, used as a protection from external threats. The concept was that people lived within the walls, while arable land were located outside, creating a kind of isolated community, visually divided from other villages, that were only linked by roads. This framework, with the two separate parts, endured until 1949, lasting almost four hundred years. In fact, as can be seen from the urban evolution of the village on the next page, until the '50s there were no substantial changes. Between the '50s and the late '70s the village began to undergo changes, which however remained localized in punctual interventions of demolition, reconstruction or construction from scratch, within the perimeter of the forts. Whereupon, with the growth of population, there was an inversion of the trend, with the village starting to expand beyond its centuries-old borders together with the construction of roads outside the village.
From the end of the 1970s, more precisely from 1979, until 1988, the village expanded around the small fort and south of the big fort; from 1988 to 1993 it expanded on south-east of the big fort; from 1993 to 2006 it expanded east of the big fort. Then, after 2006, the construction of G5 Highway, the high-speed rail line and the village expansion on east, formed today's territory of Houjicun. Now, due to the large number of young people in the village that leave for working, many houses are vacant, and the village is under serious risk of hollowing.

Fig. 3.37 ▶
Urban transformation of the Houji village from 1979 to nowadays.
Source: Author's re-elaboration

3.7 Space analysis

As mentioned, the older part of Houji Village, that can be date back to over 200 hundred years ago, could be divided into two parts, that it was decided to name big fort and small fort, with almost all old buildings located inside these two areas, while outside of those there are just a few.
Talking about the dimensions of the two, big fort covers an area of about 74,000 square meters, while the small fort, which lies in the north, has an area of about 17,000 square meters. Either have an almost perpendicular shape, although with different sizes, while the differences between the two reside, first of all, in the fact that the big fort has a much less regular distribution compared to the small fort's buildings: latter's houses are distributed along two main roads perpendicular to each other; at the same time the big fort owns more public space, having more open spaces due to its bigger dimensions. In this regard, it's important to underline the general characteristics of these kind of settlements, which usually had: walls as defense system; main streets with workshops and shops; courtyards owned by singly families; crops and arable lands positioned outside walls.
Talking about the village old walls, their current look and situation is quite bad, both for their composition, mainly adobe and in some parts bricks, and for the actions of the inhabitants; in fact, at the present time they are mostly ruining and broken in some parts, while in other parts they are intermittent and barely identifiable, after interventions of breaking or splitting by the population. Moreover, originally the forts had entrance gates, which now are severely damaged; there is only a Gate-house left which is in relatively good condition.
The emergence of fortified residential complexes appears to have been an architectural response to unsettled conditions that accompanied periodic dynastic decline in many areas of China. Rebellion, banditry, and general turmoil promoted the building of high walls around existing complexes in order to provide a level of enhanced security for the individual walled *siheyuan*[16] courtyards contained within. In many cases, as it happened in the Hou Ji village, the larger village or town itself was walled so that there actually was a nested system of fortified units: village/town, residential complex, and individual dwelling units.[...] Throughout northern China, walled villages as well as some residential complexes found within them are called *baozi* [fortresses], toponyms that remain even in the absence of the fortifications themselves (Knapp R. G., 2000).
In this framework are then located the historical houses, for the old part, and dwellings built in the last forty years for the new areas during village expansions. The first in Houjicun are different from those in ordinary cities and towns, both for layout and design, since they take form from living together as a family and every household in the fort possesses its own courtyard. Their house type follow the rules of the siheyuan, an historical type of residence

▲ Fig. 3.38-3.39
Hou Ji village walls.
Photo made by Ingrid T. Ødegård

Fig. 3.40 ▶
Hou Ji's building and road division.
Source: Author's re-elaboration

3.16 Siheyuan, literally translated is *quadrangles*, which means a courtyard surrounded by four buildings.


Legend
Historic Houses
Modern House
Old Walls
Factories
Public buildings
Main roads
Highway (south) and
railway (north)
0
50
100
200
500 m

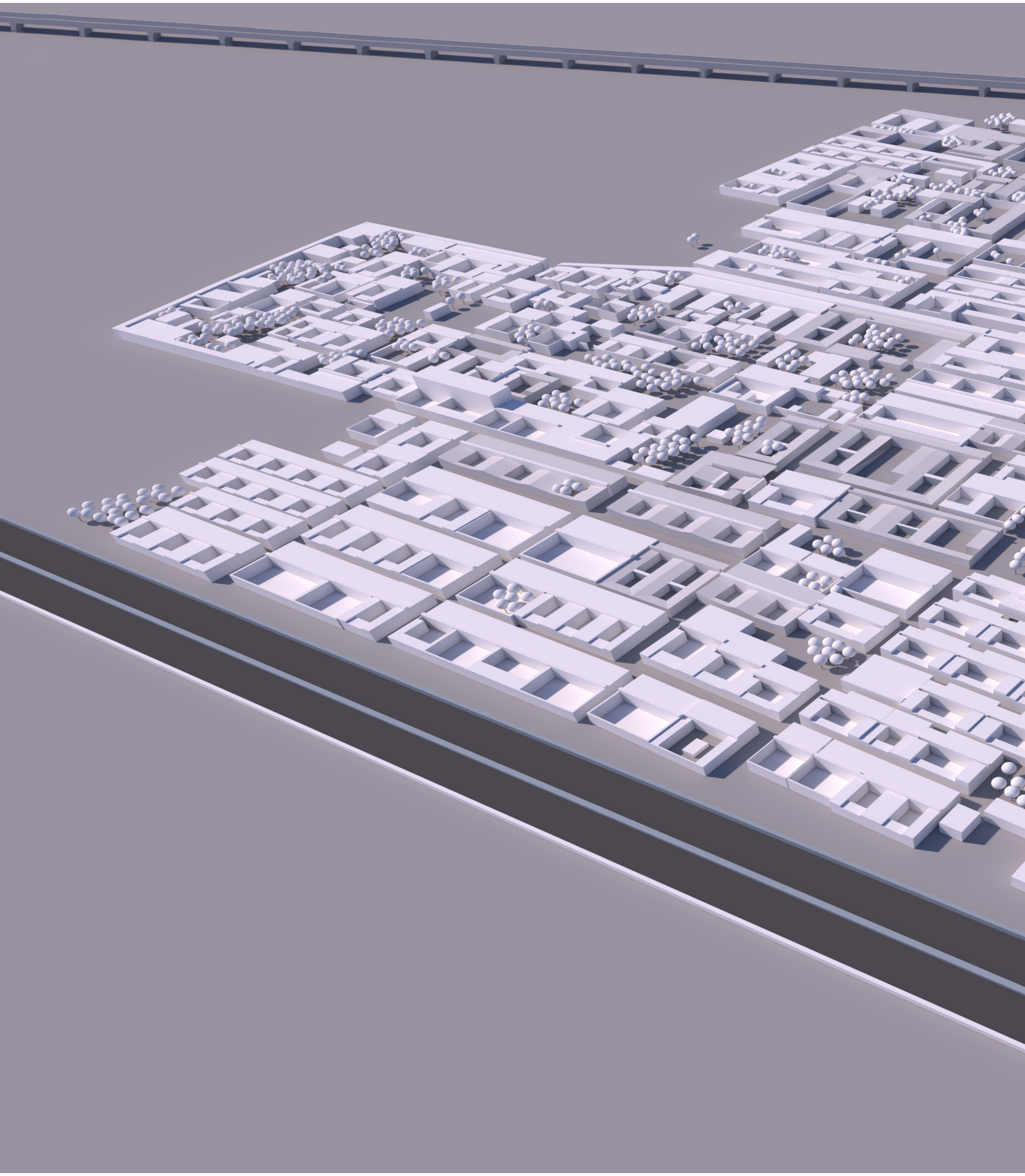
that was commonly found throughout China, with four houses (single story pavilions) oriented towards the courtyard. Its common characteristics are: central axis symmetry; well hierarchically organized courtyard space; diversity between inside and outside spaces; difference between social and private spaces; strong ancestral meaning behind architectural design. In this sense no indigenous dwelling type other than the siheyuan and its variants epitomizes so clearly the Chinese architectural principles of axiality, hierarchy, balance, and symmetry (Knapp R. G., 2000).
The internal courtyard is usually composed by a main wing facing south and located and the end of the site, wings along sides facing east and west, a wing facing north and the entrance door displaced on the south-east corner. Another important feature of this type of constructions is the horizontal and not vertical development, with buildings one floor tall, and roofs that in some cases can be walked on. This creates an urban landscape formed by large gatherings of buildings of the same height with very similar envelopes: in this case, this makes Houjicun very similar to the city of Pingyao, as regards the ancient part, as can also be seen from the images in section 3.3.
Starting from these 'macro' guidelines, different buildings were built with their own characteristics and dimensions: in fact, as mentioned, the type of dwelling, its dimensions, mirror the wealth and power of the households, as well as the number of courtyards; the latter once served among other things to connote the power of the family. For example, the Wang Family Compound, which is about 50 km far from Houjicun, with its 231 courtyards and 2,078 rooms is the largest of the Shanxi courtyard houses. It was in fact the home of one of the most important families in the Shanxi region[17].
On the other hand, the new houses in Houjicun, are much smaller and usually built by the house-owners, using local materials or prefabricated elements; moreover these dwellings are mainly one-storey and inhabited by single-family unit, with an average of only three, four people per house, usually in old age. This quantity is the same even for historic houses, no matter the building dimensions: in fact, one of the main problems that concerns Hou Ji is the aging of its population, due to the village depopulation caused by the migration of young people and adults in working age towards the cities.
Moreover, the houses built in the last century, are the result of expansions consequent to one another, based on the creation of inhabited areas as uniform as possible composed by dwellings with similar dimensions, made with low costs, connected by narrow roads parallel to each other.
A feature that unites new and old constructions, is the height of the boundary walls of the houses, which is usually at least three meters, up to even four-five: this was made to have a clear separation between the private environments and public ones, a very important element for Chinese culture.

Another common characteristic in Houjicun's buildings is their integrated climate planning, constant from centuries; all building are in fact characterized

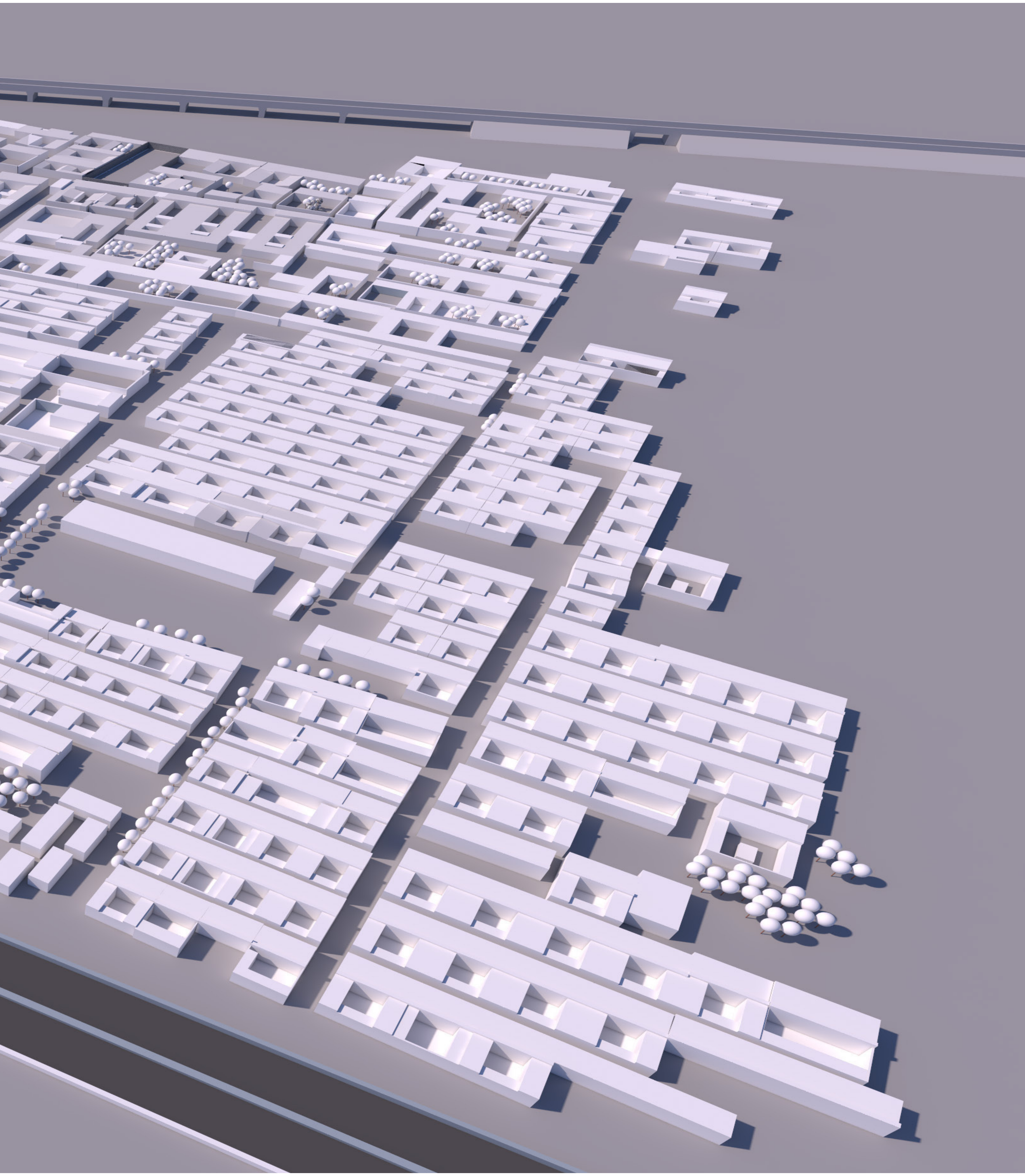
3.17 The Wang Family was one of four historically prominent families in Pingyao area whom reached its maximum power during the 18th century thanks to businesses and goverment positions. Their family compound was built between the end of XVII century and the beginning of the XIX century.

▲ Fig. 3.41
Average Hou Ji building inclination compared to the N-S axis.
Source Google Maps + Author's re-elaboration.

by almost the same orientation: they are oriented along the North-South axis, with the historical houses of the village, like Liu House, inclined by 16 degrees compared to the aforementioned axis, while the houses of new construction are rotated by about 10 degrees. This is primarily due to an integrated planning with the context and the climate of the area. In fact, with this orientation, the winter cold wind from Siberia, from North-East direction, is blocked; at the same time, the housing type with the internal courtyard, which is applied to almost all the houses in the village, developing on the north-south direction, allows to receive the winter low sun during winter cold months, while during summer, shades the internal spaces. In fact these areas are characterized by cold winters and with temperatures that can fall far below zero degrees, and hot summers, with temperatures that can exceed 30 degrees.
Talking about houses' envelope, almost all in Hou Ji are courtyard dwellings; as mentioned, during the long Chinese history, the courtyard system has always been present in its various architecture system, and here it's not an exception, indeed, it is precisely the mirror of what has just been affirmed.
Again, the kind of folk houses present in Hou Ji are different from those in ordinary cities and towns in both the overall layout and local design: that's because the majority of them take their shape from principles of living together as a family and every household in the fort possesses its own courtyard; farther dozens of contiguous houses and courtyards turn into a neighbourhood, just like the layout of Liu Courtyard in Small Fort.
Lastly, regarding the environmental quality, it is affected by the vicinity of the motorway, but since this is not an industrial production area, not by industrial pollution; in fact, the factories in Hou Ji are few and located in the immediate vicinity of the village, and have, among other things, limited dimensions and are not very impacting on the local environmental quality.
The areas surrounding the village instead are all used for crops or livestock, with little presence of wooded areas. In fact, the wooded areas in the vicinity of the village are no longer, as it were, pristine, but they are uncultivated areas or areas used in the past to obtain wood. To this, it must also be added that this part of Shanxi, especially in the plains, has few wooded areas, both for the climate and for human hands.



▲ Fig 3.41 3D conceptual view of Houjicun. Source: Author's elaboration.




▲ Fig. 3.42 and 3.43 Roads of Hou Ji village. Photo made by Ingrid T. Ødegård


▲ Fig. 3.44 Narrow road of Hou Ji village and Fig. 3.45 "Modern" courtyard in Hou Ji Photo made by Ingrid T. Ødegård


▲ Fig. 3.46 Relatevely new building in Hou Ji village and Fig. 3.47 View of rooftops in Hou Ji Photo made by Ingrid T. Ødegård


▲ Fig. 3.48 and 3.49 Courtyards in Hou Ji seen from roof. Photo made by Ingrid T. Ødegård


▲ Fig. 3.50 and 3.51 Views of typical enclosed spaces in Hou Ji houses. Photo made by Ingrid T. Ødegård


▲ Fig. 3.52 and 3.53 Views of poorly maintained courtyards in Hou Ji. Photo made by Ingrid T. Ødegård

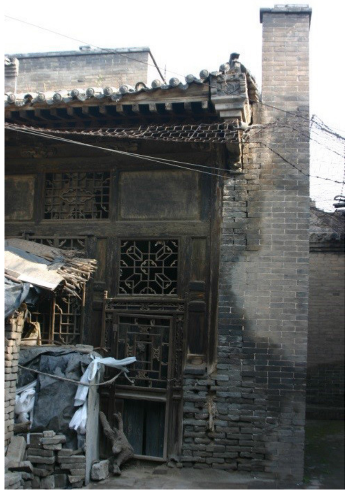

▲ Fig. 3.54 and 3.55 Views of courtyards in Hou Ji village. Photo made by Ingrid T. Ødegård


▲ Fig. 3.56 and 3.57 Indoor views of a typical courtyard house in Hou Ji village. Photo made by Ingrid T. Ødegård

3.8 Potentialities and criticalities of the area

One of the critical issues of the village is represented by the situation of the internal roads and those connected to the surrounding areas, which, as already mentioned in section 3.5, would need more maintenance or improvement interventions.
Likewise Hou Ji would need direct connections by public transport to the city of Pingyao and neighbouring villages, which are now missing: currently the nearest bus stop is at the high-speed train station, which is about two kilometers from the village.
However, these problems can only be resolved with the collaboration of the governing bodies, especially for the cost that the aforementioned works would have. Surely redevelopment and new construction in the village can facilitate and speed up the interest of local government.
Another of the recent criticalities of Houjicun lies in the conservation and maintenance of homes, in particular as regards historic homes. In fact,courtyards that have always been occupied by residents or cleaned often, have a better external appearance and architectural quality. On the other hand, the conditions are the opposite, with falling of roof and peeling off of plasterer etc., for dwellings that have not received constant maintenance. In other cases in Hou Ji, there is also a condition in which the house is destroyed by people's action, mainly caused by changes of property rights; new house owners usually have no sense of the historical value of old houses, sometimes ruining parts of the house in order to modify the internal spaces, the courtyard, etc., in others destroying the whole building to derive vegetable plots and space for animals.
At the same time, usually the historical dwellings, have two main structural problems, which are related to: moisture, both raising from the ground, sucked by the foundations and the walls which is threatening them in lower parts, and caused by rainwater falling from the roofs and splashing when hitting the ground; vegetation growing on the roofs, caused mainly by the lack of maintenance. The latter problem is present on both types of roofs, both flat and pitched roofs.
But the great historical value of these homes has attracted in recent years the interest of the South East University (SEU) of Nanjing, which in collaboration with NTNU, Norwegian University of Science and Technology, has first carried out relief interventions and redevelopment projects, as will be discussed in section 3.9, which led to the definition of the project present in this thesis. In this sense the aforementioned difficulties can become potentials by implementing appropriate interventions.
To the previous critical points, it must be added the depopulation experienced by Hou Ji in recent years; as happens in almost all small rural Chinese realities, people of working age tend to emigrate to large inhabited centers, in particular those located on the coast, looking for better life prospects; in this way, in the last decades a huge imbalance has been created between rural areas and urban areas. Just think of a fact: only in 2017 the total number of

▲ Fig. 3.58
Hou Ji village street.
Photo made by Ingrid T. Ødegård



▲ Fig. 3.59
Structural problems caused by moisture raising from the ground.
Photo made by Ingrid T. Ødegård

▲ Fig. 3.60
Roof condition.
Photo made by Ingrid T. Ødegård

rural labourers working in China's cities increased by 4.8 million or 1.7 percent in 2017, to reach a new high of 286.5 million; migrant workers now make up about 35 percent of China's total workforce of about 810 million, making up more than one third of the entire working population (National Bureau of Statistics of China, 2018). However they remain marginalized and subject to institutionalized discrimination in cities. This has created a phenomenon that is difficult to overcome in the short term, but only with structural interventions at the national level, and small interventions in villages. Stopping this phenomenon would mean giving new life to all rural realities by creating new economic prospects for the entire population that lives within them and facilitating the return of those who left them. Interventions, like those started in Hou Ji, can work against depopulation and encourage people to return to the villages rather than leave them.

Contrariwise Hou Ji has some existing potentialities, that under a redevelopment point of view, represent important starting points for any further analysis and interventions.

▲ Fig. 3.61
High-speed train station entrance.
Photo made by Ingrid T. Ødegård

One of them is certainly given by the proximity to the new station of the high-speed railway line, Pingyao Ancient City Station, which is a great strength for the accessibility to the village, in particular with reference to tourists access. The same idea applies to the proximity to the road junctions of the motorways, already written in section 3.5; nevertheless in this case, as mentioned, it would be necessary to carry out work to strengthen the current road connections between the exits of the road arteries and the village, which are currently not very efficient.

Another potentiality for the project is given by the proximity to the Shuanglin Temple, which is about 2 kilometers from Hou Ji in the village Xiaqiaotou, which is a Buddhist temple with a high flow of tourists throughout the year; therefore this element must be taken into account and exploited in the definition of the project realized in this thesis. This is because, as will be explained in Chapter 4, in the guidelines there is the willingness to create a hostel in the project site.

▲ Fig. 3.62
Corn divided in one of Hou Ji court-yards.
Photo made by Ingrid T. Ødegård

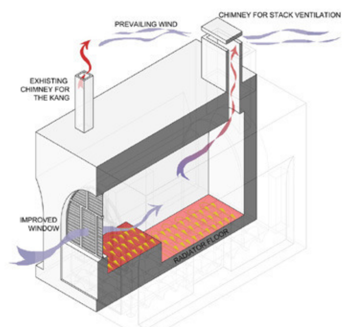
Similarly, Hou Ji, bases most of its economy on agriculture, which has always been present in this area and therefore has a long tradition. Including this factor in the new project can have a very positive impact and represent a great potential; especially as a function of integration between crops and new buildings, creating for example a system of roofs and green courts combined with a plan aimed at enhancing their cultural and social value, as well as the economic one. In recent decades there has been an ever-decreasing awareness of the population for jobs in agriculture, as a result of an uncontrolled emigration to cities in search of jobs that could allow greater profits and better living conditions. Therefore it is very important to put in place interventions to reverse this trend.

Then, once again, if exploited in the right way, the historic residences in Hou Ji, must be used as one of the main elements for raising the influx of tourists in the hamlet, representing another important starting point for the design project that will be discussed in chapter 4.

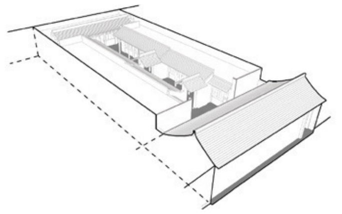
3.9 The starting point: NTNU and SEU projects in Hou Ji

Since 2014, many studies and analysis have been carried out on Hou Ji village by the South East University (SEU) of Nanjing, Faculty of Architecture, in collaboration with the NTNU, Norwegian University of Science and Technology, Faculty of Architecture and Fine Art, in good understanding with local authorities of Ping Yao City.
After an initial field study trip to Ping Yao, by professor Dong Wei (SEU) and professor Harald Høyem (NTNU/Xi'an), the historic village Hou Ji with 1700 inhabitants was selected as first case for more detailed studies.
During the fall of 2014 the work officially started, when a group of 25 students from SEU measured and made complete drawing sets of eight of the historic courtyards in Hou Ji, making at the same time a map of the entire village and taking photographs as documentation.
The thorough studies gave prominence to the above mentioned old courtyards, rediscovering their high historic and architectonic values, thus needing interventions for repairing non-structural elements and upgrading their energy performance; anyway a majority of the yards turned out to be in relatively good shape when it comes to the structural elements.
As following step, it was decided to develop a research project between years 2013-2016, entitled "Energy efficient up-grading of historical villages in Ping Yao area, Shanxi Province, China". carried on by SEU, in collaboration with NTNU, with support from the Norwegian Council of Research (NFR). The project focused on how to reduce energy demand when up-grading inhabited, existing housing structures of high historic value, taking in consideration at the same time the local lifestyle and daily life.
It was composed by three Work Packages (WP) :
• the first Work Package (WP1) focused on the analysis of the local building traditions, their historical and architectural values together with their technical state. Then it proposed guidelines for energy-efficient conservation and modernization in the domestic use, respecting the characteristics of the building typology.
• the second Work Package (WP2) focused on anthropological studies, necessary to understand how the housing structures ordinarily are used, underlining pros and cons with regard to energy efficiency.
In detail, were analysed daily activities carried out inside and outside the existing dwellings, and how thermal comfort, daylight and ventilation were perceived and influenced activities, feeling of security, belonging and other aspects of residential life.
• the third Work Package (WP3) focused on detailed building physic investigations and energy evaluations and calculation of a building in particular. It allowed to understand how a typical historical dwelling reacts and performs according to different climatic conditions. On the basis of this it was defined a chart of possible interventions that could be applied to improve the environmental performance of the building, reducing its energy demand. The analysis in WP3, as said, was carried out on a courtyard house in

▲ Fig. 3.63
Air quality detection system, and their indoor schematic application, used during the WP3 (WP3, 2014).



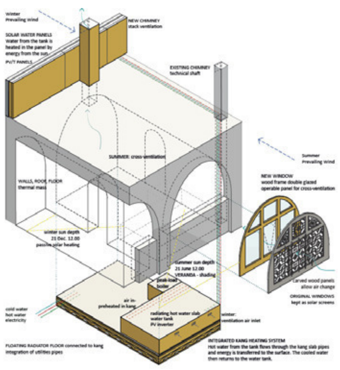
▲ Fig. 3.64
Axonometric view of energy upgrading interventions (WP3, 2014).



▲ Fig. 3.65
Liu House tridimensional view (Despa A.M., 2015).

▲ Fig. 3.66
Liu Courtyard view.
Photo made by Ingrid T. Ødegård

▲ Fig. 3.77
Liu Courtyard view.
Photo made by Ingrid T. Ødegård



▲ Fig. 3.78
Exploded axonometric view of architectural upgrading interventions (Despa A.M., 2015).

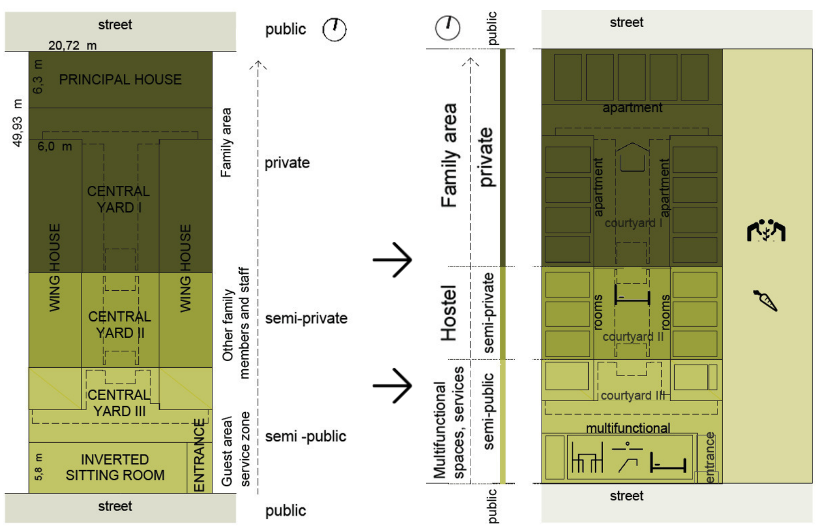
particular: it was in fact chosen as case study, the Liu Compound, which is also the biggest compound in Hou Ji. It has great importance for the village and also for the project developed in the thesis, with its great historical value that could be used, together with other interventions, to revive the local economy. The house was built at the end of Ming Dinasty (sec. XVII) by a wealthy businessmen called Liu, whom with his family, established their home where today there's the so called small fort. In particular Liu clan family residence comprises four parallel rows of courtyard houses.

After these preliminary studies, between the end of 2014 and first half of 2015, it was decided by NTNU to make a thesis related to the redevelopment of the so called Liu House. The project, entitled "Adaptive reuse and energy upgrading of a traditional Chinese courtyard house" written by the student Ana Mihaela Despa, was realized, as mentioned, in collaboration with the NTNU Faculty of Architecture and Fine Arts, Department of Architectural Design, History and Technology in Trondheim, Norway. As can be guessed from the thesis title, the aim of the project was to restructure the analysed existing building, with a modern vision, integrating the historical and architectural aspects to be preserved with an improvement of the energy performance of the envelope and use of spaces, both internal and external.

In this sense, in the project, the energy efficiency of structure, fixtures and energy systems went hand in hand with the change in use, which went from private residence to a lot with a mix of well-divided functions, that went from the public to the private; to do this, it was necessary to use as a starting point the guidelines gave by Chinese tradition regarding the subdivision of spaces: the semi-public part located at the entrance, with multifunctional and service areas, then a semi-private, with hostel rooms, then a private one, kept as a family area.

The above project ideas were developed starting from a detailed climatic analysis of the area where the project lot is located, very close to the project site used for this thesis, and then focusing on an analysis, also thorough, of the built, accompanied by different technical details, and concluding with what was the idea of the project, providing both the new functions and the analysis related to energy upgrading.

Fig. 3.79 ▶
Liu House change of functions, before and after (Despa A.M., 2015).



3.10 Why a project in Hou Ji village?

In the first place, the decision to carry out a project in the Hou Ji village derives from considerations in relation to the geographical position of the hamlet; it is in fact, as explained in the previous sections, in a kind of *boundary* position, being situated at the edge of what will be the future urban expansion of the city of Pingyao: as stated in the Pingyao's Master Planning for years 2013-2030, it is expected that the city will expand on the west side of the Ancient City, opening up a new residential area, that, it can be said, will be built around the already built high speed train station. The local administration is moving rapidly in this direction, having already accomplished the main arteries of the new area, in anticipation of the building development of the next few years.
In addition to this situation, are added two other important qualities, which have favoured the choice of Houjicun: it is both very close to the Ancient City of Pingyao, which is on the UNESCO Heritage List and consequently can guarantee a significant influx of tourists to the surrounding areas, and it is an important example of a typical Chinese rural village, witness of the Chinese cultural and architectural tradition and of the region in where it is, the Shanxi.
Therefore, the choice of Hou Ji as a development field of recovery projects has a very strong theoretical and practical basis: it is the perfect example of the internal contrast that China has been experiencing in recent decades, due to which there is a strong dualism between modernity, represented by the advancement and development of the cities, as in this case Pingyao and the maintenance of historical memory that is likely to be lost, represented by the historical buildings and villages, as in this case Hou Ji.
Hence, beyond all the above mentioned considerations, the direct consequence of the work done so far by SEU and NTNU, is to summarize with a project of one or more new buildings, all the researches and analysis carried out from the past years until now. The studies already carried out in fact have moved precisely in this direction: as mentioned in the previous section, firstly they were related to the survey of the existing buildings, then to the refurbishment of historic houses.

All this constituted, and constitutes, an excellent starting point for the project developed in this thesis, which was made possible thanks to the willingness of the professor Luca Finocchiaro (Associate Professor at the Department of Architecture and Technology of the NTNU, Norwegian University of Science and Technology of Trondheim, Norway), wanting to realize with a new project, the theoretical studies carried out previously in the village of Hou Ji.
In this sense, the concrete project objective focused on the creation of one or more pilot buildings, able to be replicated with small modifications, in rural contexts similar to that of Houjicun. But the basic idea was that in any case the project should be the result, on the one hand, of the analysis already carried out, on the other hand, of the guidelines dictated by the Chinese design, the vernacular architecture and the use of local materials; the whole combined with a modern, integrated design, which foresees the

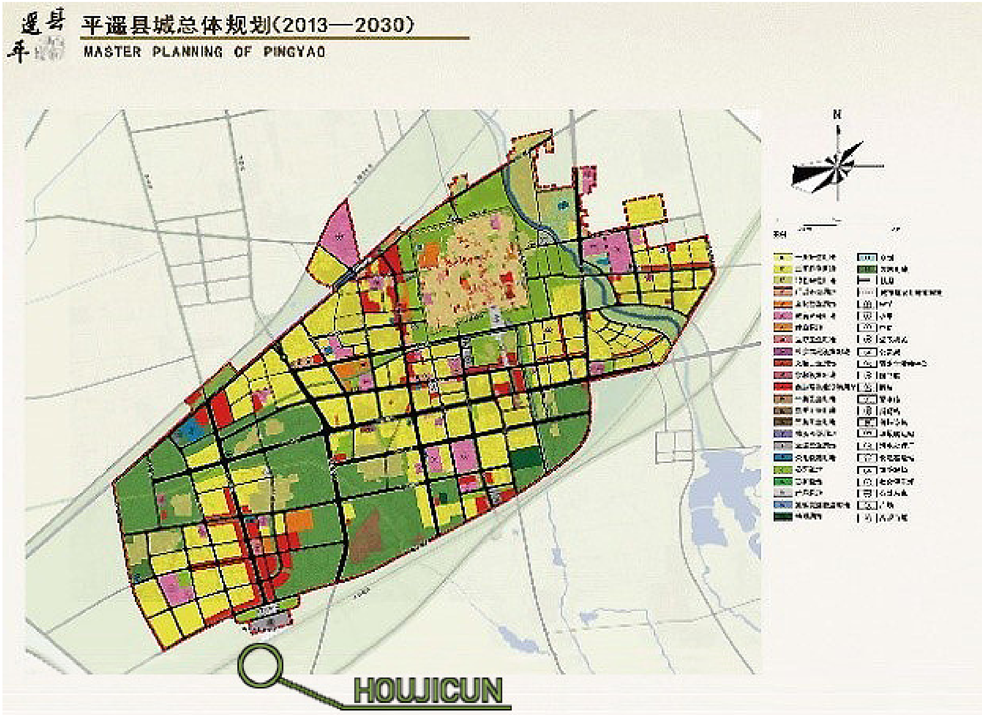


Fig. 3.80 ▶
Master Planning of Pingyao, years 2013-2030 + Hou Ji position

use of efficient and intelligent energy systems and passive systems that may help to reach the comfort conditions with the least possible consumption of resources. In relation to this last observation, elements of anthropic nature, such as the orientation of buildings, the design of performing and sustainable enclosures, etc. and natural elements, such as solar radiation, soil energy, rainwater collection and reuse, etc. are extremely important to achieve the best possible result.

Likewise, it is important to underline a concept that has greatly influenced the design choices, that of respecting the economic and social situation of the hamlet: to be clearer, the inhabitants of the village are currently living in poverty, and perform humble jobs, mainly as farmers in the countryside surrounding the village. This is why it is important to pay attention, especially to the functions of new buildings, as well as to their envelopes: it is important, not to create any imbalances, that new buildings are not too flashy, but are as simple as possible, avoiding exaggeratedly complicated shapes, also and above all with a view to shorter construction time, without the use of local labour, and with a view to integrated energy planning. In relation to the latter, the most regular is the shape of the building, the easier it is to realize an efficient insulation system with low dispersions due to thermal bridges.

Chapter 4

The Project

The aim of this chapter, as it can be deduced from the title, is to explain the project developed during the thesis path, before explaining passive strategies and active systems in detail.
The design path, as it was conceived, is the result of an integrated design in all its components: the local climatic conditions and the relative passive strategies, the use of some construction elements and the related materials, the energy systems, etc. were all elements that characterized the project choices.
Therefore, in the chapter the design path is explained starting from the climate analysis, up to the graphic representation of the interiors.

4.1 The Project Site

As a first step, the discussion focused on which kind of site to choose for developing the project. The alternatives, from the beginning, were two: the first was to use an unused area located inside the Hou Ji village, starting from the idea of minimizing the environmental impact of a new project as much as possible; the second was to use a completely new site located outside the current borders of the village.
Surely at first glance, the second option would have been the best choice, as potentially the design would have had far fewer limits, resulting easier, if possible, due to the lower presence of existing constraints. However, the first option, both because it would have been redeveloped an existing unused area, and because it would not have been 9used new land, turned out to be the most consistent with the type and idea of project set from the beginning; therefore the choice fell on the second option.
The following step was to choose the exact site to be used among those in disuse located inside Hou Ji. The choice fell on the area located in the north part of Hou Ji, closed to the several historic houses previously analysed by SEU and NTNU, including the Liu House. The above mentioned area has several positive characteristics: firstly it has a relatively broad size, about 22 meters wide and about 65 meters deep, and it has an elongated shape, which can allow the realization of several buildings in sequence and not just one, starting from the examples of historical houses typical of local Chinese architecture, with courtyards with different functions for each part of the buildings; at the same time the area faces directly, on the south side, on one of the main streets of the village, which is very important for the accessibility of the new buildings. At the same time the site has well-defined dimensions and is delimited on each side by pre-existing walls that can in a certain sense facilitate the design, because for example, knowing the dimensions, it is possible to establish the plan area of the future buildings distancing them from the border. However, it is necessary to specify how the existing walls represent concurrently a limit, since they can not be 'lowered', being adjacent to other private properties, they are a constraint with regard to solar access on both the east and west sides.
Nowadays this area, according to the data available from the analysis carried out by the South East University of Nanjing, is indicated as a mixed use area, which fundamentally does not clearly define neither the owner, nor its intended use. Originally it was part of the Liu family house property, being located within the Small Fort, which in turn was completely owned by the above mentioned family; then it changed its intended use in the last century, when it was initially used, again according to the analysis carried out, as productive housing until 1920; then it became a home until the postwar period. After this period no sure informations came to us concerning the change of property or the site owner; certainly there is that the site in the last decades has fallen into disuse to such an extent that nowadays it is submerged by vegetation, therefore requiring a new purpose of use.

▲ Fig. 4.1
The project site.
Source: Google Earth Pro + Author's elaboration

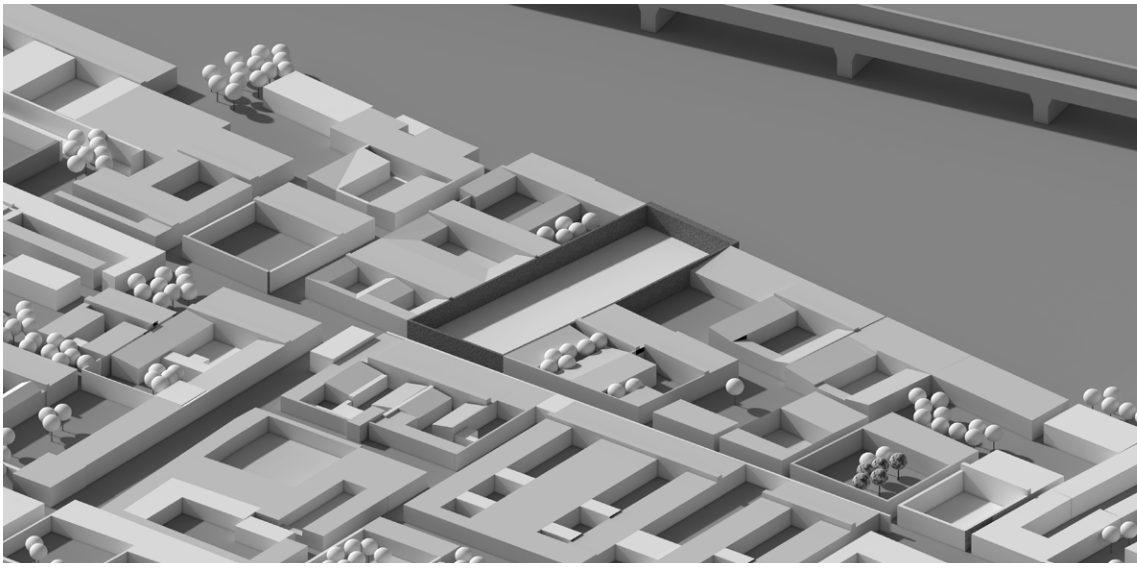


Fig. 4.2 ▶
The Project area seen from South - East.
Source: Author's elaboration

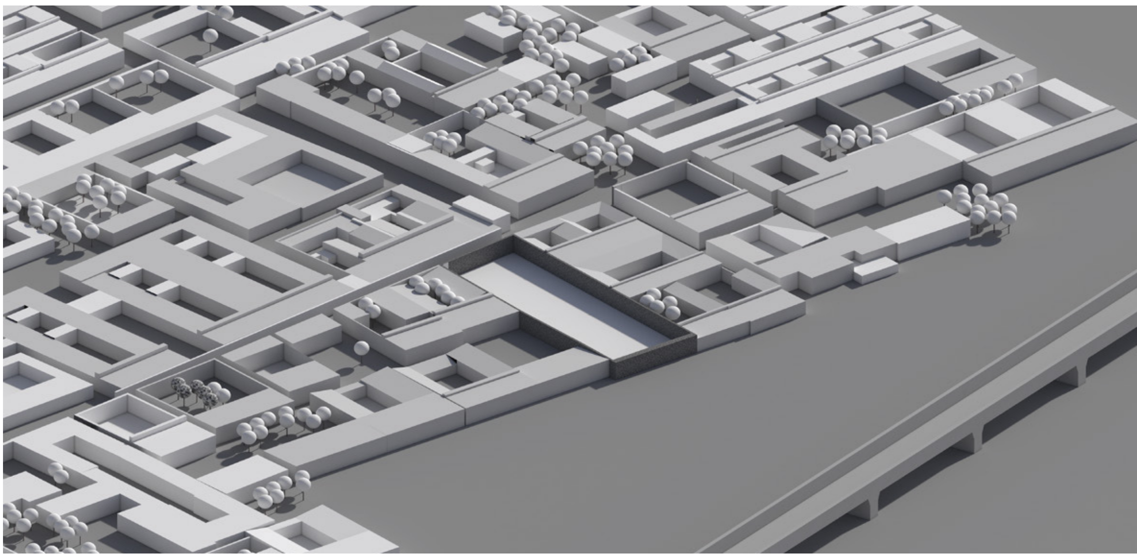


Fig. 4.3 ▶
The Project area seen from South - West.
Source: Author's elaboration

4.2 Project guidelines

The development of a project, like the one carried out in this thesis, certainly needs a broader design vision, given the difficulties in finding information, as well as for the social and economic difficulties of the place, and for all the design and symbolic characteristics that characterize the existing historic buildings of the village that must relate to a new construction project.
From the beginning it was clear how the design would have to move with maximum respect for the local reality, trying to mediate between modern characters and the retrieval of local historical and non-historical elements; all combined with an integrated energy design between passive strategies and energy systems, aimed at having the minimum possible energy consumption, made possible also by the production of energy on site.
Therefore it was important to establish right away a series of guidelines that clearly addressed the project, both at a general level and at a specific level.

4.2.1 General guidelines

> Pilot building design

The main objective of the project, was to create a pilot building, characterized by high energy efficiency, built with local constructive characters and materials and reproducible in similar rural contexts, with possible minor modifications. The building will have to respect the internationally recognized parameters to be identified as nZEB, having a very low energy consumption and producing energy on site. The goal is to create a building that in total has an energy consumption lower than 30 kWh/m^{2}year, which nowadays is the limit to classify, according to the energy certification agency CasaClima, which is one of the most important in Italy nowadays, a building as "CasaClima A". The upper level is the "CasaClima Gold", for buildings with a consumption lower than 10 kWh/m^{2}year.
Nevertheless, in such a place, the creation of something new must necessarily move together with the conservation of the existing buildings and its redevelopment. Therefore it was necessary to start from the projects carried out by NTNU and SEU, with particular attention to the Work Packages and to the thesis of Ana Despa, discussed in section 3.9; starting from them, it was possible to move with a well-defined perspective in relation to the local reality and to the characteristics that the new project should have had.
But the interest in Hou Ji could depend a lot on how the existing courtyards will be conserved and used in the future. If the present usage pattern prevails, very few owners will find it interesting to invest money in conservation, with the consequence that the buildings will decay, and the loss of cultural heritage will be substantial. The need for finding profitable use for the future courtyards, in addition to improve the owners life quality, will therefore be crucial for the future of the historic dwellings and the villages in the area.
Therefore it was important to clarify from the beginning that would be realized a project which would integrate the redevelopment plan of the existing historic

homes of Hou Ji by NTNU and SEU, and the use in new construction of new building types and energy systems, with the aim to pave the way for a renewal of Hou Ji village.

> Occupants and three intended uses

After the first design considerations, given the conformation of the site, it was decided that the design should have been directed towards the creation of several buildings, with construction and morphological characteristics as similar as possible, but with different functions. This was decided hand in hand with the choice of the intended use of the different parts of the area, this because the choice would have influenced the type of building, as well as the distribution of the buildings.
In this sense, the site is narrow and long and has the following dimensions:

width: 20.80 - 21.20 m   length: 62.40 m

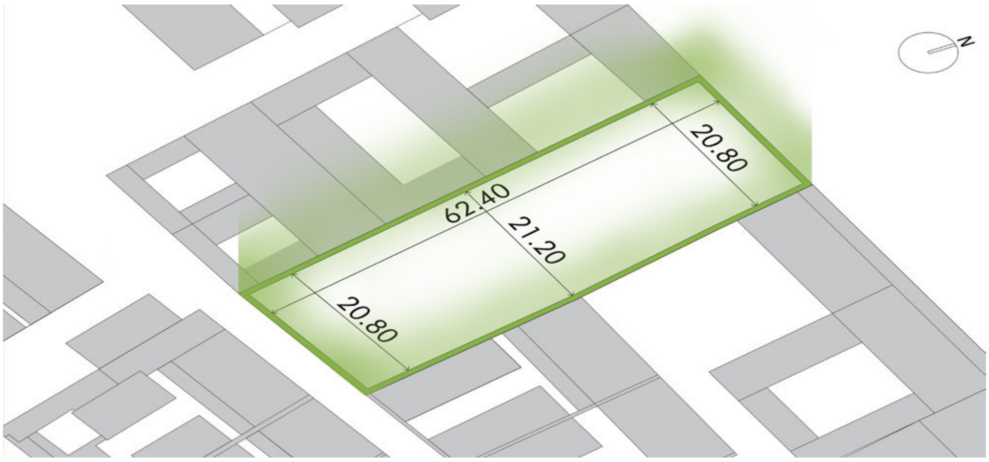
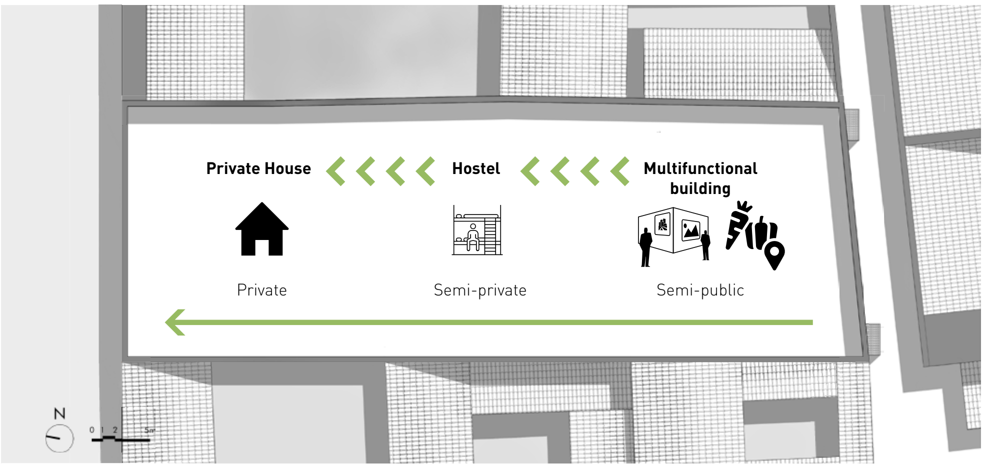


Fig. 4.4 ►
Off scale schematic representation of the project site.

Right from the start it was decided to allocate a building as a private residence, designed for a family of four to five people, who could take care of the project area throughout the year. At the same time, it immediately emerged how it was necessary to design a private house since it would have been the first choice in case of construction or reproduction in another place.
This family nucleus, likely to be found among the inhabitants of the area of Hou Ji village or the city of Pingyao, should have a medium or medium-high income and should really have interest in participating in the process of redevelopment of the village and the area.
At the same time there was the need to renovate, giving an intended use to new buildings that was not already present in the village, putting together the concepts carried out by the initial analysis on Hou Ji.
First of all it was decided to build an accommodation facility, which would put into practice the tourist reception goals designed for the area, given the proximity of the Shuanglin Temple and the ancient city of Pingyao, both UNESCO sites. The structure, designed as a hostel and therefore having affordable prices to all population segments, could be used as a base to visit the area or to learn more about the typical life of Chinese rural villages, using



◀ Fig. 4.5
Intended use of the three new building designed.

integrated farming themed workshops together with the local population.
Lastly it was decided to design a semi-public multifunctional building that could allow the local population to have a place to sell local products, fresh or cooked, or even just a space that can be used by the villagers for public activities, given the current lack of aggregation spaces.
Referring to the products sale, it is a very important concept, having the Hou Ji area a strong agricultural vocation, with most of the inhabitants occupied in that sector; therefore an intended use of this kind could increase the possibility of selling products for the local population, based on an increase in tourist attraction.
Then together with the use of the historical tradition there was the needing of a more dynamic reference, another scenario of the future use of the external space in the new project. In this way the basic concept was to introduce the idea of "agro-tourism": the rooftops and the courtyards, instead of just being paved places used only in warm periods, could have been used as space for growing vegetables and plants for the site sustenance. To do so, the goal was to integrate the ownership of the buildings in order to allow the tenants of private house to manage the hostel: the family owner, could give rooms for tourists who would like to stay in those traditional surroundings and learn to know and take part in farming activities together with the hosting family.

> Overcoming part of local traditions

In the dwellings present within the village, in many cases the inhabitants still have lifestyles unsuitable for the modern criteria of quality of life and living comfort. For example, most of domestic activities take place in a room where the kang is present, which is a raised bed made of masonry usually connected to a stove used to heat buildings and cook; therefore it is heated by the smoke from the cooking process, and represents the main source of heating during the winter season. It is understandable that the quality of indoor air is very bad and can lead to disorders and pathologies for those who live there.
In the summer instead, which can be rather hot in Hou Ji, the cooking process takes place outside in the courtyards, which brings with it other hygienic problems. Also in summer the *kang* is used for sleeping, during the daytime as well, thus not separating the internal rooms according to their function.

It is therefore important to construct buildings that have high quality standards for the life of tenants and users of buildings compared to existing ones in line with western construction and design methods.

> Guidelines from local buildings

Fig. 4.6 ▶
Image showing the uniform building height in Hou Ji and the use of flat-walkable roof.
Photo made by Ingrid T. Ødegård

Hand in hand with the overcoming of some local practices however, it was decided to utilize the most important concepts of the design of local historic houses, which is very much based on symbolic and spiritual criteria, as well as on a clear division of the spaces, strictly linked to functions and occupants. At the same time it was important that the new buildings were consistent with the neighbouring structures, with partly similar characteristics in the use of materials and also respecting the height criteria: in fact almost all the buildings in the village are one storey high, with a walkable roof; therefore since the beginning the will was to respect the local "skyline", designing buildings one floor high.

> Siheyuan

Another starting point for developing design considerations is to use the local *siheyuan* model, with its hierarchical system of sequential courts. In the local culture the courtyard works as a collective and social space for the residents,

Fig. 4.7 ▶
Five historical houses based on the siheyuan typology located south of the project site, in front of the entrance.

where each building has one door and windows addressing towards it. For domestic life it works well as a place where the family sit together performing daily life activities, where cooking takes place in the summer. Therefore it is important to use this design inspiration for including in the project courtyards that are adequately integrated with the site functions.

> Use the same construction type for all buildings

With the aim of designing buildings that are as sustainable as possible and with relatively short construction times, it was decided that the buildings should have similar construction characteristics. This is connected to the fact that the thesis is based on the design of a pilot building characterized by very precise elements, which can be reproduced with modifications of the internal spaces or of the fixtures, maintaining its main characteristics. In this sense the designed buildings should use: the same type of structure, therefore the same materials that make up the stratigraphy of walls, floor and roofs; the same passive strategies consistent with the local climate; the same type of energy system combined with the use of renewable energy production systems on site.

> Used regulations

After numerous researches concerning the Chinese and European/Italian legislative framework referred to the building sector, it was chosen to use the latters as normative references. In fact, the Italian and European regulations have much more detailed and much more stringent requirements regarding the design of new buildings with low energy consumption. The same applies to the criteria referring to the transmittance values of opaque and transparent components, which in the last few years have reached very high standards in the case of European regulations. Also regarding the renewable energy quotas that the building must produce on site: in Italy for example, according to the Legislative Decree 28/2011[1] from 2018 there is an obligation to cover with renewables at least 50% of the consumption of new buildings or buildings subjected to major renovations.

> Renewable sources

It is very important that the project foresees the use of renewable energy sources to reduce as much as possible the energy needs and the possible consumption of fossil fuels. From the outset it has been foreseen that buildings should include three systems:

• photovoltaic panels to reduce as much as possible the demand for electricity by powering electrical components and lights

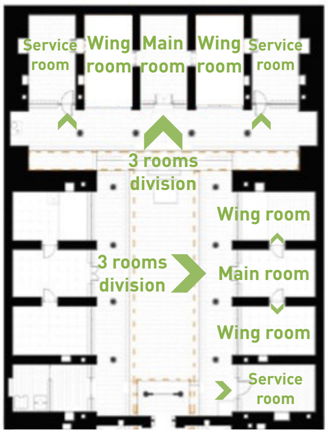
• solar thermal panels to reduce as much as possible the energy used for

4.1 Legislative Decree 03/03/2011 n.28, Implementation of Directive 2009/28/EC on the promotion of the use of energy from renewable sources, amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

heating water
• rainwater collection tank, to be used for bathroom drains or to irrigate eventual green areas.

4.2.2 Specific guidelines

> Interior spaces division



▲ Fig. 4.8
Part of the layout of the Liu House showing the interior spaces division of the local traditional architecture.

The general pattern of buildings in Hou Ji is formed by three rooms in a row, with entrance from the courtyard in the middle. This room order makes it possible to give the wing-rooms some privacy, allowing a separation of two generations, for example. In a modern design of larger buildings, this solution can be used, improving it at the same time: dividing the building into defined spaces is functional, but it is better to place the distribution inside the building, since it does not require high comfort standards, so as to avoid mixing of different thermal zones; at the same time it is necessary to place the rooms in a different way starting from the three-room subdivision system. In this sense, the goal will be to create a building divided into separate "zones" with different functions, all in relation to the best possible energy performance, but this will be explained more comprehensively in the next sections.

> Orientation of the buildings

Talking about the thermal comfort, the form and orientation of the local buildings facilitate it, mainly in the summer period, thanks to deep eaves and heavy mass in roofs and walls. But in winter, when there are very stiff temperatures, sometimes going -20 °C, in order to maintain the comfort conditions by heating the rooms, it is necessary to burn a lot of coal or wood, consequently having bad performances and indoor air quality. Otherwise the local tenants have four main measures for improving comfort:
• shifting between carrying out activities outside and inside in the different seasons
• using the heated kang, supplied as said, by coal or wood, and sometimes supplementary extra heating system as small stoves powered by electricity in the more recent house
• adapting clothing to shifting temperature
• using shutters, padded carpets and curtains at doors and windows in summer for shading from high solar radiation

▲ Fig. 4.9
Average Hou Ji building inclination compared to the N-S axis thanks to the local bio-climatic design of the traditional archietcture.
Source Google Maps + Author's re-elaboration.

Starting from this, it is clear that a fundamental guideline is to start designing buildings based on their exposure, orienting them so as to capture as much solar radiation as possible during the winter period, especially for the most used spaces. In the same way, to maintain the comfort conditions, it will be important to use external shadings, which in summer block the sunrays to enter inside the building, better if they are made with waste materials or recycled, such as beams recovered from dismantled buildings; this is necessary because orienting the building adequately means exposing it in a southerly direction to catch the low winter rays: in summer, most of the sunrays arrive from the same direction, which can cause overheating inside the buildings and increase the possible thermal loads.

> Envelope

Local buildings mainly use very thick assemblies for roofs, mainly for roofing; for this reason they are able to maintain excellent conditions of comfort in the summer. This means that using a massive roof is a good solution if properly applied. As for the walls instead, local buildings have quite heavy separating walls, but not so performing perimeter walls, resulting in high dispersions; so the goal is to re-propose the concept of heavy mass in a modern key, using thick walls inside the buildings for storing the heat in winter and cool in summer releasing them gradually, creating them in adobe that has a high thermal inertia; this combined with walls that need to have a U-value less than 0.30 W/m^2K.

> Natural light

Existing buildings have little access to direct sunlight, or rather, every part of the buildings has access to sunlight for a few hours a day, resulting in bad inside comfort conditions in each one. Therefore it is necessary to give as much space as possible to solar access in the most used rooms of the new buildings, possibly facing the less used ones, such as those of service such as bathrooms, storerooms or bedrooms, with the latter used only in the evening mainly, towards the north or east.

> Upgrades with modern bathrooms

In many cases the houses in Hou Ji don't have toilets inside, rather they are dry pail latrines with only simple roofs outside, so people suffer a lot while in the bathroom. At the same time city water can be supplied once every two days at one fixed time in order to meet the daily use; but this will change since plan for expanding the city and reach Hou Ji village are developing. It is important in this sense to delete completely this habit and realize modern bathrooms, integrating them inside the buildings, and hydraulic systems connected to the drainage system.

> Green roofs and courtyards

One of the fundamental points since the beginning of the project, was the need to use, where possible, vegetation, intended as ornamental plants or as a cultivable vegetable garden, to completely integrate the concepts of sustainability at the base of the project. To do this, in anticipation of creating courtyards and flat roofs, following the local model, the consequence has been to design courtyards and roofs so that they can accommodate plants, that are at most medium in size, so as to avoid excessive structural systems to maintain them the weight in the roof case. The roof above all, in addition

to having considerable advantages for maintaining the internal comfort conditions, makes it possible to have a cultivable surface that would otherwise be unthinkable.
This guideline goes hand in hand with the idea of "agro-tourism", mentioned previously, which aims to focus on the theme of agriculture, as a means to attract tourists and students. This is compatible with the fact that a building could be the family dwelling of the owner, which can manage rooms for tourists who would like to stay in those traditional surroundings and learn to know and take part in farming activities together with the hosting family.
This way of using the courtyards could be a possible and realistic way of combining local traditions and modernization, and at the same time giving new income possibilities for the owners of the courtyards.

> Kang for bedrooms

In the historical houses the wing rooms usually have a *kang*, which consists of a brick platform raised about a meter above the floor, with a depth of about two meters while the length follows that of the wall on which it is placed, usually the south side of the bedroom or main bedroom. The structure and operation are similar to those of a furnace or a fireplace: the system starts from a stove used for cooking housed at one end of the bed, in which wood or coal is burned. From here the fumes and gases are conveyed into the enclosed space of raised bricks to then be expelled out of the house. In this way the plan, formed by a layer of stone made smooth and horizontal thanks to a type of cement on which a soft and warm cloth is placed, the *kangxi*, is heated. In this way the kang is used during the day as a work surface and as a base for various activities, to the point that winter days are spent on it. Its dimensions allow it to accommodate beds for the entire family, even though in ancient times the place on the kang was reserved for guests or older or more important members of the family.
But the system has several weak points, such as poor efficiency, high consumption of wood and coal, risk of fires and above all poor indoor air quality, so its application to the letter is impractical: in the current project the system could possibly be used if designed with modern standards and only for bedrooms, with the use of a sort of raised heating floor.

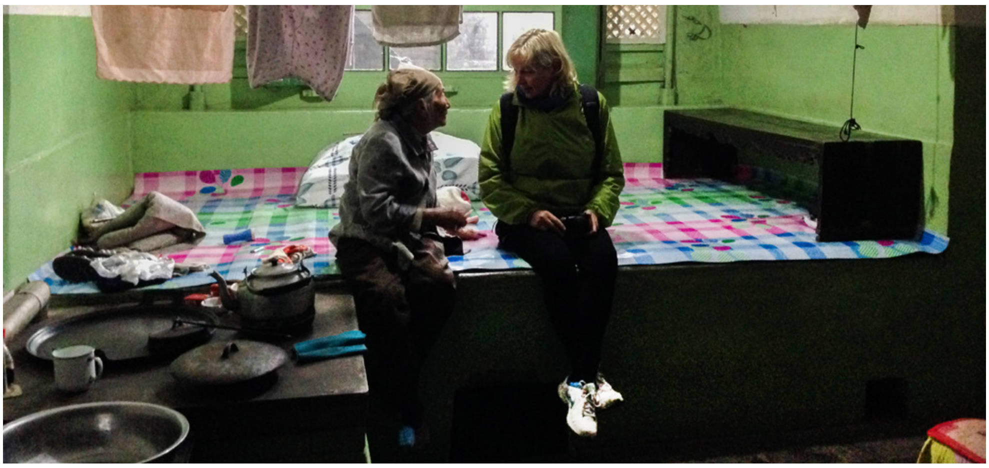
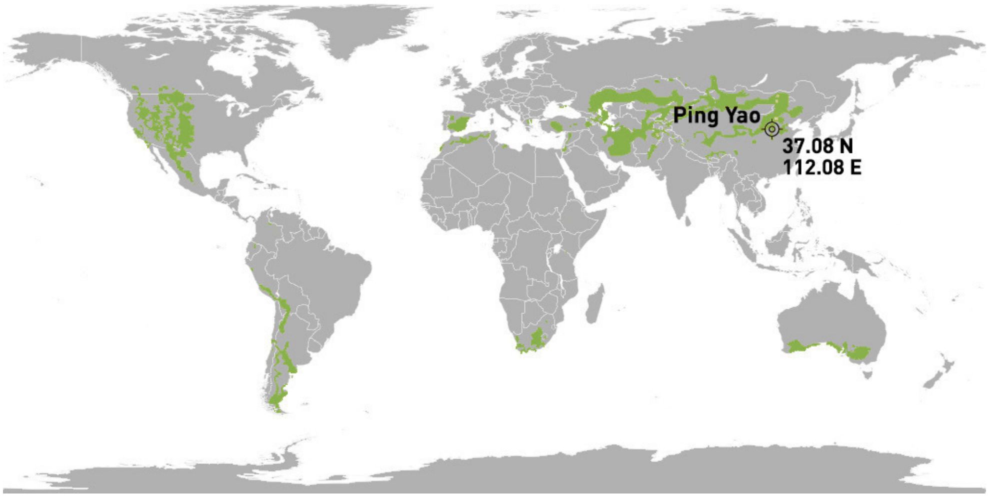


Fig. 4.10 ▶
Kang bed in the Liu House in the Hou Ji village.
Photo made by Ingrid T. Ødegård

4.3 Climate analysis



◀ Fig. 4.11
Pingyao's climatic classification, which is cold semi-arid, according to BSk Koppen-Geiger classification.

After defining the guidelines, the following action was to carry out an in-depth climate analysis for starting to define the passive strategies.
The bio-climatic design and the most appropriate compositional choices to contain energy consumption are the competence and prerogative of architectural design. The first step in this sense is an accurate climate analysis that can allow to fully understand the characteristics of the local climate, so as to integrate them, in the best possible way, in the design choices, having clear the goal of minimizing the future energy consumption of new buildings.

The Hou Ji village, located in Pingyao's area, is found in a cold semi-arid climate, under BSk Koppen-Geiger classification[2] . This type of climate, mainly cold and semi-arid with high diurnal variations in temperature, is located in temperate zones, far away from large bodies of water (Peel, 2007), like the central part of Shanxi is. This part of China is broad and flat, with villages located between mountains and ravines: for this reason the temperature here is lower than other areas in the North China Plain because of the higher altitude and the nearby mountain blocking the south-east ocean air-stream.
The following climatic data were taken from the nearest available weather station, which is located in the city of Pingyao, that being around 5 km far from Hou Ji village, in the north east direction, has the same climatic and geomorphological characteristics of the project site.
HouJi, as well as the whole area, including the cities of Pingyao and Taiyuan, has a climate that experiences great temperature variations during the year. In fact, it passes from very cold winters to very hot summers, with fluctuating intermediate seasons. In fact, over the course of the year, the temperature typically varies from -5°C to 34°C and is rarely below -10°C or above 38°C.
It can be said that summertime is often hot, humid, with temperatures quite

4.2 BSk Koppen-Geiger climate classification system, firstly published by the Russian climatologist Wladimir Köppen in 1884 then improved by the climatologist Rudolf Geiger until the 1961, is used to classify global climates in an empirical manner defining them on the basis of pre-established temperature and precipitation values, calculated according to the annual or single month averages.

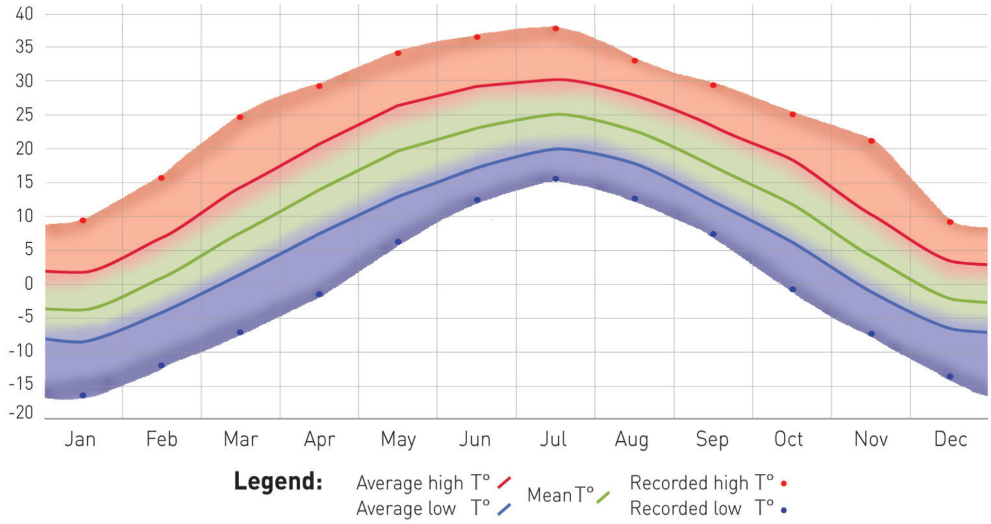


Fig. 4.12 ▶
Pingyao's average temperatures.
Source: Climate consultant+Author's elaboration

often over 30 °C during the day, especially during June, July and August that are the hottest months, with July that is the hottest month of the year, having an average of 25°C; in this month is also possible to reach almost 40 °C. June and August have a mean T° of 22 °C.

Therefore a well designed external shading system must be designed, in order to prevent the sunlight to enter in the buildings during hit months. Together with that, a good air circulation must be provided, whether natural or mechanical. The winter instead is characterized by very cold temperatures, often around 0 °C, with peaks of even -10 °C, partly caused by winds from Siberia. The coldest months are those from November to February, with January that is the coldest one, having an average temperature of -3 °C; the average T° of the other months are also low: November 3 °C, December -2 °C, February 0 °C.

Therefore it is important to design a well insulated building, favouring the solar gains related to low winter sun together with a high-performance energy system, while at the same time reducing dispersions. High performance windows will also be needed. The springtime is quite short, with temperature varying greatly between day and night, and also between one month to another: March has a mean of 7 °C, April 13°C.

Autumn days have falling temperatures, with little rain, and are cool and clear with abundant sunshine. September has a mean T° of 17 °C, October 11°C.

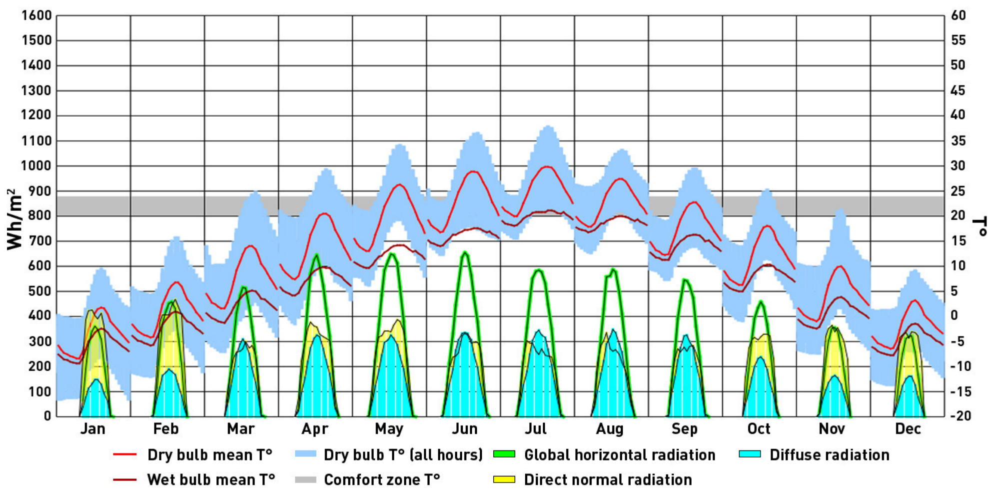
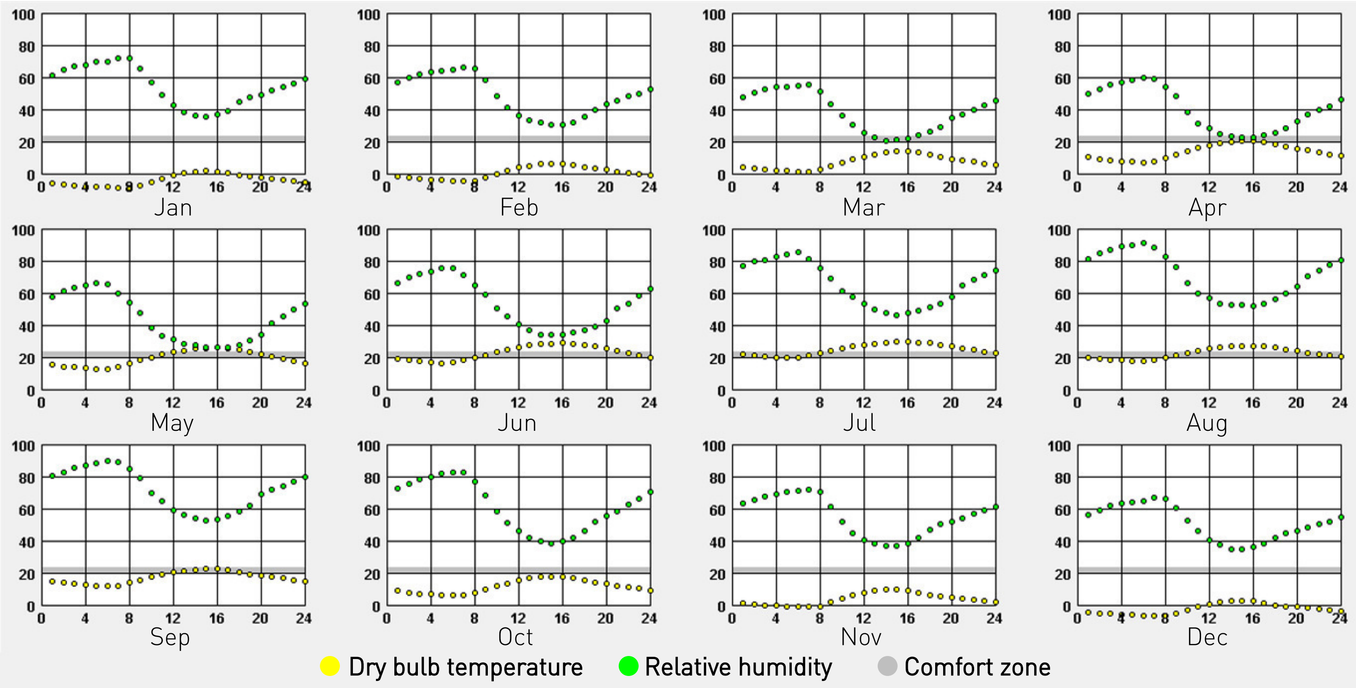


Fig. 4.13 ▶
Pingyao's average temperature and solar radiation
Source: Climate consultant



Relative Humidity (Average Monthly) %	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	54	48	38	40	44	53	65	71	72	61	55	51

▲ Fig. 4.14
Dry bulb temperature and relative humidity along the year.
Source: Climate Consultant + Author's elaboration

Regarding the humidity rate, analyzed on an annual scale, the average values obtained for most of the year have acceptable values, which lie within the range of hygrometric comfort expected for the buildings designed.
The analysis in this case made reference to the UNI EN ISO 7730[3], which defines several parameters of indoor comfort and identifies, in an ideal condition with a perceived temperature of about 20 ° C, a percentage of relative humidity RH of 50-55 %. On this basis, it is common to assume values of RH of 45% during winter and of 55% during the summer, as values of RH to be maintained within the indoor environment; to these is added a tolerance of 10%, thus having a relative humidity range of 35-65%.
These values were chosen on the basis of hygienic and sanitary criteria, which foresee for a continuous exposure to a RH lower than 30% the occurrence of mucosal irritations, while for a value higher than 70% the risk of mold growth inside inhabited environment.
In the project site, the months that present conditions with the highest risk of discomfort exceeding the established range of 35-65% are August and September, which, in particular between 23.00 PM and 9.00 PM, exceed 65%, with peaks of 85%. March and April instead are the months that present the worst discomfort conditions with values below the established range: in particular between 11.00 AM and 21.00 PM the values easily fall below 35%, with peaks of 20% of RH. It will therefore be necessary to design the building in such a way as to create natural ventilation conditions that facilitate the air movement, mainly during the night-time summer hours, while on the contrary it will be important to try to increase the internal RH values in the coldest months with passive gain mechanisms; all combined with the inclusion, in the ventilation system, of the component for air dehumidification/humidification.

4.3 UNI EN ISO 7730:2006, Ergonomics of thermal environments - Analytical determination and interpretation of thermal well-being by calculating the PMV and PPD indices and the local thermal comfort criteria

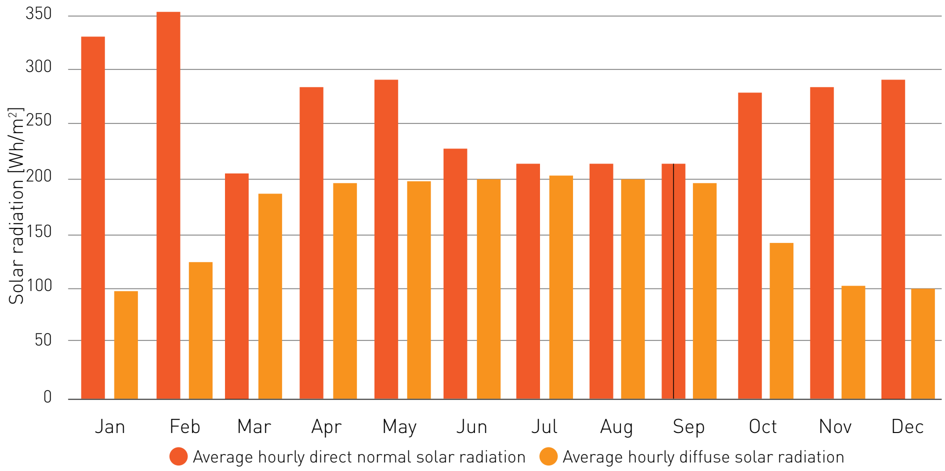


Fig. 4.15 ▶
Average hourly direct normal and diffuse solar radiation in Pingyao.
Source: Climate Consultant + Author's elaboration

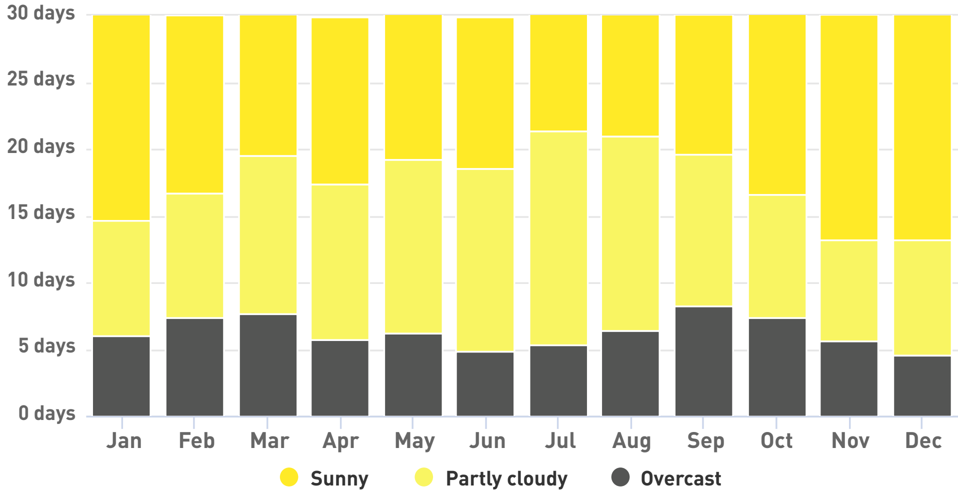
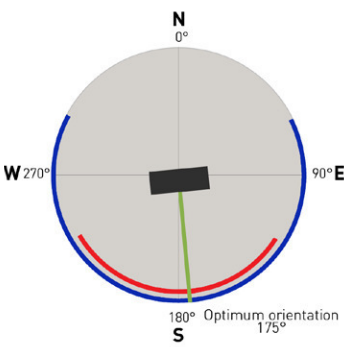
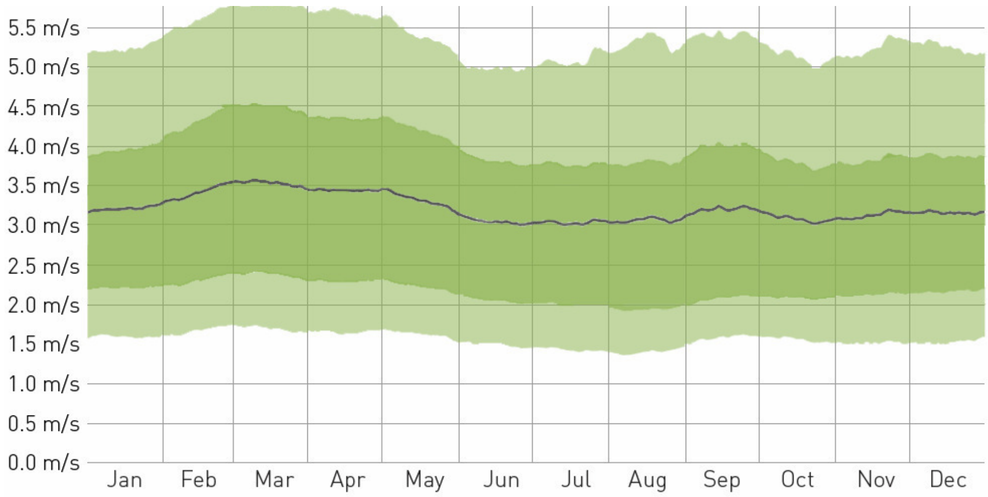


Fig. 4.16 ▶
Monthly number of sunny, partly cloudy, overcast days in Pingyao.
Source: Author's elaboration

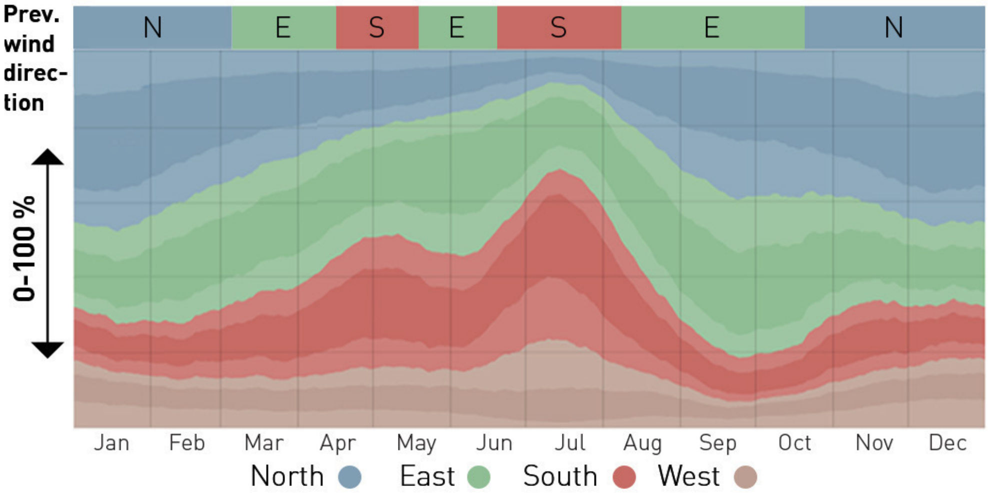
The upper graph refers to the average hourly direct normal and diffuse solar radiation throughout the year, where the first refers to the radiation that reaches directly a surface, while the second to the radiation that reaches a surface after being reflected. It experiences significant seasonal variation over the course of the year: for the direct radiation the higher values occur in the colder months from October to January, when the sun is lower, with February that has the higher one, 353 Wh/m^2. On the other hand, the diffuse radiation has an opposite path, with the hottest months from May to August that have the higher values, with July that has the higher one, 206 Wh/m^2.
From the second graph, which shows the monthly trend of sunny, partly cloudy and overcast days, it can be seen that about 40 % of the year it is possible to have clear sky, about 40 % cloudy sky and about 20 % an overcast sky.
It is therefore important, after evaluating solar gains from the windows, to think of external screening systems during the months from May to August. In the colder period, from November to March, the diffuse radiation decreases a lot and direct increases: so it will be important to use glasses that help to capture more sunrays. At the same time the second analysis, showed the convenience of installing solar and photovoltaic systems, since averagely along the year the overcast days are few compared to sunny and cloudy days.
Then, during some preliminary analysis on the software Ecotect, it was obtained an optimal orientation of 175°, based on average daily incident radiation on a vertical surface, for the new buildings that will be located in the project site, which means an inclination of 5° compared to the N-S axis.



▲ Fig. 4.17
Optimal orientation for new constructions in HouJi Village based on average daily incident radiation.
Red line refers to the hot season, blue line refers to the cold season.
Source: Ecotect + Author's elaboration

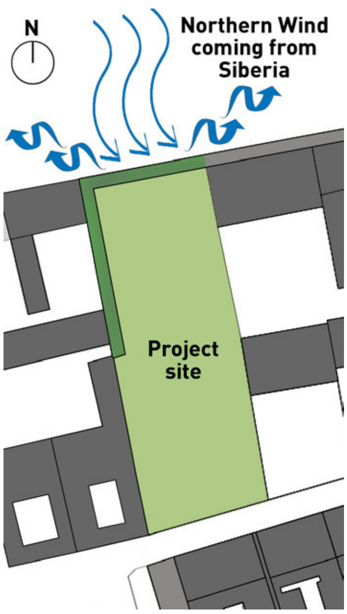


◀ Fig. 4.18
Pingyao's average wind speed.
Source: Climate consultant+Author's elaboration



◀ Fig. 4.19
Pingyao's prevalent wind direction.
Source: Climate consultant+Author's elaboration

The Pingyao area isn't windy, with speed values usually (in case of wind) in the order of 2-3 m /s, experiencing mild seasonal variation over the course of the year. The windier part of the year lasts from February to May, with average wind speeds of about 3.3 m/s.
The predominant average hourly wind direction instead, in Pingyao varies throughout the year, with the only exception of the west direction. During the hottest months in summer, from June to August, the wind comes most often from south and east direction, arriving from the Pacific coast, with a prevalence of the south, with a peak percentage of 45% on mid July.
During the mid-seasons, i.e. for spring and autumn, the wind comes most of the time from east direction, especially from beginning of March to mid of April and from mid August to mid October.
During the coldest months of the year, for about five months, from mid October to the beginning of March, the wind comes most often from the north, arriving from Siberia, with a peak percentage of 45% on the beginning of January.
After these analysis it was decided to keep the border wall existing in the north part of the site, because, besides being a relatively important historical find, being part of the old walls system of the Small Fort, it allows to completely block the harsh winds coming from Siberia during the colder months; in this way it is possible to reduce their impact on new buildings, thus increasing energy efficiency due to lower consumption to redirect them.



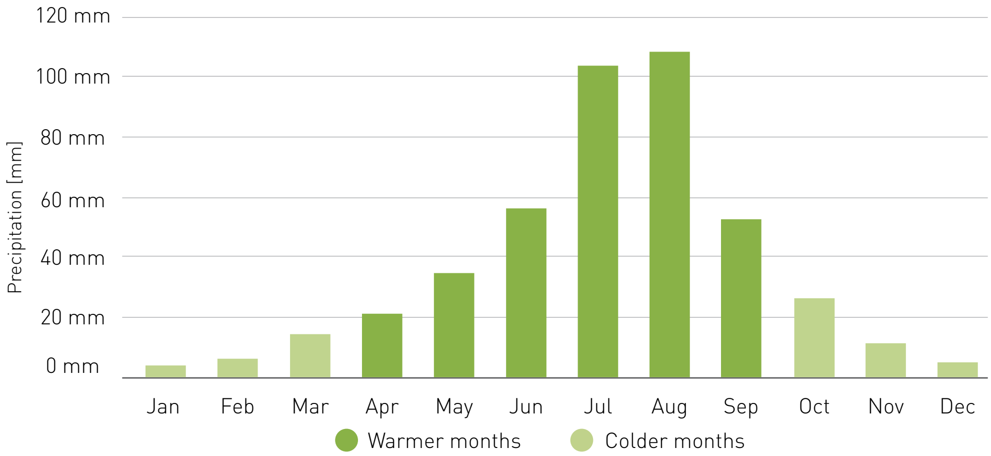


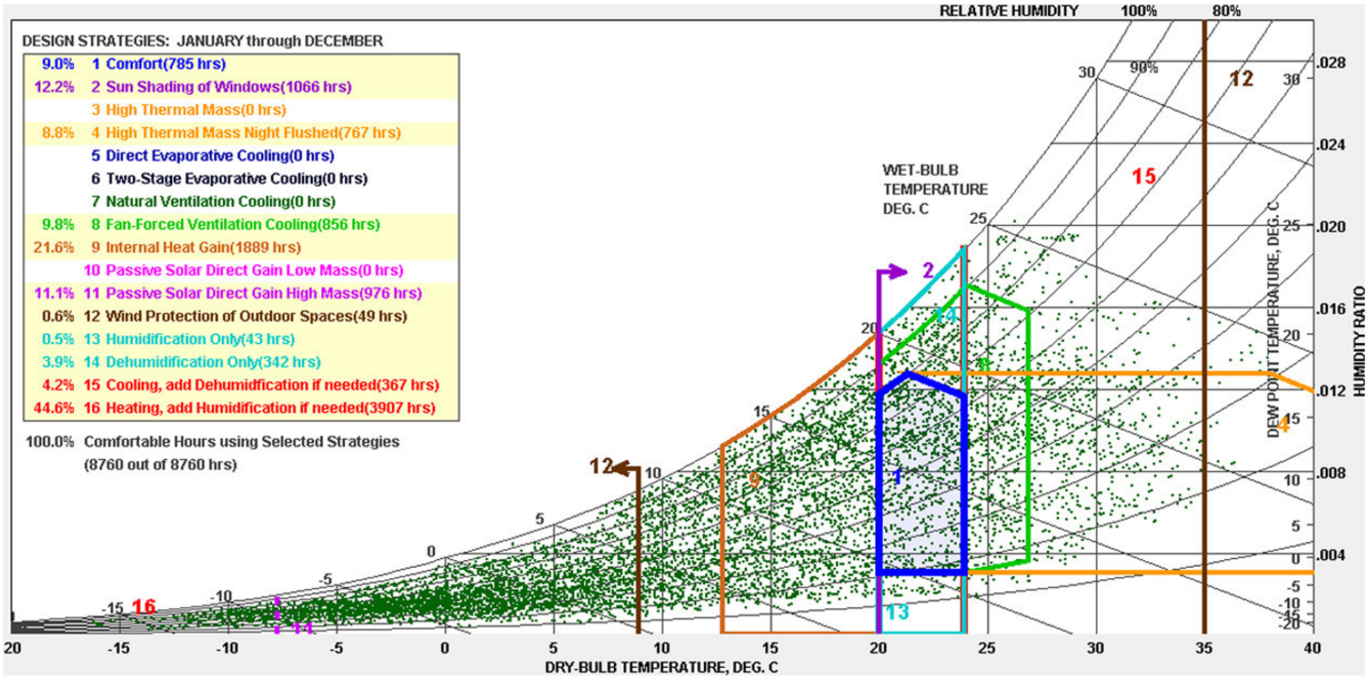
Fig. 20 ▶
Average precipitation in Pingyao. Author's elaboration

In this area, most rainfall is seen during the hottest months of the year, to be precise from May to September (rainy season), with the highest peaks during July and August, with July that is the hottest one. Instead, the dry period is seen in January, February, March, November and December.
On average, August is the wettest month, with average precipitations of about 100-120 mm, while December is the driest month with about 5 mm of rainfall.
In general, the average amount of annual precipitation is about 435.0 mm.
Talking about the snow, in this area it does not happen very frequently over the course of the year, remaining in the order of few centimeters therefore anomalous events in this sense are unlikely to occur.

At the end of the climatic analysis, the software Climate Consultant[4], used for all the studies listed in the previous pages, returned a psychrometric chart in which all the suggestions for achieving comfort conditions at the project site are highlighted, based on to local climatic conditions. This is possible since both the exact geographical location in which the analysis is to be performed and its relative climate file in .epw format have been set within the software.
Climate Consultant, performing an annual analysis from January to December, as can be seen from the chart in the next page, analyses the distribution of the psychrometric chart in each "Design Strategy zone" (i.e. the areas delimited by coloured lines, one for each strategy) in order to give back a unique list of "Design Strategies" for the location set. To do this, it analyses at the same time the position of each green dot, that represents temperature and humidity of each of the 8760 hours per year.
The percentage of hours that fall into each of the 16 different Design Strategy Zones gives a relative idea of the most effective heating or cooling strategies that could be used in order to satisfy the comfort conditions.
The psychrometric chart allows to analyse simultaneously different informations: in the X axis (and the relative vertical lines) there is the dry-bulb temperature; in the Y axis (and the related horizontal lines) there is the absolute humidity rate, i.e. the amount of moisture in the air ($kg_{water}/kg_{dry\ air}$);

◀ Fig. 21
Cold wind coming from Siberia blocked by the existing north wall in the project site.

4.4 Climate Consultant, developed by the UCLA Energy Design Tools Group, is a graphic-based computer program that allow to analyses the climate of a specific place. It uses annual 8760 hour EPW format climate data given by the US Department of Energy for thousands of weather stations around the world. Climate Consultant translates this raw climate data into dozens of meaningful graphic displays. (http://www.energy-design-tools.aud.ucla.edu/climate-consultant/)



▲ Fig. 4.22
Psychrometric chart showing the advised passive strategies for the project location.
Source: Climate Consultant + Author's elaboration

the relative humidity is represented by the curved lines, among which, the first from above is the saturation line, which shows how much moisture the air can contain at different temperatures; the diagonal lines refer to the wet bulb temperature.

As it can be seen from the chart, there are comfort conditions without the use of any strategy, only for 785 hours a year, which means 9%. Starting from this, it can be noted that there are four main design strategies. "Sun shading of windows", in light orange, equal to 12.2% of the time, allows to deduce that it is necessary to shade well during summer to avoid overheating and decrease the cooling loads; in this sense it can be useful to create a shaded area, such as a patio or porches on the south side, which would allow to enlarge the spaces of the house by shading at the same time, or to have a courtyard protected from wind, that works as a "buffer". "Internal heat gains", in dark orange and equal to 21.6% (i.e. 1889 hours), that delimits the temperature range 13-20 °C, allows to deduce that it is necessary to make great use of the internal gains of lights, people, equipment etc. to reduce the heating load in cold periods; to do this it is necessary to isolate the building well to reduce dispersion. "Passive solar direct gain", in purple, equal to 11.1% allows to infer how important it is to orient the building well and that most of the glass surface is on the south side to maximize the winter sun exposure and allow the winter sun to penetrate into daytime used spaces; similarly it is useful to use high mass interior surfaces, to store the heat, and high performance windows. "Heating", with 44.6%, is the highest value, and shows that, being a cold climate, it is advisable to have a compact and well-insulated building to maintain heat, using internal thermal masses and a high-performance energy system having inside it a heat recovery unit, given the required heating load. The other main strategies refer to: using fan forced ventilation cooling in the summer; to have a humidity control system; to use thermal mass for storing the cool having at the same time a good thermal inertia to keep the rooms cool and not conditioning summer nights.

4.4 Micro-urban and project site design strategies

There is not a real univocal rule for the construction of nearly zero-energy buildings, but rather some principles to be respected to develop a project that is as efficient as possible.
Based on the environmental and climate context, the first step is always to search for passive strategies that minimize energy demand, which is why it is fundamental to study aspects such as the shape and orientation of buildings, taking into consideration factors such as radiation, the prevailing winds, temperatures and shading, which can be obtained from an accurate climatic analysis, like the one made in the previous section.
In the same way, buildings must take into account seasonal variations, therefore in winter the solar radiation should be used as much as possible, maximizing thermal accumulation and guaranteeing thermal insulation; in summer, on the other hand, it is necessary to shade the building well, to study the best performing thermal insulation technique and take advantage of the natural ventilation.
To these elements it is added, as a last step, the definition of energy systems and renewable energy production systems, which help to reduce the total building consumption. As regards the active systems, their design must be suited on the different spaces intended use and adapt to changes in the local climate, being constantly monitored: this is the only way to achieve high levels of efficiency, integrating architecture, plant engineering and passive strategies.

> Project site

The step after the urban, historical and climatic analysis of the Hou Ji village in the design process was to deeply analyse the project site. It is identified, as described in sections 4.1 and 4.2, as an urban void, of narrow and elongated shape and is surrounded by existing walls, which in turn, on the East and West sides border on existing buildings, on the North side face a cultivated

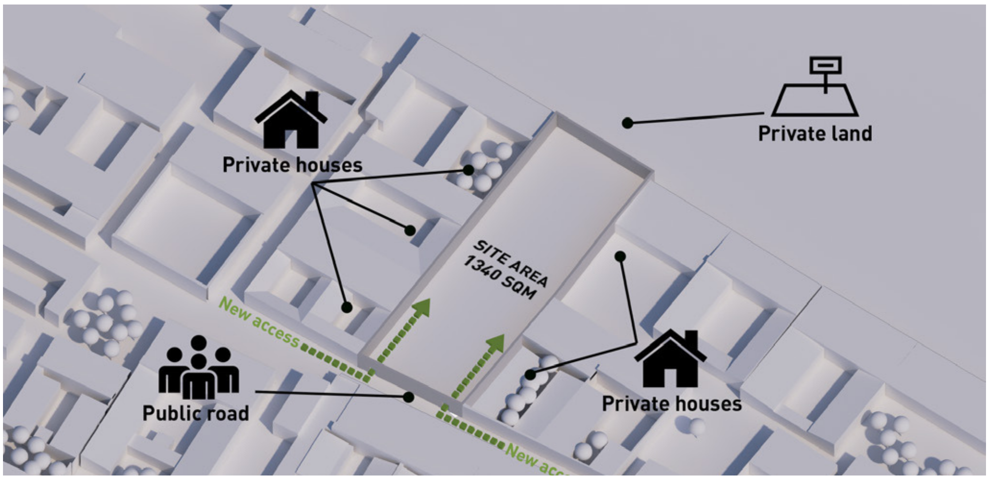
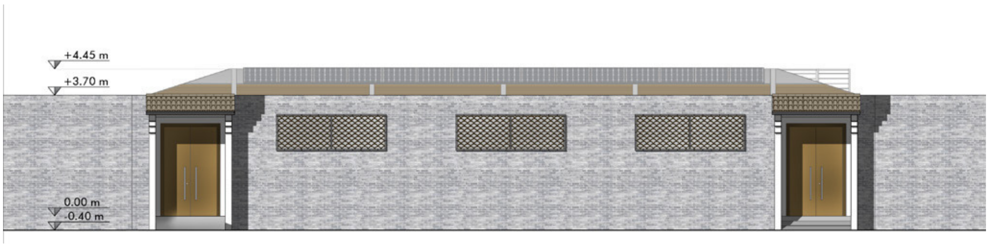


Fig. 4.23 ▶
Neighbouring properties and access to the site.

area, while on the South side they border with one of the main roads of the northern part of the village.
The project site is arranged on an area of about 1340 m^2 and it is located in a pattern typical of a rural village: the adjacent houses are all dwellings one floor high owned by single families, or inhabited by several related family units.
First of all, the accesses of the area were decided, inevitably placing them on the south side, as it is the only one facing a public road and it is assured that it can be used, while the east and west sides cannot, since they border with other properties; the north side, on the other hand, is free, but since it is not possible to have information on the property, on its possible buildability or on a possible use plan, it was decided to exclude it, to avoid serious issues in the project.
Having determined that the area would be divided into three parts during the definition of the guidelines, two entrances were designed, placed at the two ends of the southern perimeter wall, to make access easier and, above all, to create a "more private" access, usable by the owners of the area.
The entrances have large dimensions, width = 1.60 m and height = 2.70 m, in continuity with the typology of those of the historical dwellings located in the neighbourhood. In fact, as mentioned during the analysis on Hou Ji, in the immediate vicinity there are many buildings of historical relevance subject to redevelopment through the projects carried out by NTNU and SEU. Any type of access to cars and motorized vehicles was immediately excluded; the south-west entrance has been equipped with a ramp in order to allow entry to disabled people, bicycles and handcarts, while the south-east entrance has three stairs about 13 cm high each.
The entrances are raised above the street level since the latter is located about 0.40 m lower than the project site level.
Lastly, three symmetrical openings have been designed on the entrance wall, with a height = 1 m and width = 3.20 m to allow greater light access to the initial part of the area during daylight hours. This was decided starting from the fact that the boundary walls have a high height, to be precise 3.70 m along the perimeter of the project site and 4.10 m on the street side.

▲ Fig. 4.24
Entrance of a traditional house in the Hou Ji village.
Photo made by Ingrid T. Ødegård



◀ Fig. 4.25
South entrance facade.

> Intended use of the buildings and their users

As mentioned in section 4.2, at the beginning of the thesis design path, after choosing which area to use, it has been decided how many buildings to design and with which intended use and buildings users.

From the analysis carried out by NTNU and SEU it emerged how it was initially important to consider the demographic changes during a pilot project design, in order to realize the economic and social development goals. Presumably, the following groups would gather in the reconstructed district for long term:

- returned migrant workers
- people residing elsewhere finally returns to their native land (such as returned overseas Chinese)
- the retired urban rich (such as retired cadres, the intellectual and entrepreneurs)
- female from economically undeveloped area who married with local men
- practitioner of manufacturing industry whose production activity is not constrained by time and space
- local farmers
- People staying in Hou Ji for a short time: seasonal tourist; professionals, scholars and students attracted here for session of urban planning or visit; people in the region that will take this place like a wonderful tourist destination.

In the same way, the starting points for determining the intended uses of the area were the following:

- need to design a private home
- design an accommodation facility, on the basis of an increase in the tourist influx in the area
- create a new economic growth point
- provide a reference model for the reconstruction of declining rural areas and ancient villages
- starting from the local architectural tradition and combine it with a more modern vision

It therefore seemed obvious that, given also the length of the project site and the will to have different intended uses, it was necessary to design more than one building. Three uses have taken on greater importance than others, based on all the considerations made and the guidelines of section 4.2:

- a multifunctional facility that can be used by the population of the village
- an accommodation facility, as a hostel
- a private home

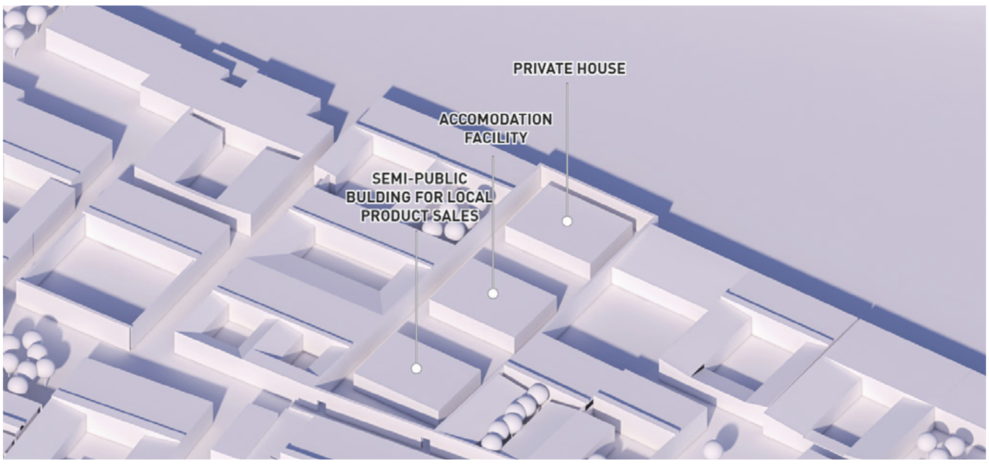


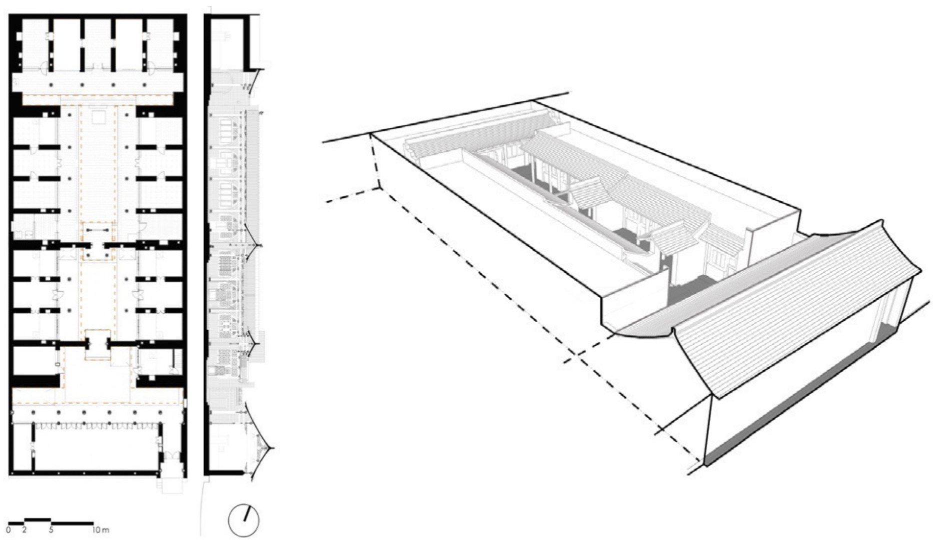
Fig. 4.26 ▶
Intended use of the three new building designed.

Each intended use puts into practice all the considerations and studies carried out. The private home project allows to have a valid reference model that can be reused in other similar rural situations as well as, in practice, to have a family that manages the project site. In this case, the tenants were planned to be a middle-income or middle high-income family returning from abroad or retired urban rich or returned migrant workers, interested in investing in the village of Hou Ji and to supervise the area.
The hostel allows to answer to the need to have a building that can accommodate tourists, based on an increase in the tourist attraction of the area, or students or people who want to visit the villages in the area and deepen the local culture.
The multifunctional building allows to create a new growth point, where food products, fresh or cooked, or local goods can be sold, giving at the same time the villagers an aggregation point. This building is also designed to be used as exhibition space

The buildings are all designed to have a single building typology, without differentiating them very much, in order to facilitate their design and construction, thus reducing construction times and costs. Thanks to this choice it was possible to adequately deepen the design of a pilot building, the central theme of the thesis.

> Design of the project site ground floor

After establishing the intended use, users and the number of buildings, a real general shape of the project was started, defining the plan of the area.
To decide layout and size of the paved surface of the buildings, several factors were analysed: firstly, traditional house styles and their main features were studied to understand what could be used and what could be rethought.
Looking at the local historical architecture, they are divided in order to have



◀ Fig. 4.27
Example of the local traditional house type.
Liu House ground floor plan, section and 3d view.
Off scale

one or more courts within them; in those similar in size to that of the project site, there are three courts.
The local houses follow the rules of the traditional *siheyuan*, with single story pavillions arranged along the perimeter overlooking the inner courtyard; the houses are of a single floor as well as for greater ease of distribution and better access to sunlight: the belief is that living on ground floor keeps the people closer to earth, to energy qi (Zhang, 2013).
The North, East and West houses have the *yaodong* structure, while the South house has the *dauzuo* structure. The yaodong are formed by equal rectangular rooms positioned symmetrically between them; the dauzuo is a unique large space.
In this sense, the traditional houses are distinguished by some characteristic elements:

- axial and symmetrical planning principle
- enclosure of space by buildings and walls
- distinct hierarchical order
- internal courtyards

The theme of internal courts has been a fundamental element in the design, as it is a very important space in the local culture.
The court is not meant to be used frequently, but has the function of being an opening to the sky and a source of light and air. The courts are usually divided by gates and occupy between 15 and 20% of the total area.
Philosophically, the courtyards acted as link between Heaven and Earth, since the Chinese regarded Heaven and Earth as a macrocosm and the human body a microcosm to reflect the universe (Chang, 1986, in Zhang, 2013); in fact, inside the courts, looking upwards it is possible to see the celestial vault uniquely and nothing else. The courtyard is seen as the hub of a miniature society of the clan family, where the centre was the family and the ideal was the harmonious living (Despa A.M., 2015).
The conjunction between courtyards and dwellings is provided by verandas, which cover the entire internal length of the buildings; they play the role of distributive space among the pavillions, protecting at the same time from the

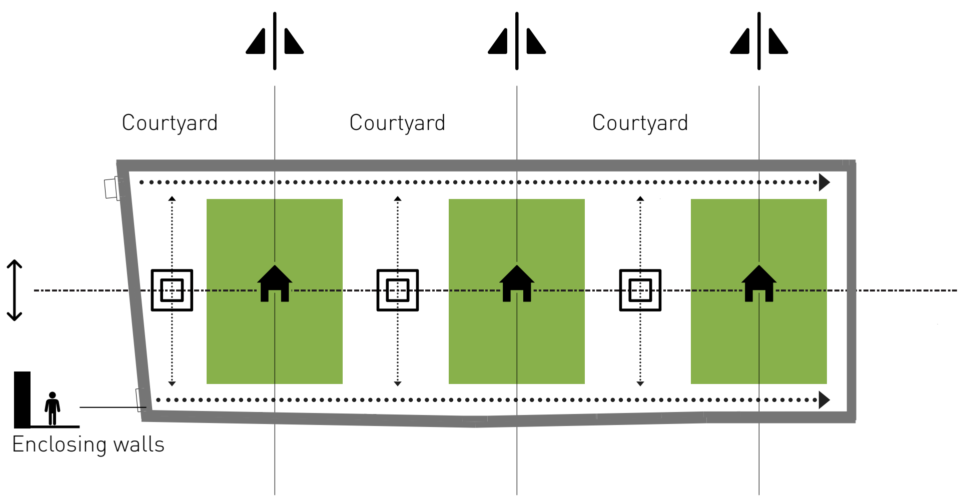


Fig. 4.28 ▶
Project site design guidelines

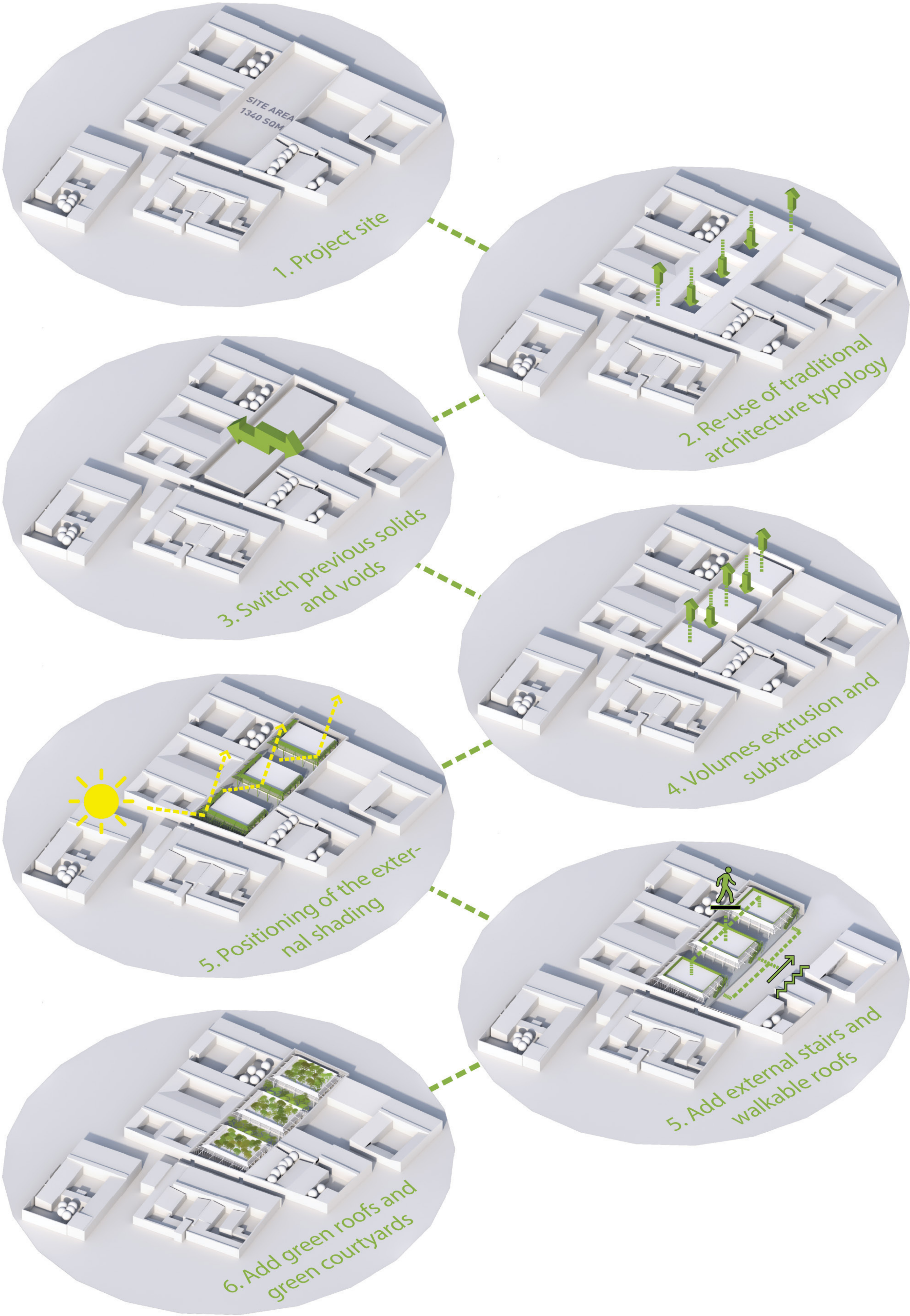
bad weather and the sun in the summer period. In the same way they act as a buffer space between dark homes and bright courtyards.
As mentioned, axiality, symmetry, enclosure and hierarchy are the basis of traditional houses design, both in plan and in height, because the symmetrical and complete form of classical Chinese courtyard houses aimed to psychologically fulfil human desire for perfection (Zhang, 2013).
To understand the meaning of "hierarchical order" instead, it is necessary to take the example of the Liu House: the entrance is in the south-east corner, then there's a transition from the public road to the first courtyard, working as a service zone or guest area, which is semi-public; progressing, there's the second courtyard reserved for family members and staff, which is semi-private; lastly, there's the third courtyard that is the family area and is private.
The hierarchical order can be seen from the intended uses of the buildings: the dauzuo, facing north, is where the staff was living and the grains was stored; then, in the wing houses people lived according to the degree of kinship: if they lived in the second or third court, depended on how close the relationship was; lastly, the Principal House, the only one facing south, is where the oldest members of the family lived. The roof of principal house and wing houses is flat, since that was used for drying the crops.
The buildings consist of "living units" formed by three rooms of 3 by 5 meters, with access from the central one, which is also the most important and representative room; it is the living room, the side rooms are the bedrooms.
All the openings face the inner courtyard, and the only door that leads to the outside is the entrance and is positioned in the living room.

For the project site, the symbolisms and characteristic elements of the local architecture were the starting point for the development of the project.
Founding elements were:

symmetry   axiality   hierarchical order
courtyards   solids/voids

Since the buildings would have been three, it was decided to place them following a hierarchical order, as in the local tradition; the more one proceeds inside, the more the buildings' function is private: the multi-functional structure is semi-public, the hostel is semi-private, while the house is private.
Using three buildings, it seemed necessary to divide the site into three homogeneous areas, in order to guarantee a consistent amount of space for each one.
Then it was necessary to give a shape to the buildings and to understand how to place them in the project site.
Initially the classical courtyard typology of the local tradition was taken up with the verandas along the entire internal perimeter; nevertheless in this way the sun exposure of the buildings would have been too discontinuous and, above all, the building circulation would have represented a big problem: the only solution for the circulation, with the rooms placed along the perimeter, would be to use the porches again, but this clashes with the nZEB design

Fig. 4.26 ►
The concept of the project


SITE AREA
1340 SQM
1. Project site
2. Re-use of traditional architecture typology
3. Switch previous solids and voids
4. Volumes extrusion and subtraction
5. Positioning of the external shading
5. Add external stairs and walkable roofs
6. Add green roofs and green courtyards

criteria, as it involves the passage from the outside to change rooms with consequent thermal stresses and heat losses; other types of arrangement, such as placing all the passages between the border wall and the rooms would have been inconvenient as a veranda would have been necessary to shade them from the sun during summer, with consequent reduction in the size of the courts and solar contributions.

Therefore the choice was to invert the concept at the base of the courtyard system: the buildings are no longer placed along the border walls but are spaced apart from them, moving towards the center, while the distribution is placed along the boundary walls; the courtyards are maintained, but instead of being narrow and stretched vertically, they are arranged horizontally along the length of the building. Thus it is possible to improve the overall distribution, the access to the buildings and their sun exposure.
To partly rethink the vision of the courts in the local culture, it was decided that they should have been a space used for most of the year, both to do something practical and to create a common space for building users.
In fact, as will be detailed in the following pages, the goal was to integrate the concept of agro-tourism and use of green spaces with the use of flat roofs and internal courtyards for having cultivable areas that can contribute to the local subsistence or can be used for activities on site, combining these concepts with the bio-climatic functions they perform.
At this point, in order to find a compromise between the dimensions of the buildings in plan and their distance from the boundary walls, it was decided that this distance should have been 2.70 meters on average, to guarantee a smooth passage and access to sunlight for all the rooms, allowing at the same time to have acceptable internal dimensions. In this way it was possible to place a row of bamboo plants along all the perimeter next to the walkways; they help to prevent overheating of the walls in summer as well as improving the perception of the space quality.
The buildings instead, in order to have a sufficient paved surface, given the dimensions of the walkways, as well as in anticipation of an eventual ease possible re-functionalization, were designed with these dimensions:

width = 16.10 meters   depth = 11.80 meters

In this way the buildings were positioned at equal distances from each other without obstructing access to solar radiation, and it was possible to place a courtyard in front of the south side of each. The building is wider than it is long for increasing the surface capturing the solar radiation and for reducing its depth; in this way the rooms are at most 4 meters deep.
The buildings are distant from each other 9.30 meters, allowing to obtain internal courtyards of about 180 m^2.
The walkways have a diameter ranging from 1 meter in the narrowest points to 1.70 meters in the widest points, which is due to: the variation of the eastern perimeter wall, the presence of the shielding structure and the bamboo row.
The walkways surround the buildings also on the north side, to allow a

uniform external distribution and give access to the buildings on each of the four sides. The same applies to the private building that is located near the north perimeter wall: after the climatic analysis, which highlighted a strong prevalence of cold Siberian winds coming from the north in winter from which the buildings must be protected avoiding to make them impact directly, as they would cause problems, and considerations on the land bordering on the north side, of which it is not possible to know owner and future use, it seemed necessary to distance the last building from the border wall. In addition to these two factors, given the conformation of the buildings, having a "blind side", as it's not possible to put windows in the perimeter walls, it would have involved the application of skylights, which however would have entered into conflict with the use of the roof. Not to mention that the circulation would have become more inefficient.
As regards the multi-functional building, there was no need to have a building

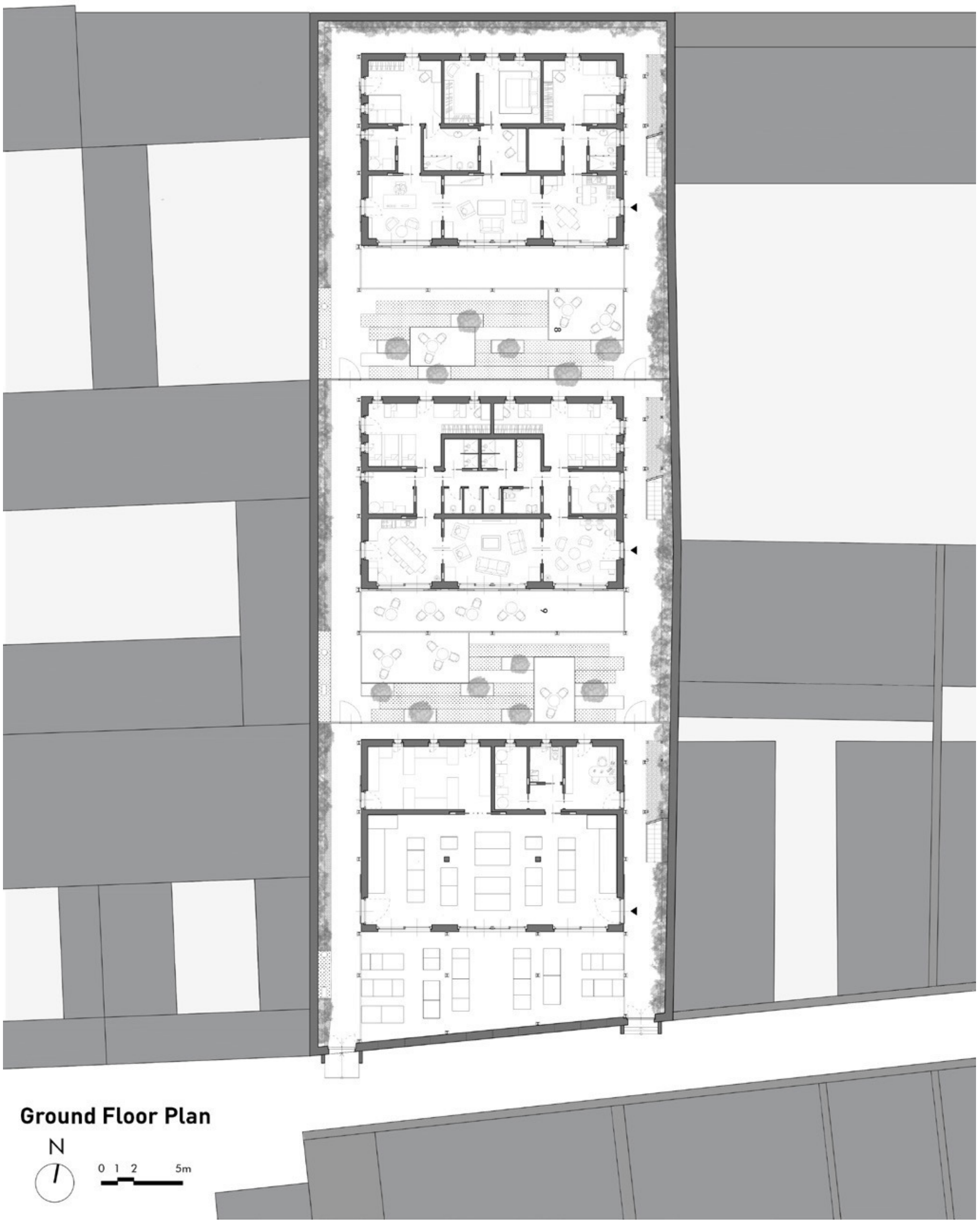
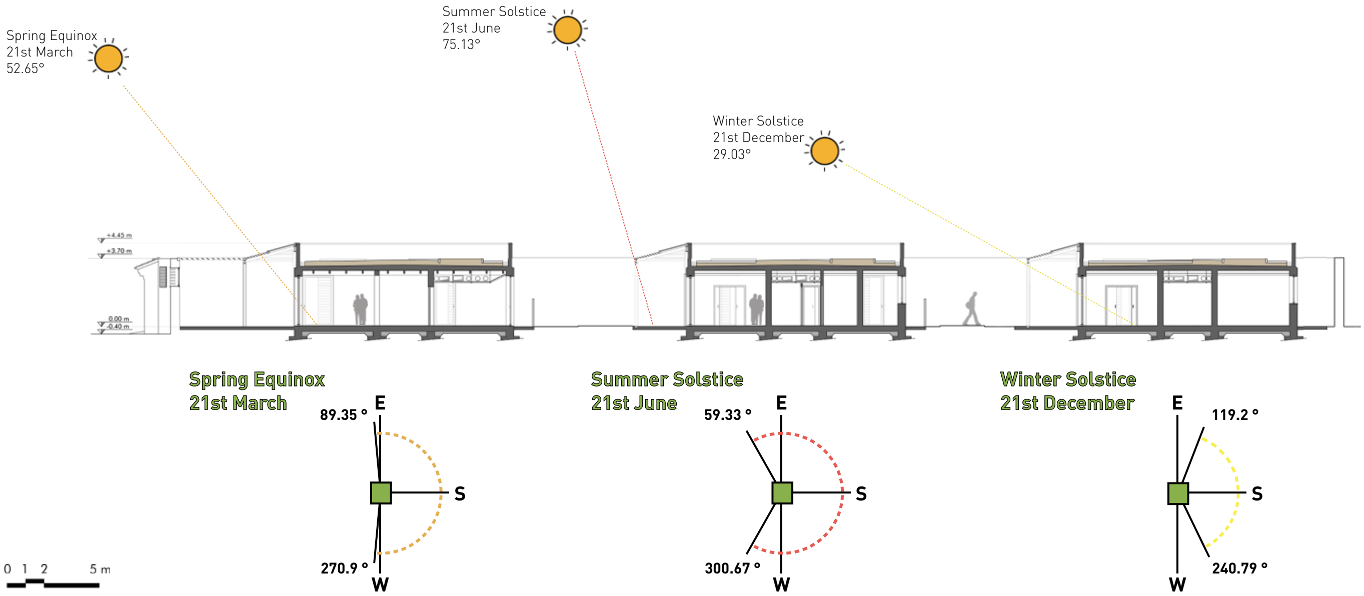


Fig. 4.30 ▶
Designed Ground Floor Plan.
Off scale

◄ Fig. 4.31
Designed Roof Plan.
Off scale.

attached to the south side that faced north, like the dauzao in local buildings; so it was decided to replace it with an open space that covered the role of courtyard and to move it away from the border wall. In this way a courtyard was created at the entrance of the site that can be used as a small market or exhibition space or common space. To increase the brightness three large openings in the entrance wall have been designed.
The project aims to create a protected internal environment thanks to the high boundary walls, isolating it from external noise, creating quiet interior spaces immersed in greenery, thanks to the courts and green roofs and the bamboo row set along all sides of the perimeter.



▲ Fig. 4.32
Sun path and height in Hou Ji Village and shading system of the designed building

> Buildings orientation

The final energy consumption of a building is also heavily influenced by its orientation, both in summer and in winter.
For a correct design of a nZEB building it is very important to use as much as possible natural elements such as solar radiation, winds or precipitations, as in the case of rainwater harvesting.
The historic buildings, as well as the entire village, already used passive design criteria during their construction: the dwellings in front of the project sire, including the Liu House, are rotated by 16 ° with respect to the axis North-South, in accordance with the prevailing wind and with the sun path. There is also the belief that for ordinary houses, the central axis should not face direct S-N but off a little because commoner's faith are not strong enough to uphold S-N energy; only the imperial palaces could face direct S-N orientation (Zhang, 2013).
From the initial analysis using Ecotect software, as explained in section 4.3, it emerged that the optimal orientation of the buildings based on local solar radiation is to rotate them by 5° compared to the N-S axis. The project site is instead rotated 11° compared to the N-S axis: therefore in order to have uniform passage spaces so as to cover the entire perimeter of the site, it was decided to position the buildings so that their external sides walls were parallel to the boundary walls. In this way the buildings are rotated 11° compared to the N-S axis.
However, it was necessary to evaluate whether having a rotation of 11 ° involved great changes in the solar gains compared to 5 ° of optimal rotation: with the Rhino[5] software and its extension, DIVA[6], a series of analysis were

4.5 Rhinoceros, or Rhino, is a commercial application software for 3D modelling of free-form surfaces created by Robert McNeel & Associates, a company based in Seattle, Washington, USA.

4.6 DIVA-for-Rhino is a daylighting and energy modelling plug-in for the Rhinoceros, that allows to carry out a series of environmental performance evaluations of individual buildings and urban landscapes including Radiation Maps, Photorealistic Renderings, Climate-Based Daylighting Metrics, etc.

◄ Fig. 4.33
Top view of the designed area.
Off scale.

performed for each degree of rotation compared to the N-S axis; it emerged that between the 5° of optimal rotation and the 11° of the project site there was a variation of 4% on the total, therefore a negligible value.
In the same way, by orienting the buildings in this way it was possible to guarantee to all sides of the building solar access at different times of the day, with the south side being exposed all day. As regards the north-facing façades, light colours have been used, both for the exterior floor and for the boundary walls, so as to create as much reflected light as possible and create brighter spaces especially in winter.
At the same time the buildings are positioned at a distance, more than 9 meters, so that they would not shade each other: with this arrangement from October to February, light penetrates extensively into the building; in the summer instead, as explained in the section of the fixed external shading system, the light does not enter the building.

> Buildings morphology

Even at the morphological level, the desire was to start from the concepts on which is based the traditional architecture, modifying some for integrating them into a modern project.
Since the definition of the project guidelines, it has been decided that the buildings would have developed on a single level, as well as the local traditional houses and those of the neighbourhood; in this way they are properly integrated into the landscape of Hou Ji. In fact the buildings of the neighbourhood, despite having different heights, are all one storey high: the difference lies in the height of the interior spaces, which can even reach more than 4 meters in height.
To avoid creating large volumes, which would have required a greater heating and cooling loads to maintain internal comfort temperatures, it was decided

that the buildings would have a net internal height of maximum 3 meters.
As regards the external appearance instead, the cladding of local buildings and historic residences, is made by a covering in exposed bricks produced on site, eventually painted; therefore, to resume this concept at a morphological level, a 2.3 cm thick stone cladding was used in a similar way, which matched well with the type of stratigraphy chosen for the external walls.
The perimeter walls and external floors, as mentioned in the previous section, are light in color in order to reflect sunlight and make the courtyards and passageways brighter, since they reflect most of the radiation without absorbing it; at the same time, the reflected radiation can partly enter the buildings so as to increase the internal brightness, particularly in the winter period; in the summer, however, thanks to the use of external verandas and the bamboo that grows along the entire perimeter, the absorption of heat by the buildings is limited to a minimum, creating, thanks to the vegetation of courtyards and roofs, a nice micro-climate inside the project area.
To reuse the theme of the verandas, which are arranged along the entire length of the local buildings, the external shading system of the new buildings was designed in a quite similar way: it is positioned on the East and West (between the buildings and the boundary walls) and South sides to block solar radiation during summer, therefore inverting the circulation space and buildings of the traditional architecture.
The buildings, instead, as will be detailed in the next section, both for internal distribution and for the arrangement of fixtures and entrances are based on principles of symmetry and axiality, as well as local dwellings.

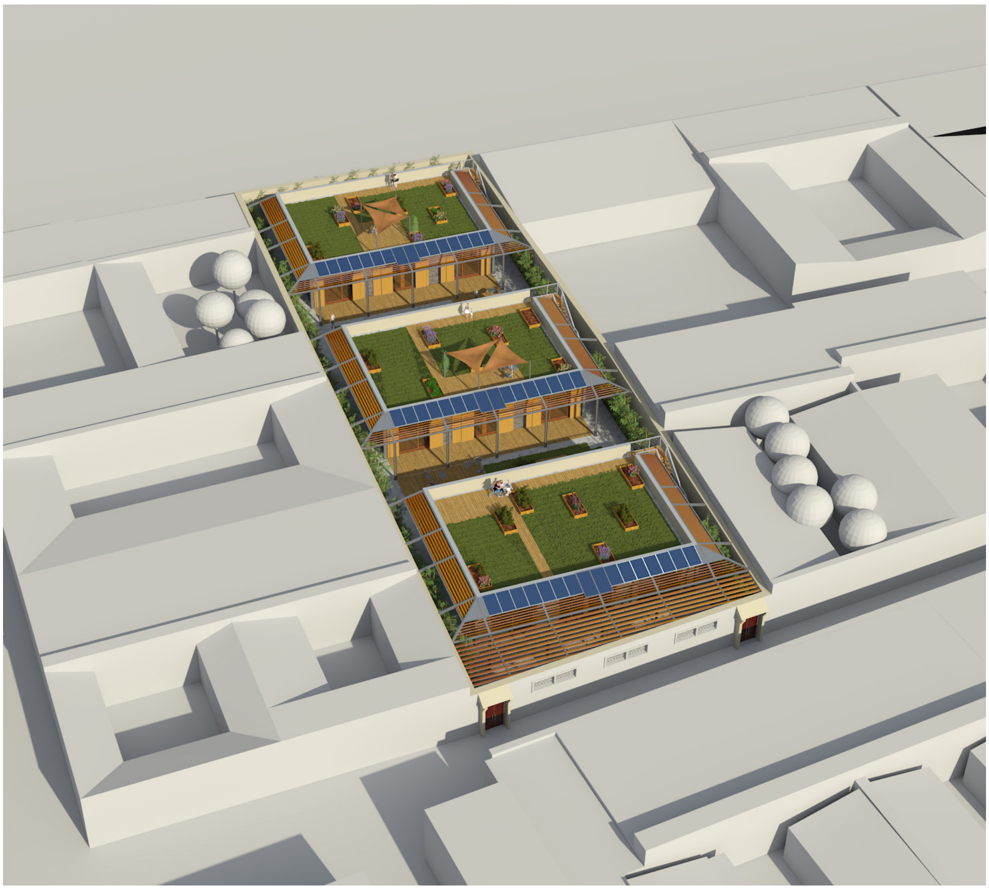


Fig. 4.34 ▶
View from south-west of the designed buildings.

4.5 Project buildings features

As with the micro-urban scale and the site scale, the design of the individual buildings followed part of the guidelines of the local tradition, combining them with modern design. The difference, given the scale of detail, lies in the fact that in this case all the choices have as a main goal the design of nZEB buildings, for which fundamental principles were: design the layout of the spaces according to their intended use, use of passive strategies, use of performing assemblies and high-performance energy systems, green integration.

This means that: the heat must be captured as much as possible in winter and stopped in summer, it is important to ensure a good level of natural ventilation and passive cooling, it is necessary to have a good level of natural lighting and make sure that the heat losses are minimal, with the right characteristics of isolation of opaque and transparent elements.

It is clear, therefore, as a nZEB building in a very cold climate, as in Hou Ji, is different from one built in a warm climate; here, also following the in-depth climate analysis, it emerged how the strategies aimed at heating, maximizing solar inputs and maintaining heat are much more important, given the rigidity of the external climate for most of the year.

As already mentioned in the previous section, the traditional architecture, for the arrangement of the interior spaces is based on symbolic and spiritual criteria, as well as on a clear subdivision of the spaces, closely connected to the functions and occupants, such as:

• Harmony and homogeneity
• Use of axial and symmetrical planning
• Topological order together with feeling of privacy, intimacy and protection
• Distinct hierarchical order

To combine these features with a construction that exploited passive strategies as much as possible, the buildings were organized starting from the internal layout, so that it was as symmetrical and harmonious as possible, giving a clear subdivision to the spaces according to their function, also thanks to a reasoned arrangement of the fixtures.

In the same way, as described in the previous section, buildings with a compact shape have been designed to limit dispersion as much as possible.

While designing a nearly zero-energy building it is important to take into account the geometry of the house. During the design process is important to be aware of the fact that any irregular shape in the house design could result in unwanted increases of energy demand caused by thermal bridges.

The shape and size of a building can all have a significant impact on its useful energy requirements. The more compact the building is, the less is the area of thermal envelope that causes transmission heat losses. In addition, a compact building usually also means less square meters of expensive thermal envelope to be invested in and maintained in the future. The compactness ratio has a pronounced influence on the heating and cooling demand, independently of the thermal transmittance value (U-value) of the building fabric.

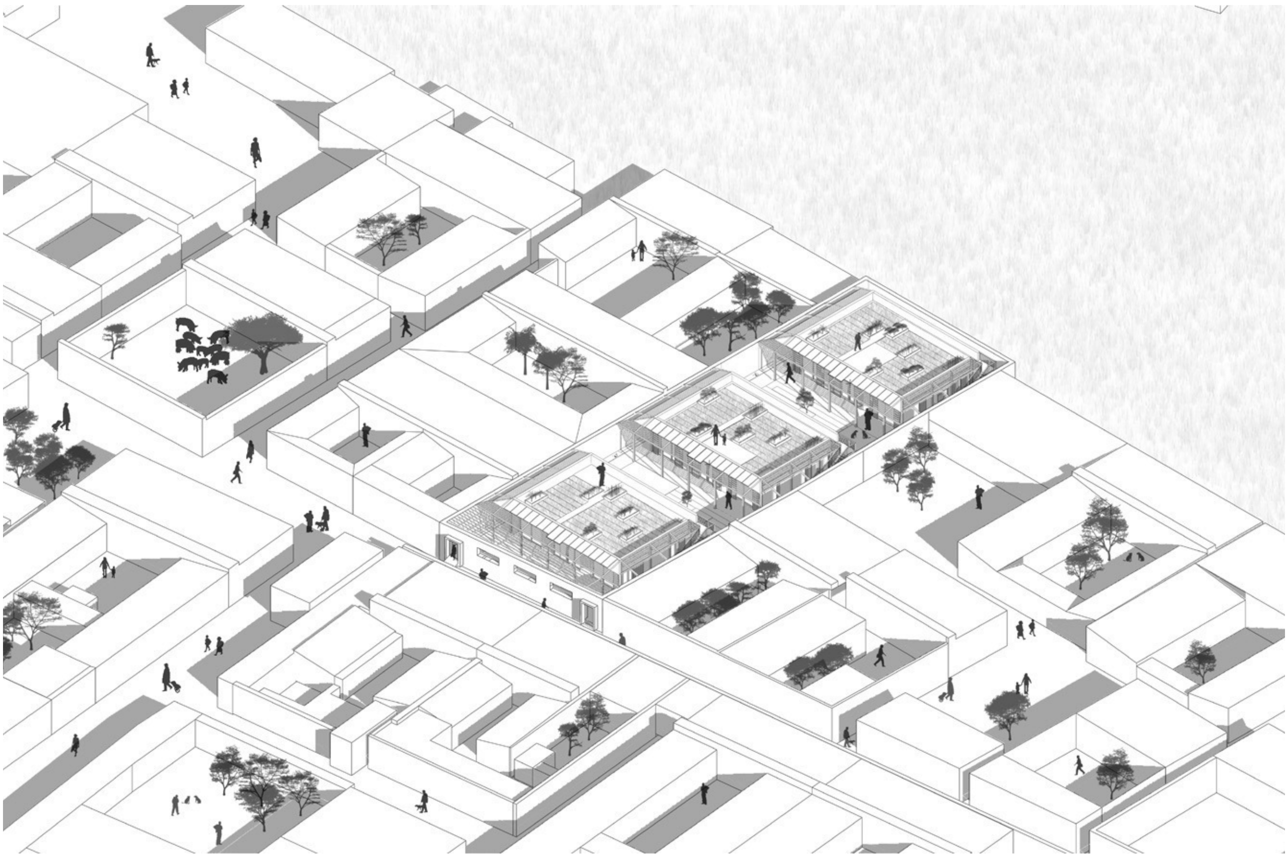
Fig. 4.35 ▶
Graphic view of the designed area and neighbourhood.

An interesting parameter in this sense is the "shape factor" which relates the surface of the envelope (S) and the heated volume contained within it (V): the larger the surface the greater the dispersions. To overcome this problem, buildings have a simple and compact shape, and have no overhangs or protrusions, to limit the dispersing surface as much as possible and not create thermal bridges. The form factor S / V is 0.97: this is due to the fact that the buildings are one storey high otherwise the value would have dropped a lot.

The buildings are one storey and integrate into the local landscape, not creating heavy alterations in the village "skyline".

Then, one of the most important components of the project, are the internal courtyards, which unlike traditional culture, in which they have a more symbolic meaning, in this case take on a more practical role: they become a space that in addition to visually connecting a building to another, it can be used as an external space for the building users and as a space used as a vegetable garden or garden, as regards the hostel and the private house; in the case of the multifunctional structure the courtyard is designed to be a space used as a product sales space or as an exhibition space.

The roofs instead are flat like most of the buildings in Hou Ji; the difference lies in the fact that, compared to traditional houses, whose roofs are walkable but made of stone, since they were once used to dry the crops, here they have as the courtyards, a more practical function: like an extension of them they present a double function, external spaces for tenants or used for growing medium-sized plants.



4.5.1 Buildings layout

From the analysis carried out by NTNU and SEU emerged as, according to the need for young people, interior design should be advanced and modern; therefore, in anticipation of an increase in interest in the area, the modernization of housing of the pilot project is one of the key element of the interior design.
The classical appearance of local architecture has many unique characteristics but they should characterize only the historical buildings, as an example of traditional life and history of Hou Ji: urban tourists will have interests to visit theses architectures or study them for their historical value, they will not want to see their reconstructed copy.
The buildings have an internal height of 3 meters, so as to give as much volume as possible to the interior spaces, given that already the boundary walls, due to their height, can bring a sense of closure. The service spaces have instead a false ceiling to house the ventilation distribution system: in this way the height passes to 2.40 meters in the lowest points.
In the same way a greater internal height has allowed to use wider windows to capture more solar radiation in winter, while in summer thanks to porches is avoided overheating, as they block most of the sunrays on the east and west sides and all on the south side. In the same way this height has allowed to install all the air distribution system and the technical system in the service-zone false ceiling.
The layout of the rooms and their occupation follows a strictly hierarchical system in the Chinese architecture. Taking the siheyuan as a reference, the main pavilion located to the north, with windows that open to the south, receives better sun exposure, and is therefore reserved for the householder or the elderly. The pavilions that open to the east and west are assigned to the younger children, depending on the importance they have in the family. The unmarried daughters occupy the most hidden rooms in the house, as they were not allowed to reveal themselves to the public. The pavilions with the least sun exposure, for example those facing south, with windows that open

◀ Fig. 4.36
View from south east of the designed area.

to the north, are usually assigned to the servants or used for daily activities such as cooking or study.
In the buildings designed these concepts are carried forward: each one has an internal division that follows a precise hierarchical order, based on dogmas of axiality and symmetry typical of the local architectural tradition, obviously making changes to adapt them to modern architecture.
The buildings have the following dimensions:

width = 16.10 meters depth = 11.80 meters

Having these dimensions as a basis, their internal layout has been arranged in zones based on the function of the rooms, allowing in this way to have interior environments that adapt to the uses of the tenants.

4.5.2 The multifunctional building

Starting from the site entrance, the multifunctional building is composed of an outdoor courtyard, used as a sales space or exhibition area of about 100 m^2, while the interior is divided into two zones: a public-zone, also used as sales/exhibition space 15.30 meters wide and 6.80 meters deep, therefore of about 100 m^2; a private-zone, 3.90 meters deep, which is reserved for all services, where there are an office of 12 m^2, a bathroom of 4.5 m^2, a technical room of 7.7 m^2 and a storage room of 29.4 m^2.

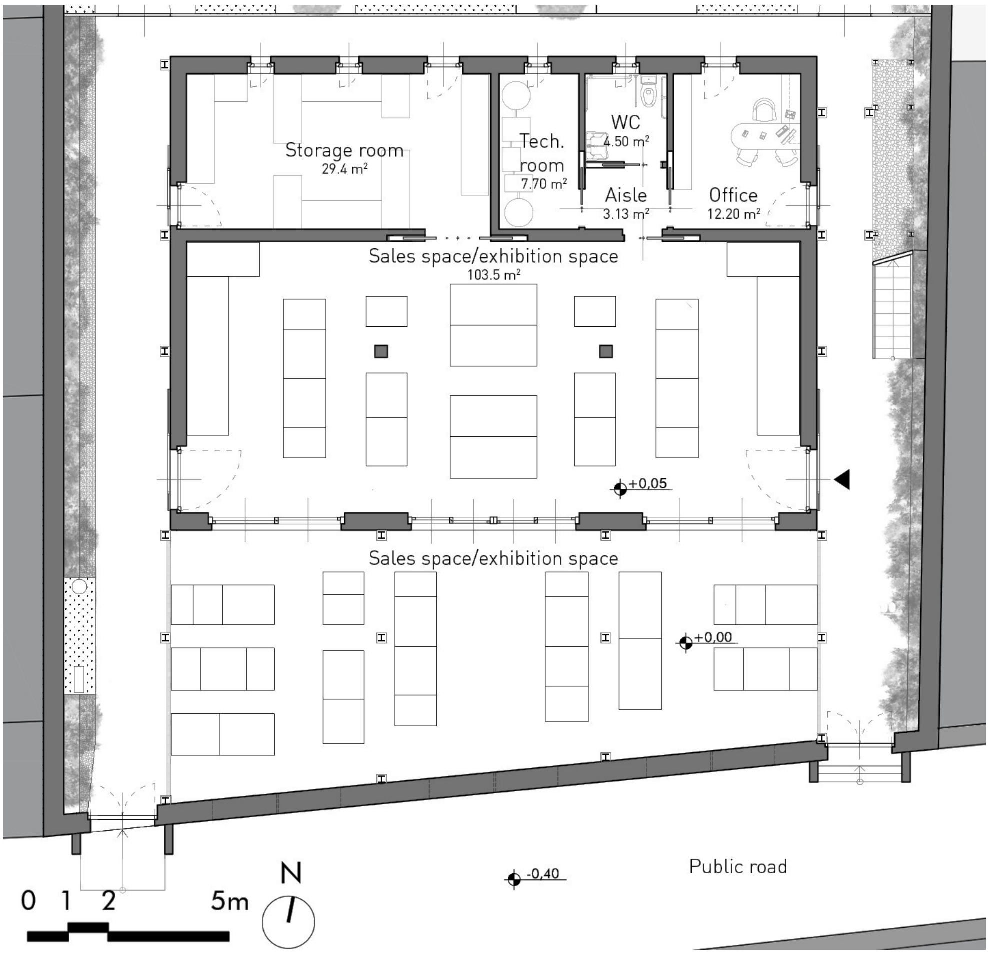


Fig. 4.37 ▶
Ground Floor Plan of the multifunctional building.
Off scale

The interior has been divided into two parts since in this way it has been possible to give more space to the public functions, which is the fulcrum of this building, and to position all the service spaces, which do not require particular exposure characteristics on the north side. The roof is designed to be a green roof, where it is possible to cultivate at most medium-sized plants, and is designed to connect to the hostel's green roof-courtyard system, thus providing additional space to develop the agro-plant tourism.
The salon, which reverses the layout of the dauzuo of the siheyuan, which was the first environment and was exposed to the north, in this case is as wide as the dauzuo but is south facing.
The hall has two symmetrical entrances to each other, 1.50 m wide on east and west sides, while the widest windows are positioned on the south side; the latter are 3.20 m wide, 4.10 m and 3.20 m; their height is 2.70 meters.
The service areas all have glazed elements, with symmetrically arranged windows, but in this case they are much smaller due to their exposure: the deposit has two glass door, one on the east side 1 m wide and the one on the north side of 0.80 m; the windows are 1.50 meters high and 0.50 m wide; office fixtures are the same size as those of the storage room.
The main shading system of the building is that of the verandas formed by a steel structure with salvaged beams and bamboo lamellae: on the east and west sides it only protrudes by 1.40 meters and is inclined at 15°; on the south side in the first section it has the same inclination, and above it the photovoltaic and solar thermal panels are installed, while the second section is horizontal and joins the perimeter wall that delimits the site to the south. In the last case the shading system is used to create an external place sheltered from bad weather and sunrays: given the intended use of the building it does not need particular passive solar contributions during the winter period because it is not continuously occupied; in summer, instead, the shading helps to repair from the strong radiation.
Beyond the verandas, every window and glass door, except for those on the north side, has sliding screens in steel and bamboo that offer additional protection from sunlight and an additional tool for security.
Lastly, outside the building there is a staircase, made of steel and wood, which

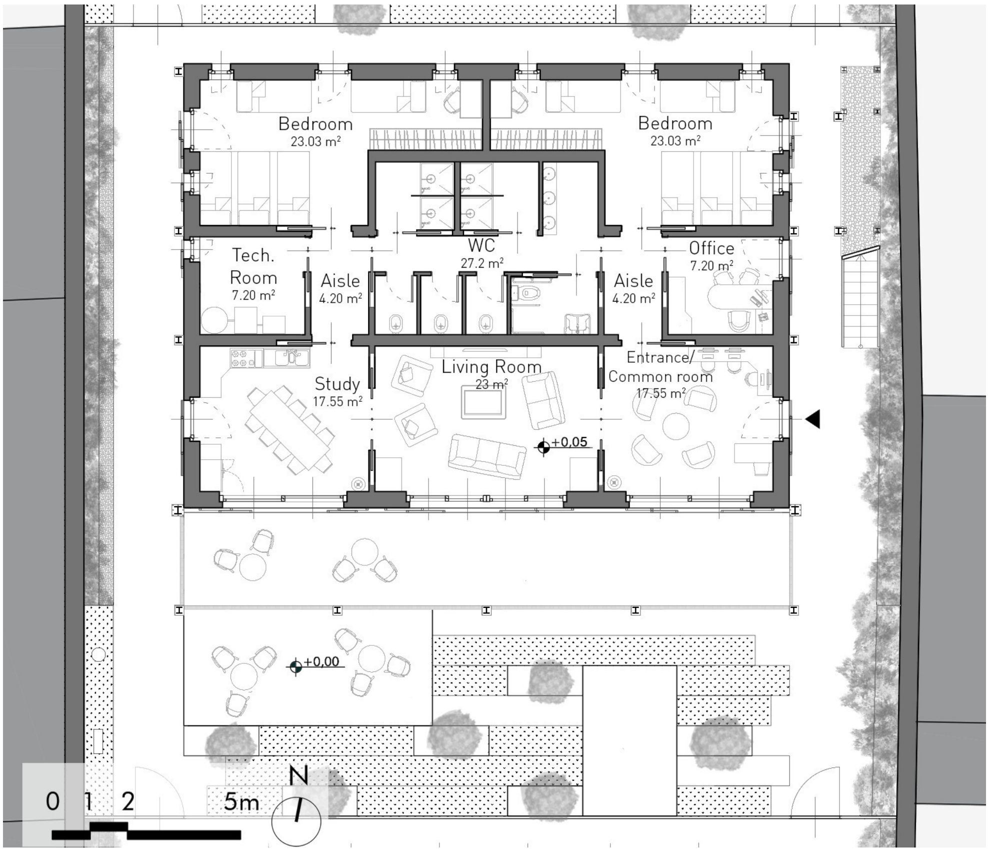
◄ Fig. 4.38
Internal view of the hall in the multifunctional building.

Fig. 4.39 ▶
External view of the outdoor courtyard of the multifunctional building, in this case used as a sales space.

allows access to the green roof, 0.90 meters wide (tread 0.29 m, elevation 0.175 m) which reaches a height of 3.50 meters, i.e. the roof decking.

4.5.3 The hostel

The hostel, as well as the multi-function building is composed of the courtyard-building system, but in this case in addition to the 120 m^2 open courtyard and the building, there is a 42 m^2 veranda located along the entire south side, which thus becomes an additional external space.
The courtyard is designed to have two functions: outdoor space for users and a vegetable/normal garden, which can be used by tourists who want to learn more about local culture, which is very much based on agriculture, or as an educational space for students, as well as a system for produce food.
Also in this case, the roof is designed as a green roof, creating together with the courtyard and the roof of the multi-function building a large green space usable by tourists, students and site owners. On the roof there are also repaired common areas for users.
The hostel, unlike the multi-function building, despite having the same structure and the same envelope, is divided into three zones: day-zone, service-zone and night-zone.
The day-zone is arranged along the south side of the building, and being the best exposed side it includes the most used areas: the entrance/common room of 17.4 m^2, the kitchen of 23 m^2 and the second common room of 17.4 m^2. In this case, in winter it is possible to make maximum use of the solar gains, which allow to have higher temperature values and daylight factors inside.
The day zone has the widest fixtures positioned on the south side, and are 3.20 meters wide, 4.10 meters and 3.20 meters; their height is 2.70 meters. Then it has two entrances symmetrical to each other, 1.00 m wide and 2.70 m high, one on the west and one on the east side.
The service-zone is located in the central part of the building, and consists of all the spaces relating to the services of the structure: the administrative



◀ Fig. 4.40
Grounf Floor Plan of the multifunctional building.
Off scale.

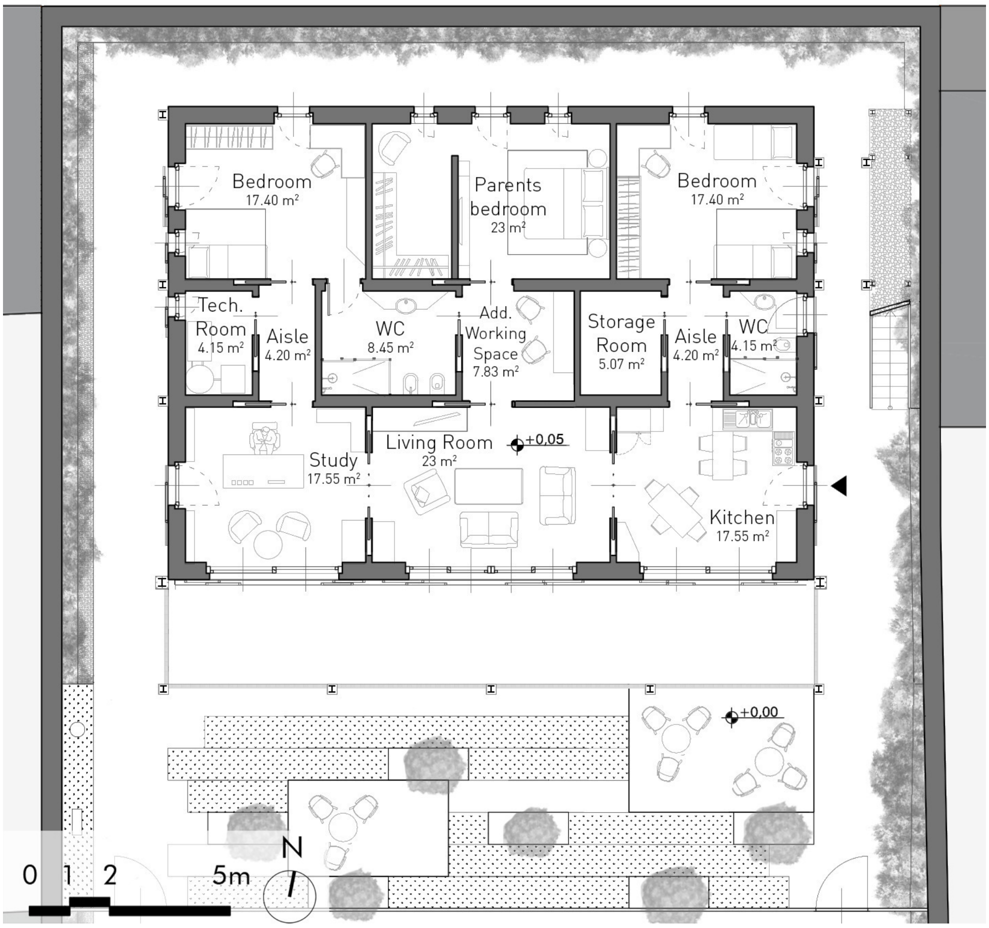
office of 7.3 m^2, bathrooms (one for the disabled) and showers (the latter divided for men/women) 27.3 m^2, the two corridors of 4.4 m^2, the technical/ storage room of 7.3 m^2.
As it can be seen, the distribution space is reduced to the minimum, so as to increase as much as possible the spaces for the other rooms and create linear and simple interior spaces.
The two large bedrooms of 23 m^2 each, form the night-zone, which is arranged along the entire north side; the rooms are designed to accommodate five people each, but this number may rise if bunk beds are used instead of single beds.
The bedrooms have two entrances through glass doors from the outside, also arranged symmetrically, one on short sides, 1 m wide and 2.70 m high, and one on the north side, 0.8 m wide and 2.70 m high. The windows instead, also symmetrically arranged, are much smaller due to their exposure, 1.50 meters high and 0.50 m wide.
The doors and windows are positioned in axis to facilitate cross ventilation, in the case in which those on the same axis are opened simultaneously, as in the day-zone, or between day-zone and night-zone, or in the service-zone.
The main shading system of the building is that of the verandas formed by a steel structure in recycled beams and bamboo lamellae: on the east and west sides it protrudes by 1.40 meters and is inclined at 15 °; on the south side the shading system has the same inclination, with photovoltaic and solar thermal panels installed above it, and protrudes 2.8 meters. In the latter case the veranda serves to create an additional external place sheltered from bad weather and sunrays: in summer it helps to repair from the strong

Fig. 4.41 ▶
Internal view of one of the two bedrooms inside the hostel.

solar radiation, not allowing it to enter inside the building, while in winter the sunrays are lower and penetrate for the whole length of the day-zone. In addition to the verandas, every window and glass-door, except for those on the north side, has sliding screens in steel and bamboo that offer additional protection from sunlight and an additional tool for privacy and security.
The Technical room faces on the external walkway, in order to have a window, 0.50 x 0.50 meters, to ventilate it in case of occurrence, as generation systems, both heating/cooling and ventilation, are located inside it.
Lastly, outside the building there is a staircase, made of steel and wood, which allows access to the green roof, 0.90 meters wide (tread 0.29 m, elevation 0.175 m) reaching a height of 3.50 meters, i.e. the roof decking.

4.5.4 The private house

The private house is located at the innermost point of the project site, being also the most private space; the building is thought to be the home of the family that will take administrate the area, taking care of the greenery and managing hostel and multifunctional building.
The private house is composed of a courtyard-building system very similar to that of the hostel, therefore the 120 m^2 open courtyard and the 42 m^2 veranda placed along the entire south side are again present, thus becoming an additional space external; in this case the morphology of the court varies.
The courtyard is designed to have two functions: additional outdoor space and garden (cultivable or not), usable by tenants.
The flat roof is also in this case designed as a green roof, creating together with the garden space of the courtyard a system of cultivable green; on the roof there are also repaired common areas for users, which in case of need can be converted into green space.
The private house, like the other two buildings, has the same structure and the same envelope, but inside it is divided into three zones, such as the hostel: day-zone, service-zone and night-zone.
The day-zone is arranged along the south side of the building, and being the best exposed side, it includes the most used areas: the kitchen of 17.4 m^2, the living room of 23 m^2 and the study of 17.4 m^2. In this case, in winter it



◄ Fig. 4.42
Grounf Floor Plan of the private house.
Off scale.

is possible in winter it is possible to make maximum use of the solar gains, which allow to have higher temperature values and daylight factors inside.
The day-zone has the widest fixtures positioned on the south side, and are 3.20 m wide, 4.10 m and 3.20 m; their height is 2.70 meters. Then it has two symmetrical entrances to each other, one on the east side in the kitchen and one on the west side in the studio, 1.00 m wide and 2.70 m high.
The service-zone is located in the central part of the building and consists of all the service areas; starting from the east side: a bathroom of 4.15 m^2, an aisle of 4.2 m^2, a storage room of 5.07 m^2, an additional working space of 7.83 m^2, the second bathroom of 8.45 m2, an aisle of 4.20 m2 and the technical room of 7.3 m2. The Technical faces on the external walkway, so as to have a window, 0.50 x 0.50 meters, to ventilate it in case of occurrence, as the generation systems, both heating/cooling and ventilation are located inside it. As it can be seen, the distribution space is reduced to the minimum, in order to increase as much as possible the spaces for the other rooms and create linear and simple interior spaces.
The night-zone, instead, is arranged along the north side of the building and is composed of three bedrooms: the side bedrooms designed to accommodate one or two people, depending on the family, occupy an area of 17.40 m^2; the central room, which is the largest, is the parents bedroom, and has an area of 23 m^2, with a wardrobe room inside.
The two side bedrooms have two entrances from the outside through a glass door, one on the short sides, 1 m wide and 2.70 m high, and one from the north side, 0.8 m wide and 2.70 m high. The windows instead, also symmetrically

Fig. 4.43 ▶
External view of the internal courtyard of the private house.

arranged, are much smaller due to their exposure, 1.50 meters high and 0.50 m wide. The parents bedroom instead has a glass door of 0.80 x 2.70 m and two symmetrical windows of 0.50 x 1.50 m.
With this internal distribution it was possible to divide the spaces according to their functions, with the bedrooms, separated from the "representation" areas and the services arranged in the central block.
Doors and windows are positioned in axis to facilitate cross ventilation, in the case in that those on the same axis are simultaneously opened, as in the day-zone with windows and doors between kitchen and study; or along the three axes that are formed between day-zone and night-zone, i.e. kitchen-bedroom 1, living room-parents bedroom, study-bedroom 2.
The main shading system of the building are the verandas composed by a steel structure with recycled beams and bamboo lamellae: on the east and west sides it protrudes 1.40 meters and is inclined at 15 °; on the south side it has the same inclination, and photovoltaic and solar thermal panels are installed above it, and protrudes 2.8 meters. In the latter case the fixed shading system serves to create an additional external space sheltered from bad weather and sunrays: in summer it help to repair from the strong solar

Fig. 4.44 ▶
External view of the internal courtyard of the private house.

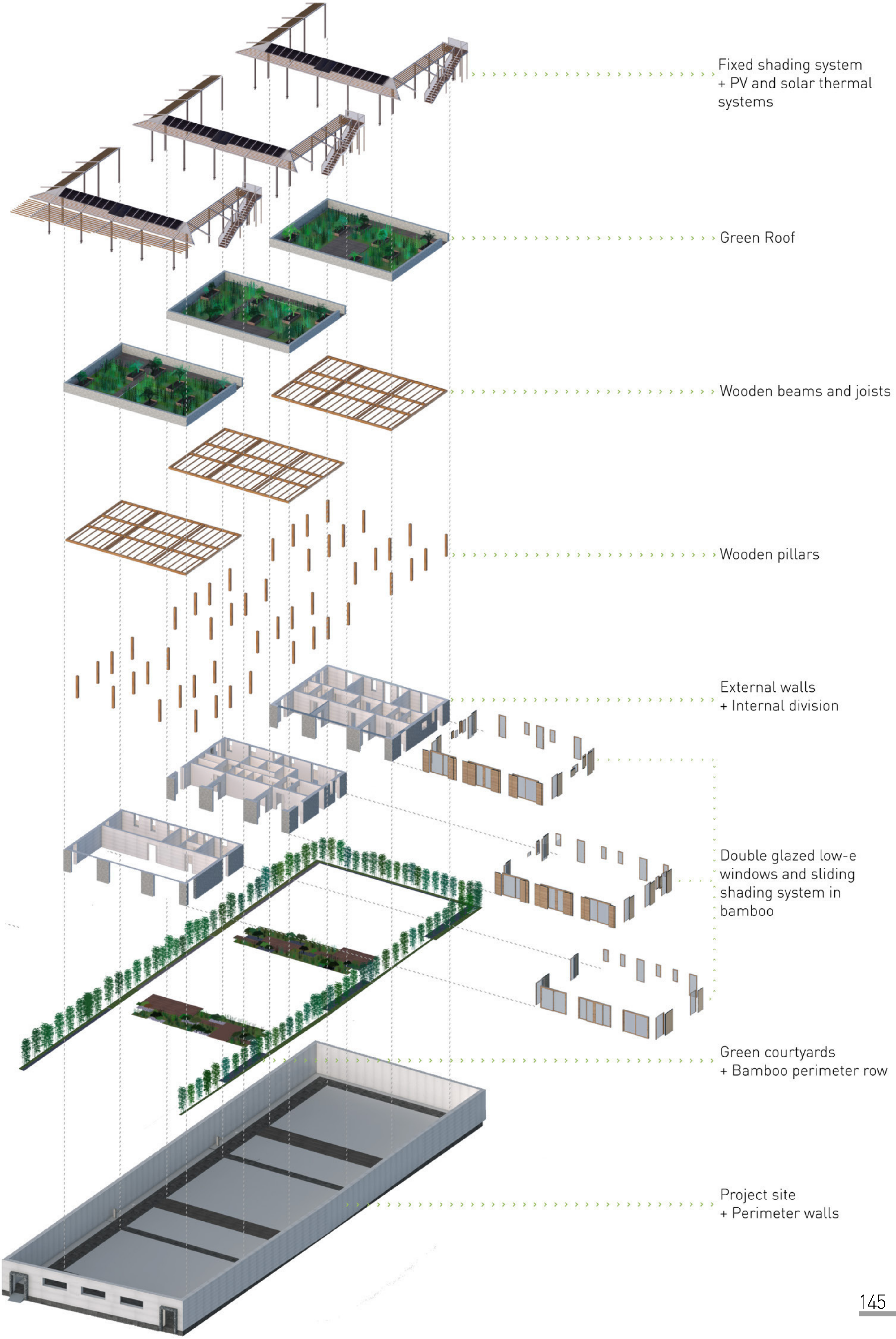
radiation, not allowing it to enter the building, while in winter the sunrays are lower and penetrate for the whole length of the day-zone. In addition to the verandas, every window and door-window, except for those on the north side, has sliding screens in steel and bamboo that offer additional protection from sunlight and an additional tool for privacy and security.
Lastly, outside the building, in the east side, there is a staircase, made of steel and wood, which allows access to the green roof, 0.90 meters wide (tread 0.29 m, elevation 0.175 m), reaching a height of 3.50 meters, i.e. the roof decking.

Fig. 4.45 ▶
Exploded view of the designed buildings.
Off scale

◀ Fig. 4.46
View from the kitchen towards the study in the private house

◀ Fig. 4.47
View from the living rooom towards the kitchen in the private house.

◀ Fig. 4.48
Parents bedroom in the private house.



Fixed shading system
+ PV and solar thermal
systems
Green Roof
Wooden beams and joists
Wooden pillars
External walls
+ Internal division
Double glazed low-e
windows and sliding
shading system in
bamboo
Green courtyards
+ Bamboo perimeter row
Project site
+ Perimeter walls

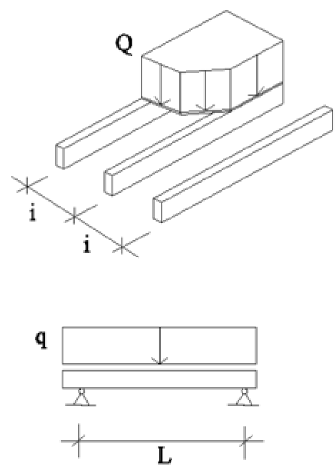
4.5.5 Structure pre-dimensioning

The structure of the three buildings is made of fir wood and is the same in all. In all cases the structure is regular, with all the pillars that are positioned on well-defined and orthogonal axes, thanks mainly to the regular shape of the building.
Longitudinally the pillars are positioned symmetrically compared to the E-W axis of the building: starting from the south side, the first row of pillars is positioned inside the perimeter walls, the second row is positioned at 3.90 m, the third row 2.65 meters far and the fourth row, which corresponds again with the outer wall, is 3.90 meters.
Latitudinally the distribution follow the same strategy, with the pillars symmetrical compared to the building N-S axis: starting from the east side, the first row of pillars located inside the perimeter walls is 4.45 m far from the second row of pillars, which in turn is 5.85 meters from the third, while the fourth row, which is again positioned in the outer wall, is 4.45 meters far.
The pillars are made of laminated fir wood, and are fixed on concrete foundations, which are made together with a concrete slab.
Regarding the weight of the roof, it was taken as reference a load with the saturated soil, of 300 kg/m^2, that is 3.00 kN/m^2, taking into account all the roof layers, including soil and plants and occasional additional loads. To be sure of designing a structure that is certain to not run into structural problems, an accidental load q_1 = 0.50 kN/m was taken as reference, for a total of 350 kg/m^2, that is 3.5 kN/m^2.
After this step, beams and pillars were pre-dimensioned according to the active regulations, using for the calculation the section of beams in the buildings most subject to stress, highlighted in the image on the following page.

wood: laminated fir wood
beam span L = 5.80 m
distance between centers of the beam i = 3.90 m
arrow allowed k = L/200
permanent load g_1 = 3.00 kN/m^2
accidental load q_1=0.50 kN/m^2
total load Q = $g_1 + q_1$ = 3.50 kN/m^2
total load q = $(g_1 + q_1) \times i$ = 13.65 kN/m

The beams have the following dimensions: base = 200 mm height = 350 mm

The pillars have the following dimensions: base = 300 mm height = 300 mm



▲ Fig. 4.49
Reference for structural calculations

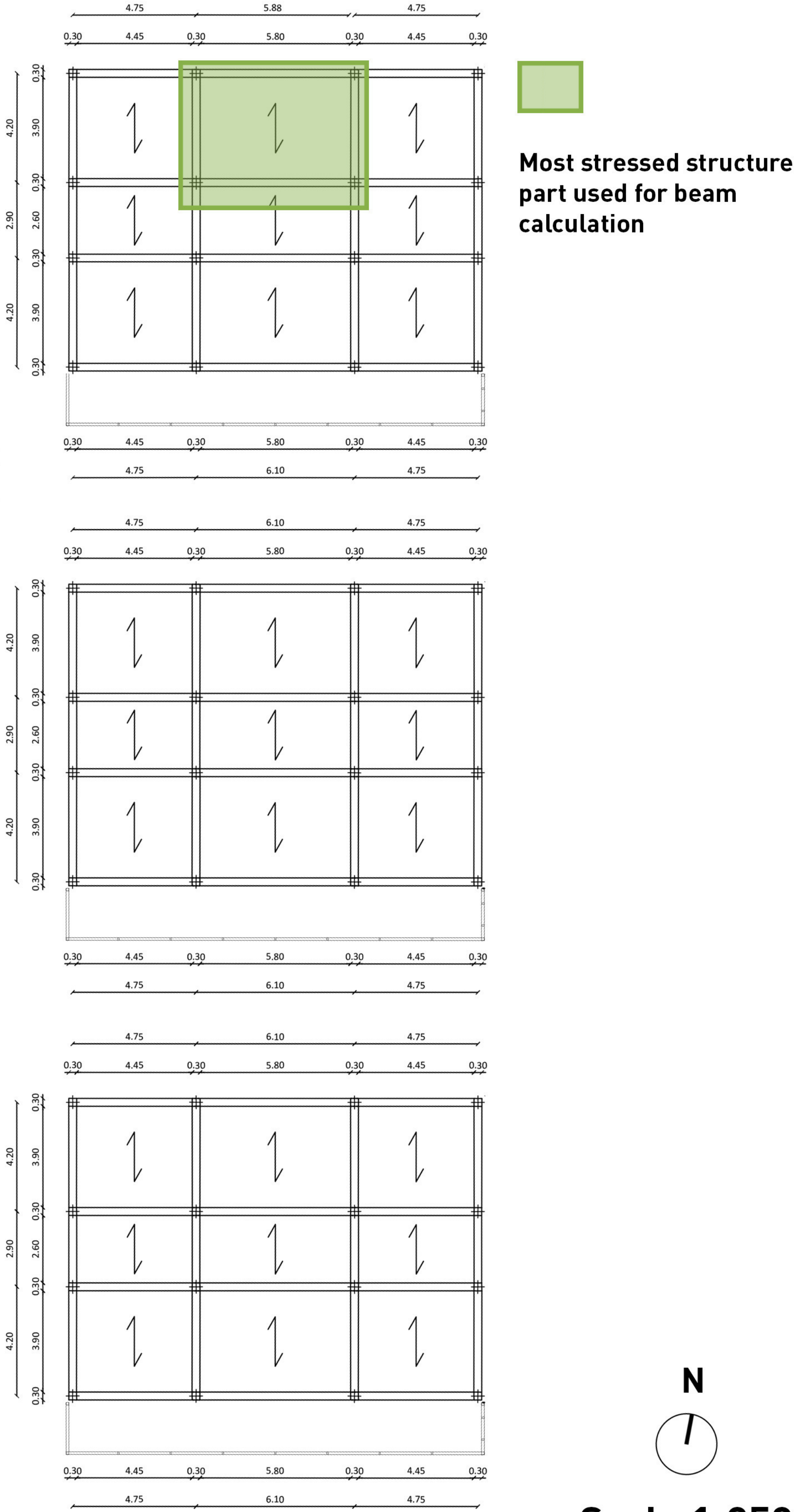
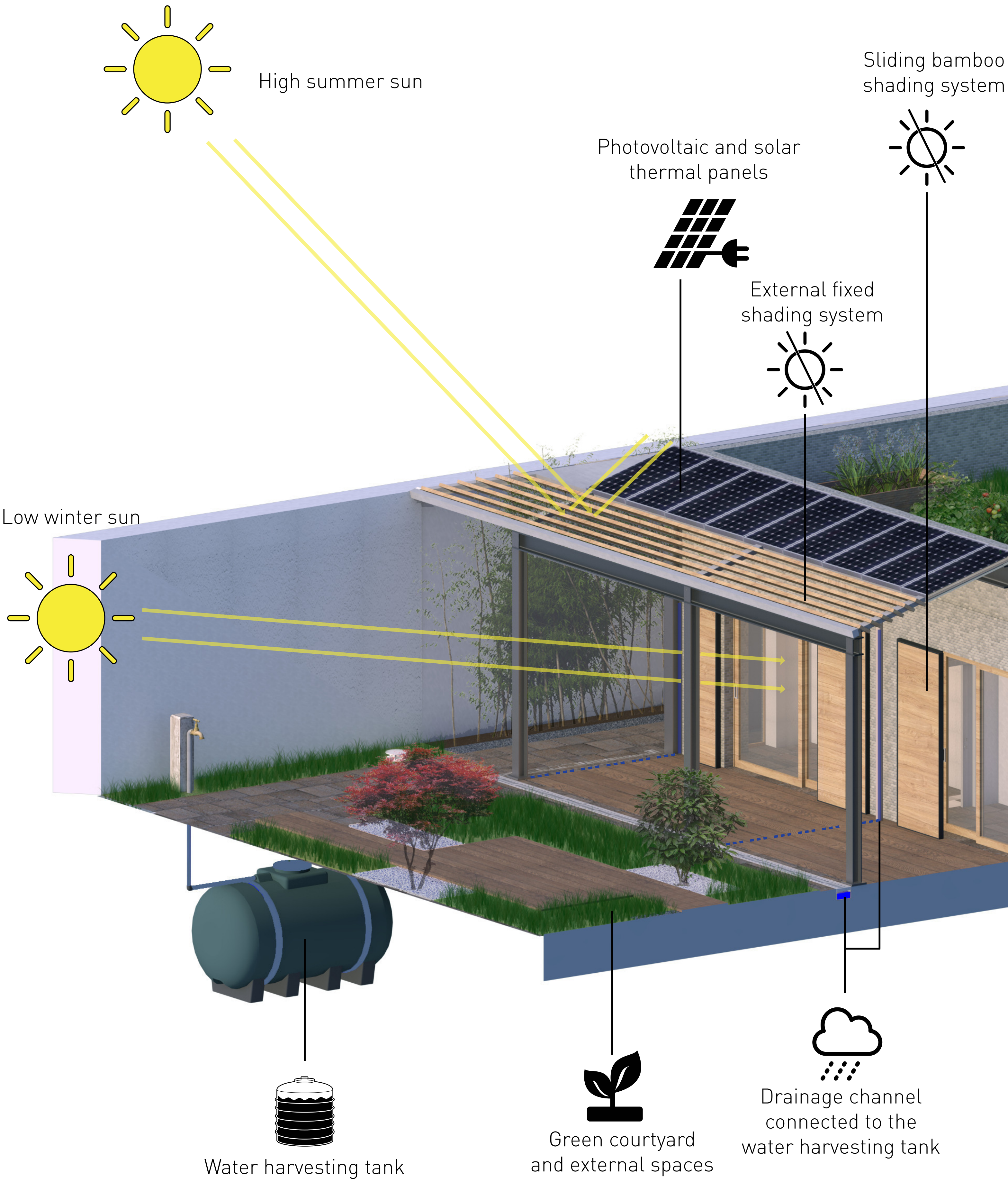
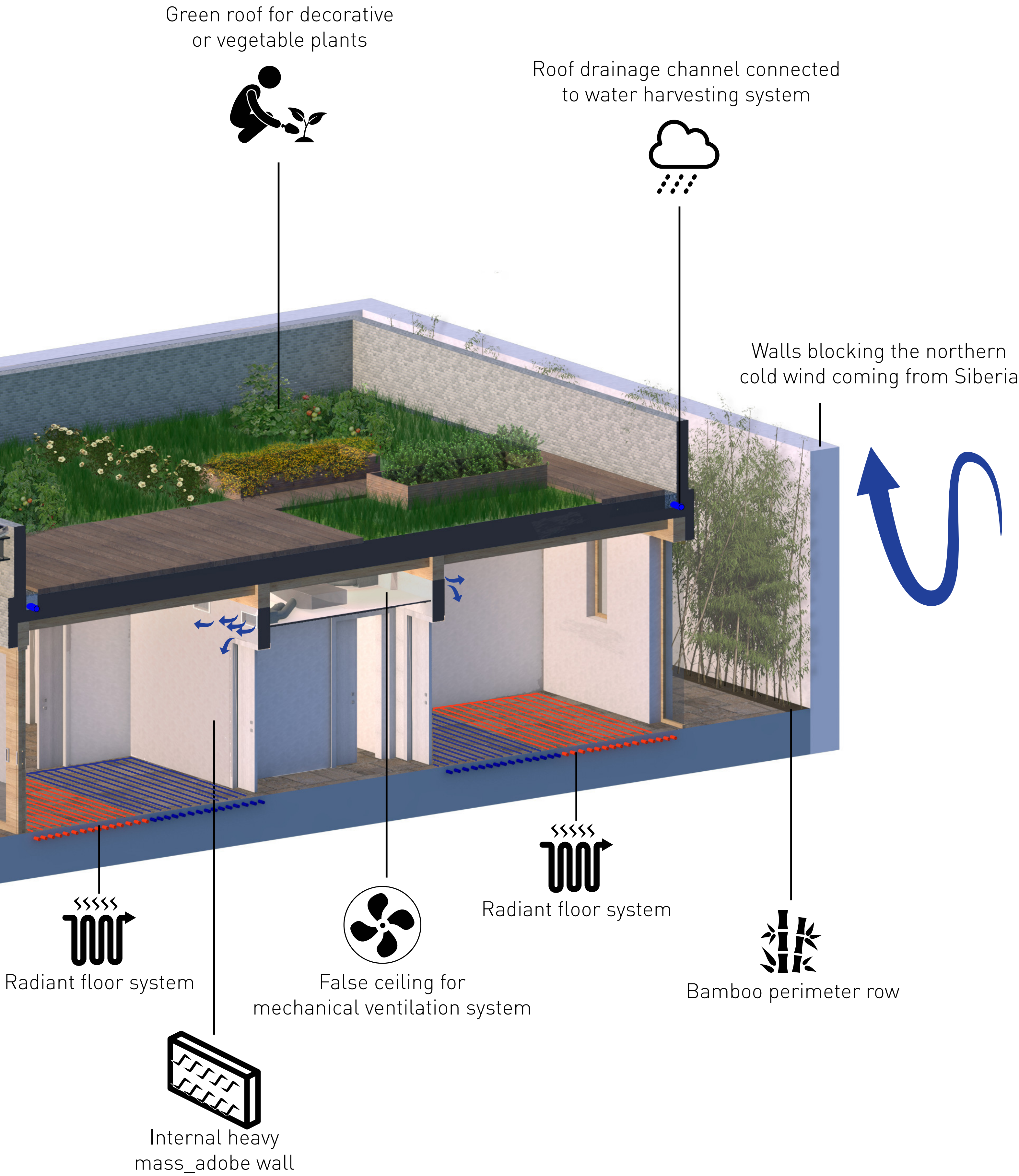


Fig. 4.50 ▶
Structural plan of the designed buildings.
Scale 1:250

▼ Fig. 4.51 Perspective section of the pilot building typology containing the design strategies.

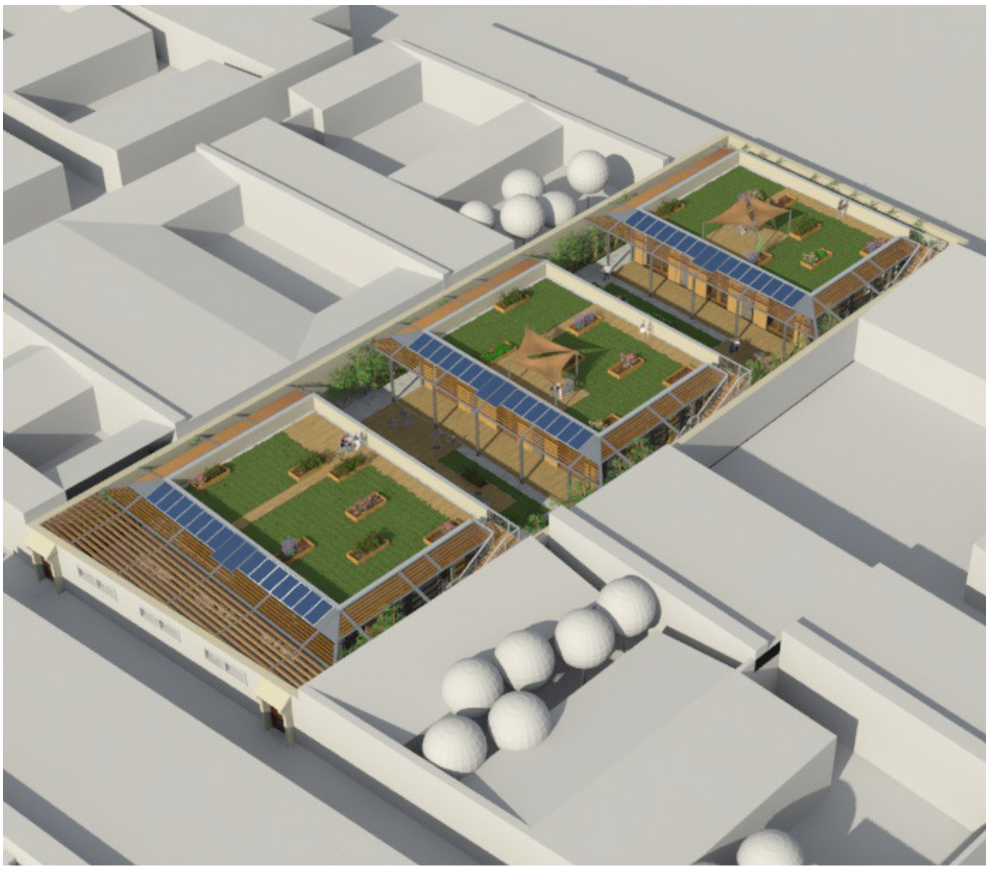



Green roof for decorative
or vegetable plants
Roof drainage channel connected
to water harvesting system
Walls blocking the northern
cold wind coming from Siberia
Radiant floor system
Radiant floor system
False ceiling for
mechanical ventilation system
Bamboo perimeter row
Internal heavy
mass_adobe wall

4.6 Technological solutions

4.6.1 Green roof, garden courtyard and bamboo rows

For the Chinese tradition the number of courtyards symbolizes the wealth of a family, so modest houses usually have only one courtyard, while the homes of nobles and wealthy merchants may have numerous courtyards with gardens and pavilions inside them. In this project, to overcome this concept, the courtyards and roofs spaces have been divided equally.
To propose the concept of agro-toursim intended for tourists or students or visitors to the village, as well as to give an extra form of sustenance for the inhabitants, while increasing biodiversity and air quality and climate of the , it was decided to assign the inner courts and roofs to green; this means that the courtyards, instead of being simple paved open spaces become aggregation spaces for users, as if they were an extension of the house, combining the presence of greenery at the same time. The green in the court has a double function, since in summer, when the greenery is more luxuriant, it can shield the solar radiation, while in winter when the cultivated plants are less and of lower stature they do not block the radiation that thus penetrates inside the buildings. The only exception to this provision is the courtyard of the first building, in which there was the need to obtain a space for exhibitions and sales outside.



◀ Fig. 4.52
3D view of the project site from south-east where it can be seen the green courtyards-green roofs system.

Fig. 4.53 (up) ▶
View of the lateral walkway from the east side of the hostel towards the private house.

Fig. 4.54 (down) ▶
View of the lateral walkway from the west side of the hostel towards the private house.

◀ Fig. 4.55
View of the internal courtyard of the private house.

But the green roof, in conjunction with the courtyards, has important ecological functions, enclosing within it a good part of the considerations made since the beginning of the project: firstly, thanks to the evapotranspiration of the vegetation it allows to reduce the temperatures inside the project site, excluding the formation of "heat-islands"; therefore thanks to the presence of the plants it allows to reduce the presence of pollutants, retaining fine particles and absorbing CO_2; diversifying the vegetal species of roof and courtyards and using local species as much as possible, it is possible to recreate ecological niches, for the local insects and small birds.
In addition to the roof-courtyard system it is added the bamboo row, which runs around the entire perimeter of the project site, with the exception of the border wall to the south. This design choice was made to improve the vision and the liveability of the side walkways, while also providing a good solution to avoid overheating of the walls in the summer period, choice that, together with the green courtyards and the use of light coloured paving, allows to greatly reduce overheating.
At the same time, the bamboo row forms a continuous green system in the courtyards, like a "sheet" that runs from one border wall to the other the courtyards space: visually the walls are covered by bamboo, then there is a

◀ Fig. 4.56
View of the internal courtyard of the hostel.

Fig. 4.57 ▶
3D view of the 3 component system of the courtyards: medium-trunk trees, bamboo wood flooring and vegetable garden / lawn.

short interruption due to the walkways, then there are vegetable gardens and plants, then there's again a small interruption due to the floor, to conclude with the bamboo plants covering the other side wall.
To design the courtyards, the project started by dividing them into longitudinal strips with a width of 0.80 m, thus rationalizing the space and filling the area in front of the buildings, leaving the side passages free.
Then it was designed a simple form that could be integrated into this layout, that is a rectangle of sides 0.8 x 2 meters. Thanks to this design strategy it is possible to dynamize the layout of the courts, that at the same time can be re-formulated and rethought according to the needs of the users: in case of need, the single rectangular units can be moved, or it is possible to zoning the cultivation of particular plants or create areas with aromatic herbs or fruit plants or decorative greenery.
Once this step was completed, three different types of use of rectangular units were defined:
• soil for green of low-medium stem, fruit plant or cultivation
• bamboo wood flooring for walkways
• soil for medium-high decorative or fruit trees
For both green courtyards, in addition to the walkways, rectangular areas have also been designed, also paved in removable bamboo wood, allowing to create external spaces for building users while connecting pedestrian passages at the same time. Even the shape of these areas was designed using multiples of 0.8 m to create visually uniform spaces.

For the greenery maintenance in the project site, regular work is necessary to avoid in particular that the plants ruin structures or parts of the building; therefore the project requires that the site owners take care of both the green roofs and the courtyards.
An interesting fact refers to a local tradition that occurs once a year, during the *Qingming Festival*[7] or *Sweeping the tombs festival*, that is on 4th/5th April: on this date the whole family meets to look after the family tombs, and to clean the roofs of the buildings of the family courtyard. Therefore this tradition could be used to completely settle the whole area once a year.

4.7 The Qingming, or Ching Ming festival, is a traditional Chinese festival observed by the Han Chinese of China, which usually is on the 15th day after the Spring Equinox.

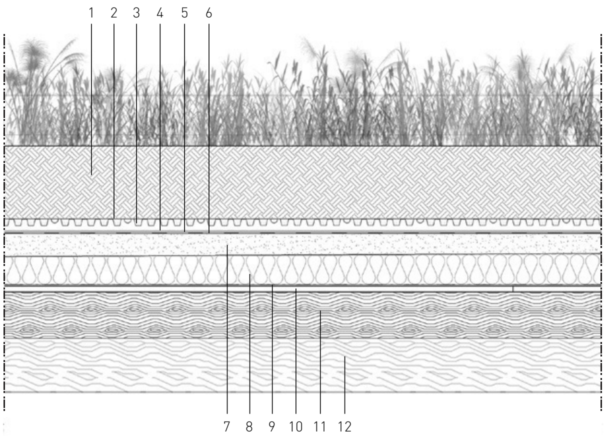
◀ Fig. 4.58
3D view of the 3 component system of the green roof: wooden box, bamboo wood flooring and vegetable garden/lawn.

As the courtyards, the green roof has a dual function: on one hand, it represents an added value for buildings by giving space to the green that would otherwise be used for normal flooring or for a normal roof, and on the other, above all, it provides great support as a passive strategy; in relation to the last concept, as well as reducing the temperatures inside the project site and the presence of pollutants, retaining fine particles and absorbing CO_2, excluding the formation of "heat-islands", and creating ecological niches, the green roofs of buildings designed act as a thermal mass: in winter, thanks to this type of stratigraphy, little heat is lost, while in summer the loads due to solar radiation are prevented from entering the building, thanks to the presence of the green, which partly absorbs and reflects the radiation, and soil. The green roof has a great weight as a passive instrument, as will be highlighted in section 5.7.
For designing the roof stratigraphy it was taken as a reference the regulation UNI 11235[8]. When designing a green roof, there are three main types to choose from, which are: extensive, with shallow soil, about 70 mm, that support sedums, moss herbs and grass and do not include pedestrian access; semi-extensive, with a soil layer of about 150 mm, which allows to plant a wider variety of plants and requires only periodic maintenance and can provide pedestrian access; intensive, that has a soil layer from 150 mm upwardsand allows medium-stemmed plants to rise and allows pedestrian access, but requires a constant level of maintenance.
The green roofs designed in the project are of the intensive type and have a soil layer of 250 mm, which, as mentioned, allows to plant plants of higher height and wider variety.
On a morphological level, the green roof follows the same guidelines as the courtyard, being designed to have a regular division, being divided into rows of the same size; in this way the owner can change the layout according to his needs: the design started from a simple division into longitudinal strips of width 0.80 m, as well as those of the courts, to then combine it with one

4.8 UNI 11235:2015, Instructions for the design, execution, control and maintenance of green roofs

Fig. 4.59 ▶
View of the green courtyard-green roof system of hostel and private house.

The latters, 20 cm wide, are composed of a steel flange support, covered on the external side by a thin brick veneer, while on the high interior where the green roof is, by a 3 mm steel flashing painted with light paint, as well as the upper edge of the parapet. The height is 1 meter.
Following the instructions for a correct design of the roof drainage, it was planned to install roof outlets at the four corners of the roof, with inspection dwells over each outlet to allow regular inspection and cleaning the vegetation from the outlet grating. Together with this, the stratigraphy of the roof was defined.
Talking about the green roof assembly, as mentioned the outermost layer is the extensive soil mix of 250 mm; the following layer is a filter membrane 0.8 mm thick. Furthermore, the water outflow from a green roof is fundamental, and involves two motions, one for vertical infiltration in the substrate and one for sub-horizontal drainage towards the drains. In this case, a 3 cm thick recycled HDPE drainage board was used, with a compressive strength of 1600 kN/m^2.
The waterproofing membrane is coupled with the root barrier, and they are both 3 mm thick, and serve to completely block the passage of water and roots to prevent damage to the structure of the building; it is therefore necessary that they are installed properly. In addition they, along the edges of the green roof, go up for a stretch overlapping with the vapour retarder of the parapet, to avoid any kind of water infiltration.
After the two membranes the sand sloped creed, of 5 cm is positioned in the point often seen on the edges, which has an inclination of 1% to allow the water to flow out.
Then there is an insulation panel in wood fiber of 10 cm, which has a high compressive strength and a high insulating power, in conjunction with the fact that it is recyclable like natural wood in case of replacement or removal; coupled with the soil it has an excellent insulating power.
Then it is positioned a vapour barrier to avoid humidity rising from interior



1. Intensive soil mix 250 mm
2. Filter membrane 0.8 mm
3. Drenage system 30 mm
4. Protection fabric 3 mm
5. Root barrier (HDPE) 3 mm
6. Waterproof membrane 3 mm
7. Sand sloped screed (Incl. 1%)
8. Wood fiber insulation panel 100 mm
9. Vapor barrier
10. Wood protection board 30 mm
11. Wood joist 80x160 mm
12. Wood beam 200x350 mm

Thickness	47 cm
U-value [W/m^{2}K]	0.226

◀ Fig. 4.60
Assembly, thickness and thermal transmittance of the green roof of the designed buildings.

simple form, a rectangle of 1 x 2.40 meters. In this case the small rectangular areas are bounded by 20 cm high wooden planks, which lay on the earth layer to increase the overall thickness, in this way a greater soil thickness is obtained in order to plant different varieties of plants. These boxes are arranged transversely compared to the rows.
Then to facilitate access to all parts of the roof, without using too much space for walkways, an 80-cm-wide bamboo-paved pedestrian path was designed, which from the point of arrival of the staircase creates an L, "cutting in two" the roof: this pathway is the same for all three green roofs. What varies is the common area designed on the roof, which is positioned at the end of the path: for hostel and private house it is similar in size, respectively 18 and 20 m^2, while for the first building it is not foreseen; in the last case a small rectangular area is positioned in the corner and can be used to lay support tools or work material, since a common space is not necessary. The common areas of hostels and private houses are shaded from solar radiation thanks to the placement of curtains attached to a light metal structure.
First of all, after having finished to design the structure of the building in detail, defining the exact size of the parapets, to understand the effective area of the roof, it was planned to install a 300 mm wide layer of gravel along the entire perimeter inside, bordered by parapets.

Dimensions	1350 x 600 mm
Thickness	10 cm
Thermal conductivity	λ_D= 0,046 W/m K
Density	230 kg/m^3
Specific heat	2.1 kJ/kgK
Vapor diffusion resistance	μ=5
Sound absorption	α_w= 1,00 (class A)
Reaction to fire (EN 13501-1)	Euroclass E
Compressive resistance	100 kPa

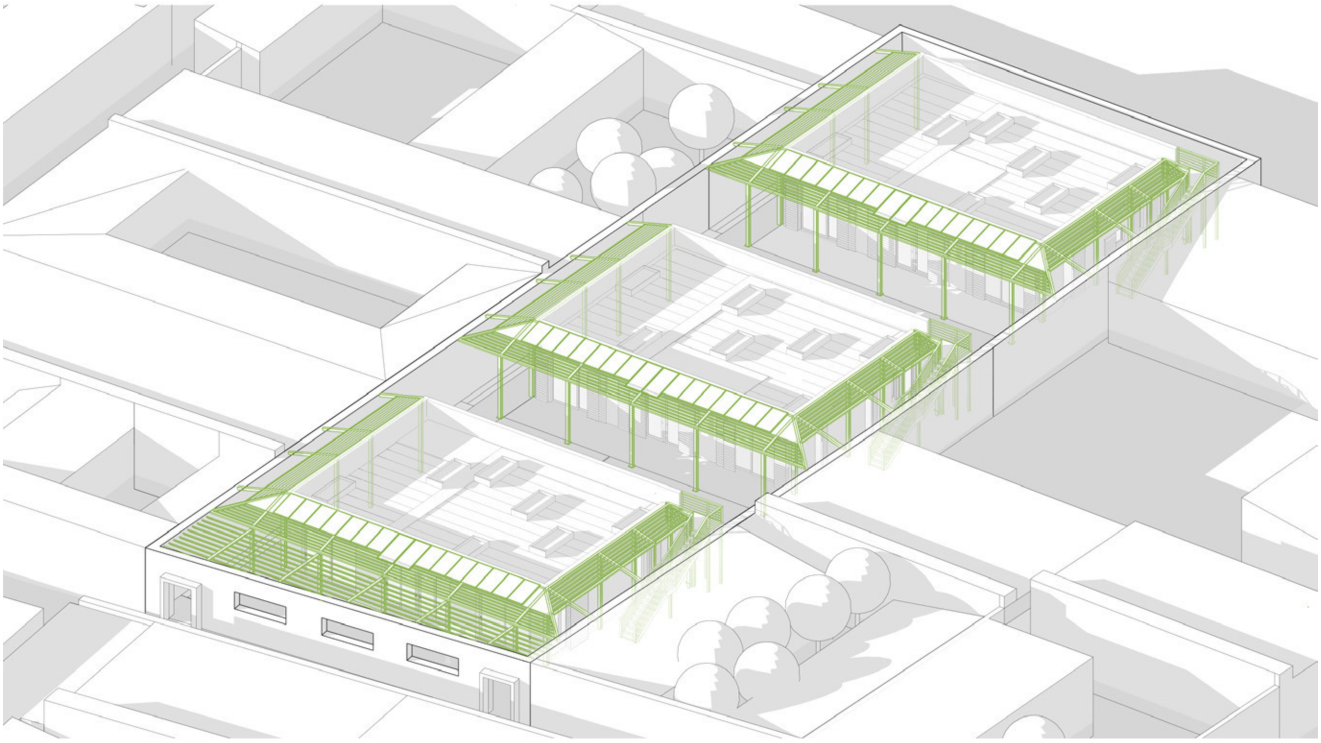
◀ Tab. 4.1.1
Thermal and physical characteristics of the wood fiber insulation.

spaces of the buildings.
Lastly there is the internal wooden structure of the building, which includes a wood protection board of 3 cm, a wooden joist 80x160 mm and wood laminated beams 200x350 mm.
As said, the green roof represents an excellent solution in terms of insulation: in fact the plants on the roof shade its surface, dampening the incoming thermal load and cooling the air thanks to the evapotranspiration; enough said that green roofs hold and accumulate 50 to 90% of rainwater and return it to the environment through evaporation. In addition, the earth works as thermal mass, increasing the insulating power of the assembly. As detailed in section 5.7, the use of green roof has made it possible to reduce the energy demand, decreasing the heat losses in winter, and heat access in summer due to high solar radiation.
Another advantage is the insulation from an often underestimated pollution, the "electro-smog": 15 cm of light substrate of a roof garden absorbs more than 90% of the emissions in the frequency range of the mobile cellular network and of the transceivers.
The typical load of this type of green roof is 200-550 kg/m^2, with an average for accessible green surfaces that can be used in similar constructions, which averages a weight of 350 kg/m^2; for this project a weight of 400 kg/m^2 was taken into account in the worst case of water-saturated soil.
The designed green roof, given the thickness of 25 cm of the soil, if intended for cultivation, is suitable for vegetables and fruit plants, such as salad, onions, aromatic herbs, courgettes, aubergines, squash, cabbage, melon, strawberries .
Thanks to the use of wooden tanks in the roof it was possible to increase this value, being able to use more demanding fruit plants and vegetables: tomatoes, green beans, raspberries, blackberries, currants and similar plants in fact need a substrate thickness of 28 up to at 40 cm.
In the same way small bushes and small trees with a maximum height of 2-3 meters can be planted.

4.6.2 Fixed external shading system

A fundamental component of the passive strategies used for the building is the fixed exterior shading system, which redesign the theme of the verandas of traditional local houses as explained in section 4.4, improving and adapting it to seasonal climatic variations.
The new verandas, being the buildings oriented towards North-South (with a rotation of 11 °) are arranged along the three sunny sides of the buildings, East, South and West.
The structure, to avoid the creation of thermal bridges, is disconnected from the house, and is composed in this way:
• in the hostel and the private house, the first row of small steel pillars is placed close to the buildings on all three sides; the second row, is present only on the South side and is 2.50 meters away, while for the East and West sides it is not present as the structure joins directly on the existing perimeter wall.
• in the multifunctional building the design is the same, with the difference that on the south side the structure is extended to the boundary wall of the with the road.
• there is an exception to the framework of the structure in correspondence with the stairs that connect the ground fllor to the roof on the East side. Starting from the fact that that part of the building does not need particular shading being sunny only in the early hours of the day and that maintaining the structure unchanged would have meant having an obstacle for the passage on the stairs, the shading projection has been reduced: two pillars have been positioned just before the stairs structure at a distance of 1 meter from those close to the building.

▼ Fig. 4.61
View of the designed area highlighting the fixed external shading systems.



• on the south side there are two pillars placed close to the building, and they are positioned at the corners with a distance between them of 16 meters to avoid obstacles for the sliding external shields of the frames: to maintain the loads of the structure and of the solar panels and photovoltaic systems positioned on the south side, the size of pillars and beam in this section has been increased. The porches are composed of two main elements, the steel structure and the bamboo lamellae. This type of configuration makes it possible to have a light structure that resists weathering.
For the base of the structure it has been designed to have concrete foots on which to bolt and weld the pillar base through plates and bolts. The horizontal beams use the same principle, being welded and bolted to the load-bearing pillars. The bamboo lamellae are instead bolted to the horizontal beams.
The oblique part of the shading system in the East and West sides protrudes by 1.40 meters; the south side of the verandas is more elongated than the other two, given the greater amount of incident sunrays, and protrudes by 2.75 meters.

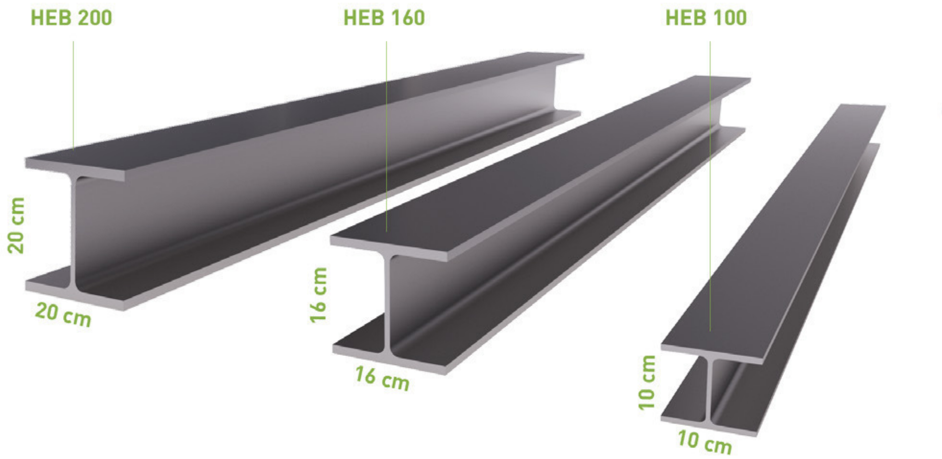


Fig. 4.62 ▶
Steel beams used for the shading system structure.

The steel beams used for the fixed shading system and the stairs structure are the following:
• HE 200 B for the two pillars without intermediate support
• HE 160 B for the main structural system
• HE 100 B for the stairs structural system
The horizontal joists are also made of steel and have the following dimensions: base = 10 cm height = 7 cm. The structures of the photovoltaic and solar thermal panels are attached to the joists.

On the east side the pillars are distant, starting from the south side:

2.50 m - 4.35 m - 2.75 m - 4.10 m

On the east side the pillars are distant, starting from the south side:

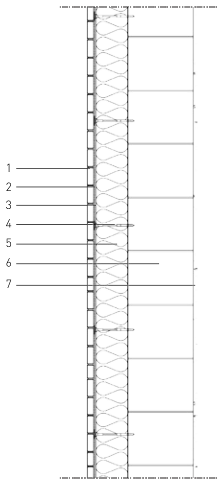
2.50 m - 4.35 m 2.75 m 2.86 m

On the south side the pillars are 4.05 meters far from each other.

4.6.3 Walls

The assemblies of external and internal walls of the buildings have been chosen after a careful analysis of different solutions. The starting points were: low cost, time of construction, possibility of producing part of the materials on site and good values of transmittance, thermal inertia and insulation.
Great importance has been given especially to the insulation and thermal inertia of the walls, as well as to their capability of storing heat and cool; this because the project develops in a cold climate, with temperatures under the comfort conditions for most of the year: during winter months, January that is the coldest one, has an average temperature of -3 °C, while November 3 °C, December -2 °C, February 0 °C.

> External wall



1. Brick cladding 23 mm
2. Support grid+mineral adhesive and smoothing 6 mm
3. Reinforced plastering with metal grid+adhesive and smoothing 8 mm
4. Insulated anchors for mechanical fastening
5. Hemp insulation panel 100 mm
6. Multi-layered blocks in expanded clay 250x200x250 m
7. Lime/Mortar plaster with metal grid 20 mm

Thickness	42.7 cm
U-value [W/m^{2}K]	0.226

◄ Fig. 4.63
Assembly, thickness and thermal transmittance of the external walls of the designed buildings.

The external walls, with a thickness of 42.7 cm and U-value = 0.226 W/m^{2}K, are designed for being massive, creating a high-performance envelope that has low heat losses in winter and high thermal inertia in summer.
Starting from the inside, there is the plaster, painted in a light colour, to allow most of the light to be reflected inside the buildings, increasing the brightness of the rooms. Then there are the blocks in expanded clay, which are composed by a mix of water, sand, gravel, expanded clay and cement: in this way they are comparable to natural stone, making them 100% recyclable. The dimensions of the blocks are 250x200x250 mm, and although they are not load-bearing, their size and weight allow anchoring the insulation and the external wall cladding. These blocks are used in all the perimeter walls of the buildings, while earthen blocks are used for internal partitions.
Thus, after the blocks, there is the coat insulation, which is used along all the perimeter walls. To choose the external walls insulation, the fundamental

Dimensions	250x200x250 mm
Holing percentage (of the total volume)	22%
Average block weight	10 kg
Density	1000 kg/m^3
Average compressive strength f_{bm}	3.5 N/mm^2
Specific heat	1 kJ/kgK
Vapor diffusion resistance μ	7.5
Sound insulation R_w	52.9 dB
Fire resistance EI	240 min
Thermal resistance R	1.13 m^2K/W

Tab. 4.1.2 ▶
Thermal and physical characteristics of expanded clay blocks.

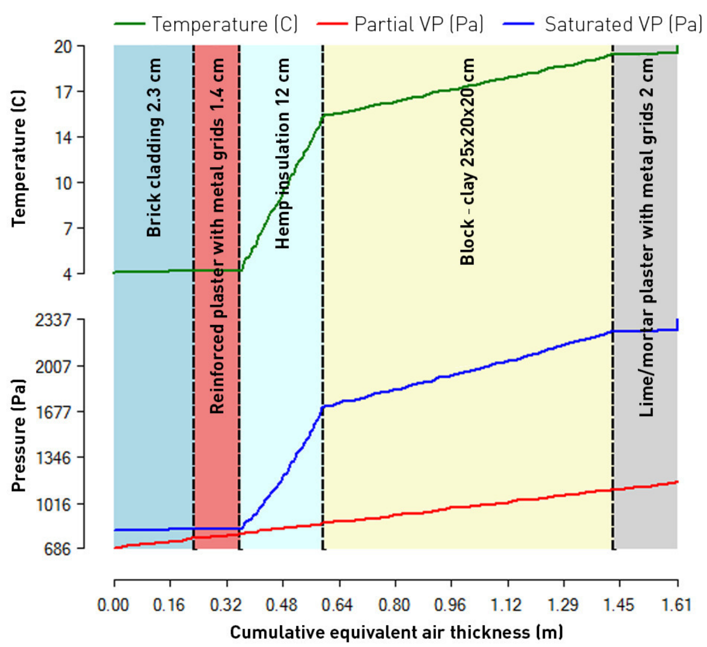
discriminants were to use a product that combined good performance, ease of installation and high sustainability of the production and disposal process. Thus, 12 cm hemp panels were chosen, composed of 87% hemp fiber and 13% polyester fiber, without additives, which makes them a biodegradable and ecological product; this type of panels works also well as thermal-acoustic wall insulation system and can be applied on masonry systems, as in this case. Other important features are that this type of insulation is highly transpiring and resistant to humidity, is unassailable by insects and rodents, is resistant to mold and completely recyclable.
This insulation thickness was chosen because after some simulations with the DesignBuilder software, which will be detailed in the next chapter, it has been noted that increasing the insulation thickness on the one hand would have diminish the heating consumption, since more heat would have been maintained in the building, but on the other hand the cooling loads would have increased in the hottest periods. This happens because in the warmer months, together with the high external temperatures, with July having an average temperature of 25 ° C, June and August of 22 ° C, there would be the difficulty of disposing internal heat loads, due to the excessive thermal inertia. The right performance compromise between summer and winter was to use 12 cm thick insulation.

Dimensions	625 x 800 mm
Thickness	12 cm
Thermal conductivity	λ_D= 0,039 W/m K
Density	100 kg/m^3
Specific heat	2.3 kJ/kgK
Vapor diffusion resistance	μ=3,9
Sound absorption	α_w= 1,00 (class A)
Reaction to fire (EN 13501-1)	Euroclass E
Compressive strength at 10% of the relative deformation	CS (10) ≥ 17 kPa

Tab. 4.1.3 ▶
Thermal and physical characteristics of the hemp insulation.

The outermost layer of the assembly is composed by the cladding: onto the hemp insulation there is a reinforced plastering with metal grid joined with an adhesive and smoothing, 8 mm in total; then, there is a support grid on which the mineral adhesive and smoothing is applied, 6 mm in total. After this layer it is positioned the actual external cladding, made of stone bricks, with a thickness of 2.3 cm. The fixing of the insulation-cladding system is possible thanks to the use of screw-insulated thermal dowels, which hook onto the expanded clay blocks; to ensure correct system stability, the dowels have at least 2.5 cm of expansion zone inside the blocks.
The walls, moreover, have an excellent thermal displacement, that is the time difference between the time when the maximum temperature is recorded on the external surface of the structure, and the time when the maximum temperature is recorded on the internal surface of the structure; this element is important for determining summer thermal comfort and, as such, has important repercussions also in terms of energy savings.
During the hottest periods, it's important to have a thermal displacement of at least 8 hours, but an optimal displacement is around 12-16 hours: in this way the heat will enter the house at night, after 22.00 PM , when it's possible to use the natural ventilation which can rely on the outside environment with lower temperatures, therefore reducing the cooling need. For the used assembly it was obtained a value of 12 hours of thermal displacement.
The assembly has a good thermal quality, and according to the analysis carried out with DesignBuilder: it emerged that the wall has a good total U-value, equal to 0.226 W/m^{2}K, and it is free of condensation, as can be seen from the graph below in the so called *Glaser diagram*[9] performed for the month in which the worst humidity conditions for the condensation inside the wall can happen, i.e. January.

> Glaser diagram for January

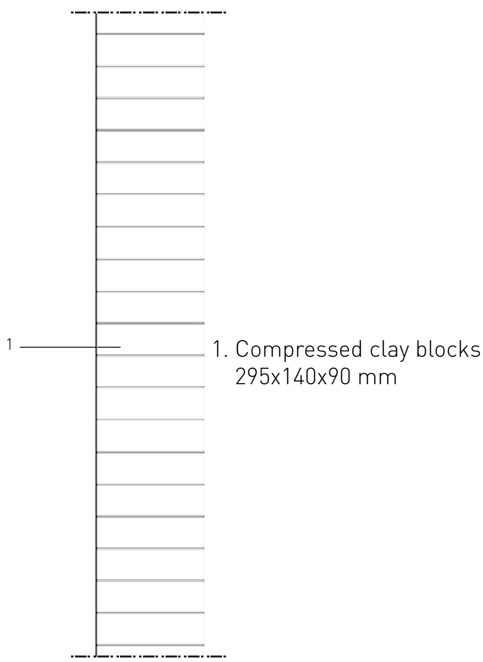


◀ Fig. 4.64
Glaser diagram of the external walls for January.

4.9 The Glaser diagram is a graphic method that allows the study of condensation inside a wall comparing the partial vapour pressure value with that of saturation; the formation of condensation in a layer can happen when the partial pressure value is greater than that of the saturation pressure.

> Adobe internal walls

The interior walls of the buildings, as well as the external walls, are designed to have a good thermal inertia, in particular those that delimit the service zone. Referring to the latter, they are designed to be the internal thermal mass of buildings, storing heat and cool based on the period of the year. They are made of adobe mixed with straw, forming earth compressed blocks of width = 14 cm, height = 9 cm and depth = 29.5 cm, arranged so that the wall thickness is 29.5 cm and have a thermal conductivity of 0.18 kW/mK.
Adobe is very useful in winter since it is able to absorb heat during the day keeping the house cool and then release this stored heat at night, warming the interior of the house. This behaviour is due to the high specific heat capacity of adobe which is an important factor that allows this material to reduce the thermal gradient of earthen houses (Parra-Saldivar and Batty, 2006).
The blocks can be produced on site using craft tools, to then be dried in the sun, as it happened for the bricks used in the local houses.
Also the compressed earth blocks designed, consists in monolithic masonry units made with earth and straw where consolidation is achieved by mechanic means without chemical processes that change the material's nature (Jimenez-Delgado and Canas-Gerrero, 2006).
Regarding the hostel and the private house, the adobe walls of 29.5 cm, delimit the service-zone, dividing it from the night-zone, i.e. the bedrooms, and the day-zone, with the most used rooms. In the multifunctional building they divide the service-zone and the sales/exhibition space. In this way, as mentioned, the walls allow to absorb heat and cold produced by the internal energy systems and gradually release it, thus reducing consumption.
All other internal dividing walls are 15 cm thick, with some minor variations, with few walls in the hostel 10 cm thick. All interior walls are painted in a light colour.



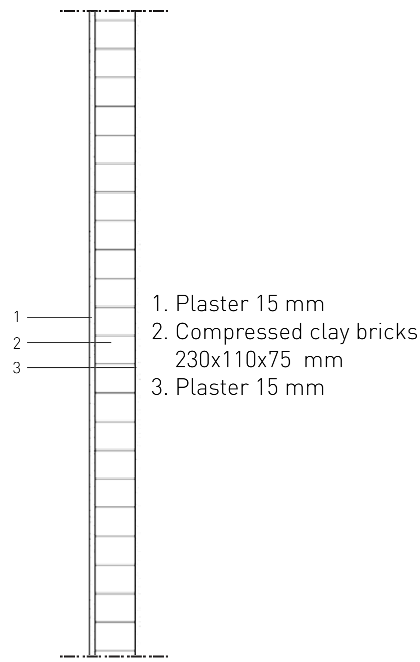
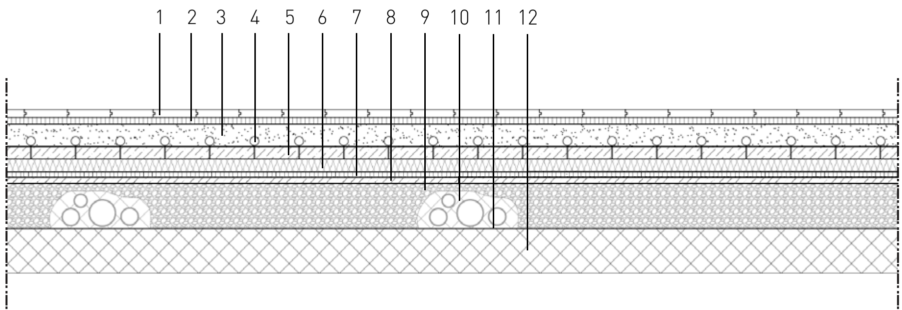


Fig. 4.65 ▶
Internal adobe walls of the designed buildings.

4.6.4 Floor

Being the buildings one-storey high, with a flat green roof, the only internal floor is the one in contact with the ground. To have a floor that was easy to position, that could be disassembled and repositioned in case of damage and that was performing, the choice fell on a dry floor.
Thanks to this type of floor assembly it is possible to have numerous positive effects: in the first place, the use of glues in the installation is avoided and there is a reduced energy cost of production of the components; in addition, it is obtained a high rate of recyclability of the materials used, since they have all been positioned dry and can be easily dismantled.
The only exception is the concrete subgrade, which in this case is 10 cm thick, which it is necessary to use it since it serves to create a stable base, together with the foundations, on which developing the building, dividing it from the ground. Using this type of assembly it is also possible to avoid harmful emissions, which can occur with the use of some plastic materials, and guarantee the transpiration of the floor.
As regards the installation of the components, with a dry structure times are considerably reduced, thus limiting costs ensuring at the same time a good stability over time.
In the same way, in case of damages in the radiant system, it is possible to easily identify the problem by removing the surface layers and replacing them, without particular complications.
Lastly, at the end of the life cycle of the floor or in the event of total replacement, all the components can be disassembled and reused or recycled.



1. Bamboo pavement 96x960x15 mm
2. Gypsum fiber panel 15 mm
3. Dry sand 50 mm
4. Polyethylene heating pipes + Pipe holder clip and screw
5. Wood fiber panel 30 mm
6. Hemp insulation panel 50 mm
7. Gypsum fiber panel 15 mm
8. Wood fiber panel 25 mm
9. Granulated volcanic rock mineral 100 mm
10. Covering cement
11. Transpirant fabric 1 mm
12. Concrete subgrade 100 mm

Thickness	40 cm
U-value [W/m^{2}K]	0.24

◀ Fig. 4.66
Assembly, thickness and thermal transmittance of the internal floor of the designed buildings.

The outermost layer is the concrete subgrade, 10 cm thick; on it, it's firstly laid a 1 mm transpirant fabric in polyethylene, on which are fixed electrical and water systems; once covered and blocked, a dry substrate composed of insulating mineral granulate is placed; then a wooden fiber panel, 2.5 cm, and a gypsum fiber panel, 1 cm, are installed.
Therefore, to increase the thermal insulation, an insulating panel in hemp for floors, 5 cm thick, was placed; on it there is a wood fiber panel. Above the latter, the radiant floor system pipes are fastened. At this point all is covered by a dry sand screed with an optimal granulometric curve, ideal for the heat transmission, 5 cm thick.
Above the layer of dry sand a "sub-floor" is then placed, made of 1.5 cm hard gypsum fiber panels, onto which the bamboo wood parquet is installed; the latter, 1.5 cm thick, is directly nailed to the plaster subfloor.
The parquet is composed by interlocking bamboo tiles, which have the following dimensions: width = 9.6 cm length = 96 cm thickness = 1.5 cm.
When the work is finished, the surface of the parquet is perfectly calibrated, without jumps between one plank and another, as has could happen with the glued installation.
As regards the vapour barrier, it is always essential to position it between the subgrade, on which the water systems and electrical systems are placed, and the insulating panels on which the radiant system pipes are fixed. This is made in order to avoid problems related to rising damp, which can create condensation and ruin the components of the assembly.

4.6.5 Windows

Multiple factors influence the windows efficiency, making certain types of window frames or window glass much more suitable than others, depending on the area in which they will be applied and the climatic conditions to which they will be subjected.
Regarding the chosen openings, the first guidelines were dictated by the climate analysis, which highlighted, given the prevalence of low temperatures during the year, the need of using high-performance windows, which would allow to have low heat losses. At the same time the windows should have had an adequate g value, to capture the highest possible percentage of sunlight during the coldest months, so as to reduce the heat load due to heating, while at the same time increasing the light transmission as much as possible.
The analysis started from the window types used in local buildings: historic buildings use single glazing, which therefore guarantees very low performance, while the construction standard of new homes now requires the installation of double-glazed windows.
Therefore the provisions of the Italian legislation were evaluated, which with the DM 11/01/2017[10], defines the transmittance limits of the windows for new

4.10 Italian ministerial decree 11 January 2017, Adoption of minimum environmental criteria for interior furnishings, construction and textile products.

construction interventions depending on the climate zone.
The area of Pingyao, as defined in the climatic analysis, corresponds to the climate zone F: in this case there is a limit of U = 1.60 W/m^{2}K.
To connect the initial indications, with the normative standards, the choice was directed towards the use of low-emissivity glass windows, which appeared to be the most suitable for the design requirements.
Today their application field foresees the use in two types of windows: those with low-emissivity double-glazed glass, coated on one side and filled with argon or air inside; those with three-sheet low-emissivity double-glazed glass, equipped with two film-coated plates filled with argon or air. However, triple glazing has a higher average cost than double glazing, in the order of 10-20% more, is much heavier, weighing on the frame structure and the glass is less transparent, greatly reducing light transmittance; referring to the latter, during the mid-seasons, when the heating is not used, they have an excessive isolation, not allowing the sunrays to pass and heat the internal environment. As a result, triple glazing is suitable for dwellings exposed to harsh temperatures, such as mountain homes, or for houses constantly exposed to cold winds.
Therefore the choice fell on the use of double glazed windows, which reach all the necessary values, both thermal, acoustic; those with triple panels would be excessive for the project carried out in this thesis, both in terms of cost and performance.
Regarding the gap between the glasses, it is filled with argon gas, whose properties allow the heat losses to be reduced.
The chosen glasses have the following values:

Window composition (from in to out)	4 - 20 - 4 [mm]
Thickness	28 mm
U_g value	1.1 W/m^{2}K
g value	65 %
Light transmittance value	82 %

◀ Tab. 4.1.4
Assembly, thickness and thermal transmittance of the internal floor of the designed buildings.

Talking about the window frames instead, mainly three materials are used nowadays: wood, PVC and aluminium. Therefore it is necessary to understand which is the best application in terms of thermal and acoustic insulation, to evaluate the component cost, which clearly depends on the economic availability, and to understand the atmospheric conditions that the fixtures want to resist over time.
The wooden frames provide good thermal insulation, and for this reason they are often applied in cold places. Furthermore, wood gives the possibility to be cut, finished and personalized according to the project requirements. On the other hand, wood suffers prolonged exposure to the sun and to the weather in general, requiring some maintenance in order to last for years.
Regarding the wood type to use, in colder climates the best choice are the conifers, or trees with needle-like leaves. On the other hand, the trees with

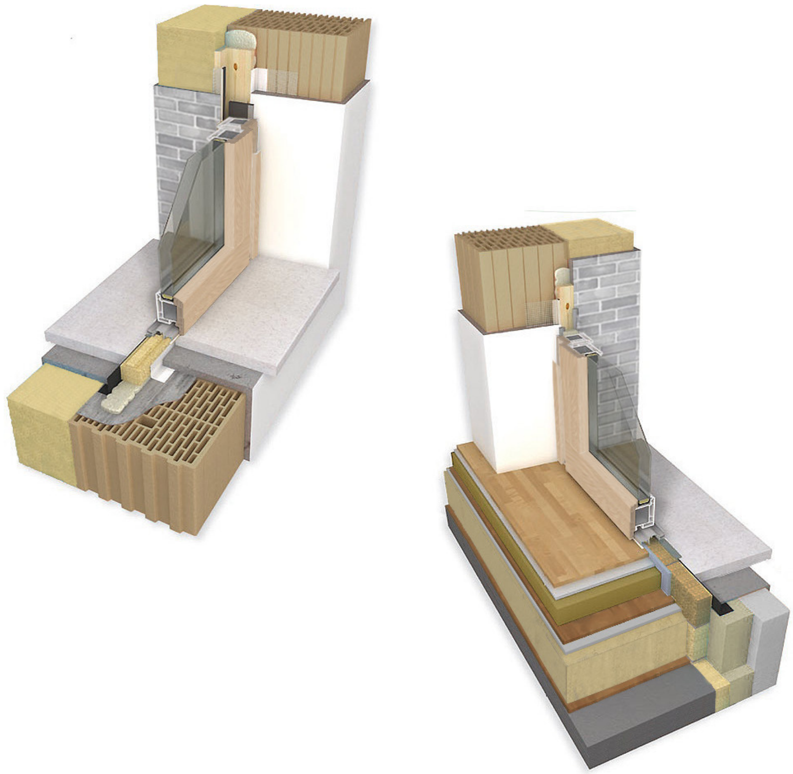


Fig. 4.67 ▶
Graphic rendering of window (on the left), and glazed door (on the right) used.
Source: Author's elaboration

broad-leaves are indicated for a milder climate. A valid alternative is the teak, a wood whose characteristics give it high resistance to the elements and a good durability.
The aluminium frames are a valid alternative since they offer some substantial advantages: the main one is that they do not deteriorate over time, resulting in a long-term investment; in addition, they weigh little and are ideal if large-sized frames are needed, or whose shape should be moldable. On the other hand aluminium is a conductive material therefore it does not provide good thermal insulation, or even acoustic; furthermore, condensation is often formed due to the difference in temperature between the inside and outside of the building. But nowadays to compensate for these problems, aluminium can be used very effectively in combination with wood, with considerably higher costs.
The PVC (polyvinylchloride) frames instead, are the cheapest on the market and they can be modelled according to needs, in terms of shape or colour; in addition, unlike aluminium, they guarantee good thermal and acoustic insulation without creating any condensation problems.
The main contraindication is the potential deterioration of PVC itself when exposed to certain conditions: the prolonged exposure to the sun, for example, strongly undermines the solidity of the PVC frames and, consequently, their effectiveness in insulating the house acoustically and thermally. Another negative aspect is the inability to restore the original state of PVC in case it deteriorates.
Since each of the three materials has advantages and defects, which make them more or less suitable depending on the project, the last option is to evaluate fixtures that take advantage of a combination of two of the materials above mentioned, combining the best features of each.

In the aluminium-wood fixtures, for example, the external part is made of aluminium, but on the inside they have a wooden cover that increases the thermal performance. This combination can be the best one since it limits defects and maximizes advantages of both materials. As a result, the frame becomes resistant over time, a characteristic of aluminium, and exploits the thermal and acoustic insulation that wood guarantees over the years. The main negative aspect concerns the costs of aluminium-wood fixtures, as processing requires both materials to be processed, thus increasing the costs of the frames themselves.
For this project, finding a compromise between costs and fixture performance, it has been chosen to use the wooden frames, thanks to all their favourable characteristics related to insulation.
The total width of the frames is 15 cm, and its U value is 1.327 W/m^2K. It is then possible to make an example calculating the total transmittance of a window designed for the private house, that is one of the windows facing north in the bedrooms, of 50x150 cm.
The formula is:

$$U_w = \frac{A_g + A_f}{A_f U_f + A_g U_g + l_g \psi_g}$$

where

A_f = frame surface
A_g = glass surface
l_g = glass perimeter
U_f = frame transmittance
U_g = glass transmittance
ψ_g = distance correction value of the glass

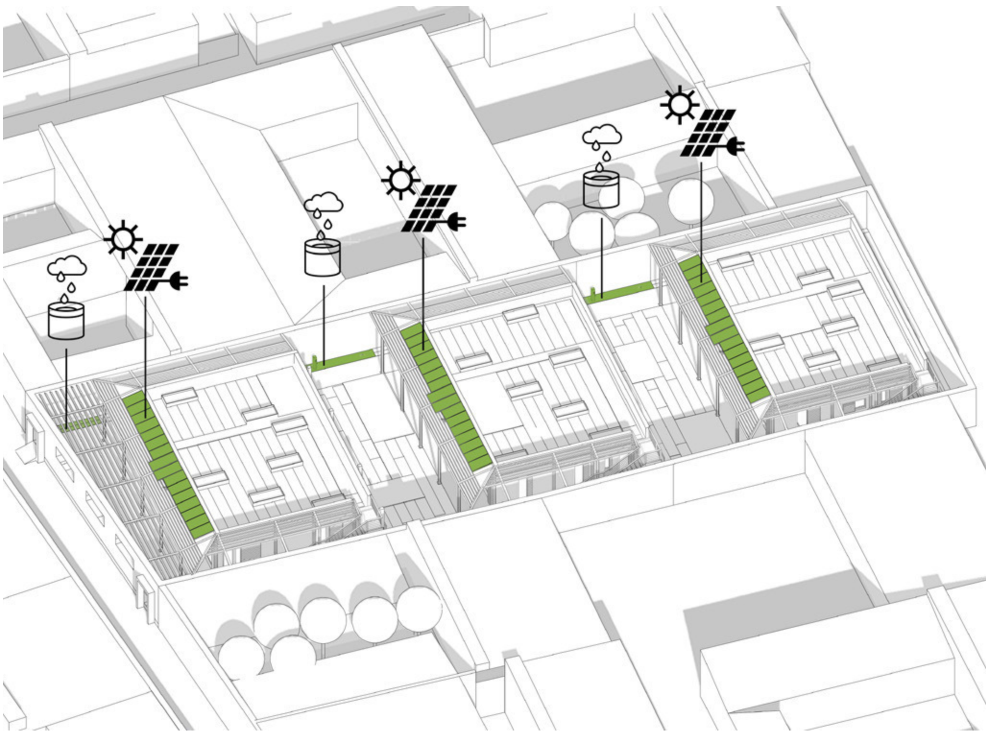
$$U_w = \frac{0.434 + 0.533}{0.533*1.327 + 0.434*1.1 + 3.3*0.048} = 1.38 \ W/m^2K$$

4.6.6 Systems for RSE and water harvesting

Renewable source energy (RSE) production systems have also played an important role in the design. The most important are the photovoltaic and solar thermal systems, which, as will be detailed in chapter 6, in the first case are used to produce electricity to cover the internal consumptions, in the second case to produce domestic hot water.
The panels are positioned above the south side of the porches, being the

one most exposed, and are inclined at 15 °, following the inclination of the structure. According to the project objectives the panels will be connected directly with the respective technical rooms of each building, so as to have a direct connection with energy systems and meters. To confirm the intention to use the panels, analysing the graph that shows the average monthly trend of sunny, partly cloudy and overcast days in the climate analysis, it emerged that: about 40 % of the year it is possible to have clear sky, about 40 % cloudy sky and about 20 % an overcast sky. Therefore it could be convenient to use systems aimed at exploiting solar energy.
At the same time, since the project envisages the creation of green courtyards and green roofs, which require significant amounts of water, it is necessary to consider the possibility of installing a rainwater collection system.
This type of system does not represent a novelty for the Hou Ji village, since from the studies carried out by NTNU and SEU, it emerged how numerous dwellings use cisterns for collecting water, positioning them inside the courtyards or on the roofs.
Due to the conformation of the project site, it was planned to have a water collection system for each building, which canalizes the water flows through drainage channels or pipes. For the ground floor channels and pipes are positioned at the edge of the walkways, while on the green roof, it is already present a system of pipes and inspection wells that runs along the entire perimeter; either will be connected by pipes to the cistern. To do this, floors, as well as the roof assembly, will have a slight inclination to favour the water outflow, of 2%.
The water will be collected in underground cisterns, to protect them from sunrays, placed inside the courtyards near the border wall.

Fig. 4.68 ▶
Position of the RSE system used in the designed area: the water collection tanks are positioned on the east side of the courtyards; the photovoltaic and solar systems are located on the external shading systems.



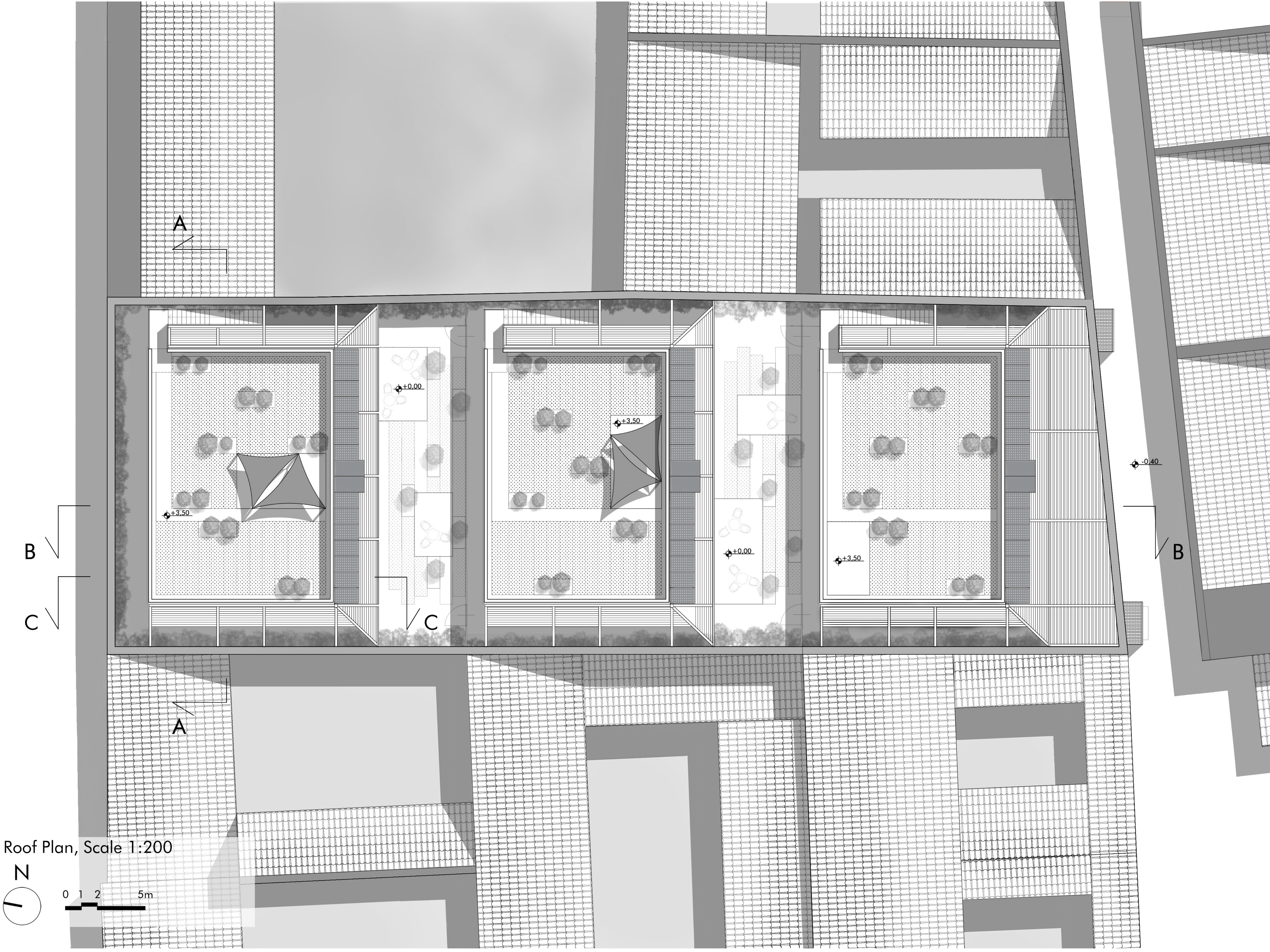
4.8 Project drawings

1. Outdoor sale space
2. Sale space
3. Space for office/administration
4. Aisle
5. WC
6. Technical room
7. Storage Room
8. Gardening space/Common area
9. Solar greenhouse
10. Entrance/Common room
11. Common room
12. Kitchen
13. Office
14. Women Showers
15. Men Showers
16. Common bedroom
17. Living room
18. Study
19. Bedroom
20. Master bedroom
21. Kang
22. Additional working space

Ground Floor Plan, Scale 1:200

N

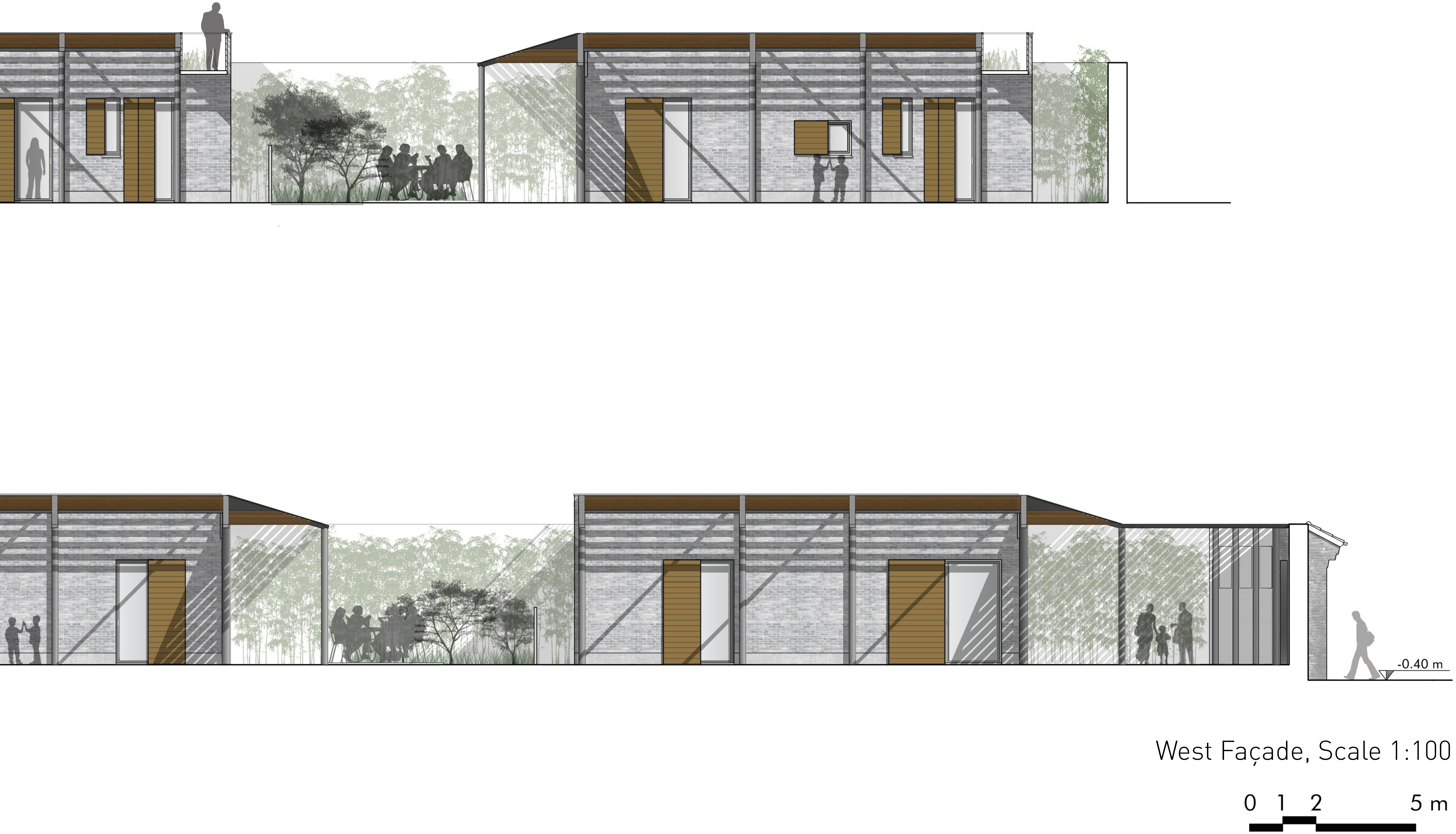
0 1 2 5m



Roof Plan, Scale 1:200

East Façade, Scale 1:100

0 1 2 5 m



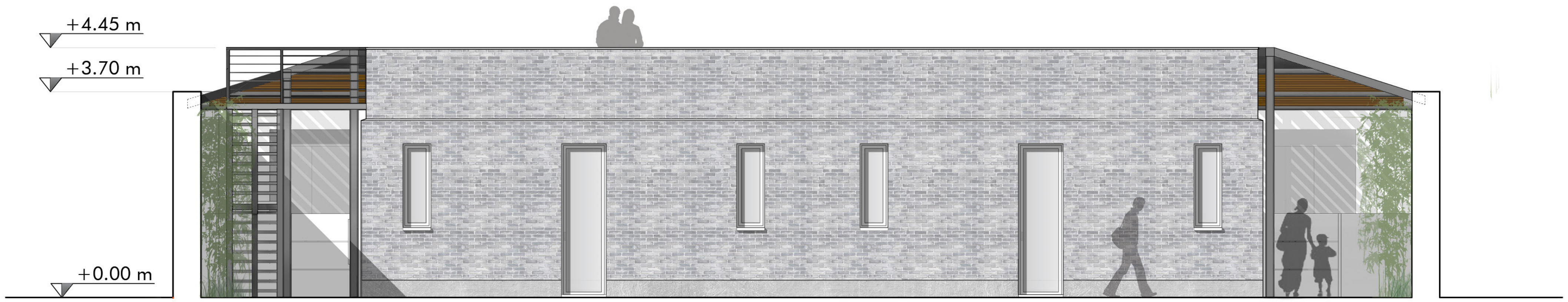
West Façade, Scale 1:100

South Façade, Private house and Hostel, Scale 1:100

0 1 2 5 m

North Façade, Multifunctional building, Scale 1:100

0 1 2 5 m



North Façade, Hostel, Scale 1:100

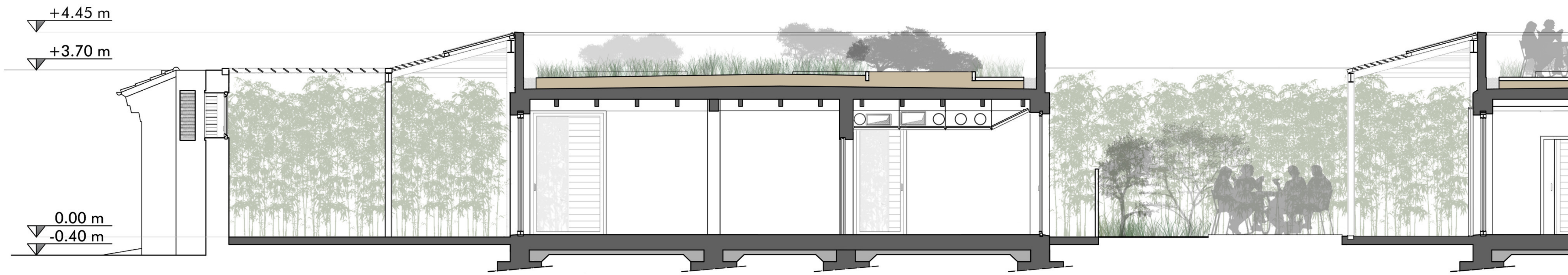
0 1 2 5 m

North Façade, Private house, Scale 1:100

0 1 2 5 m

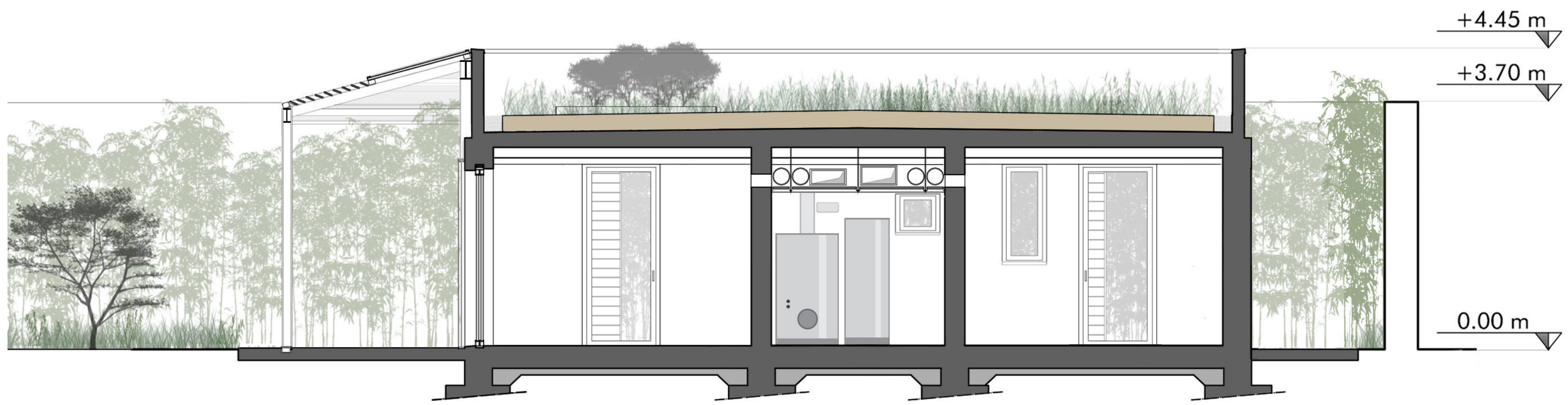
Section A-A, Scale 1:100

0 1 2 5 m



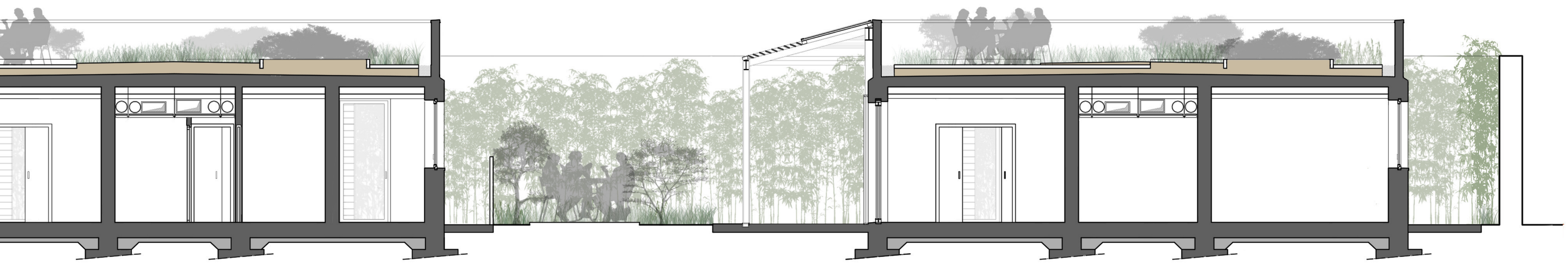
Section B-B, Scale 1:100

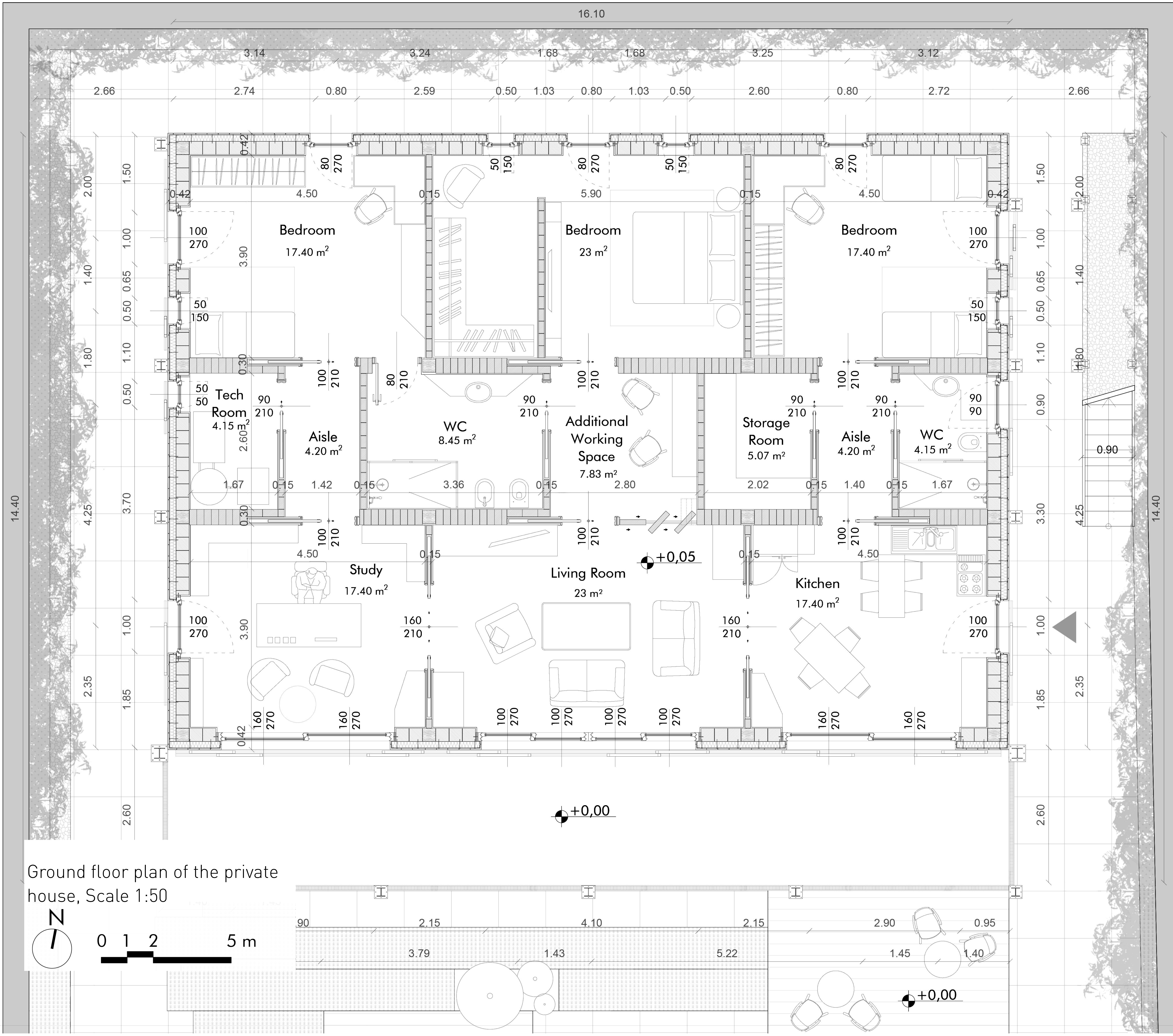
0 1 2 5 m



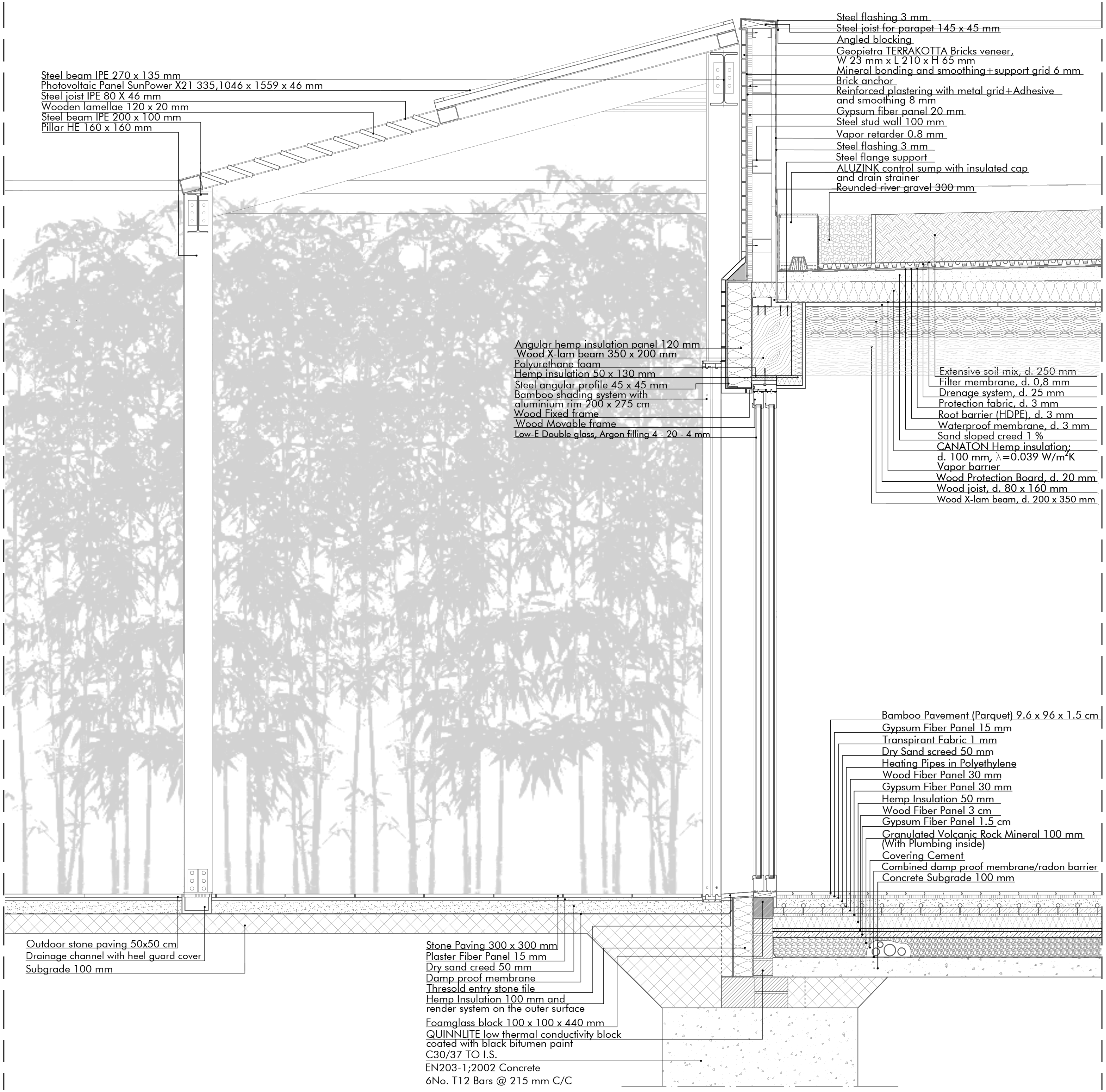
Section C-C, Scale 1:100

0 1 2 5 m





Ground floor plan of the private house, Scale 1:50



Technical detail, Fixed external shading system - building
Scale 1:20

0 0.2 0.4 1 m

Chapter 5

DesignBuilder & Passive Design

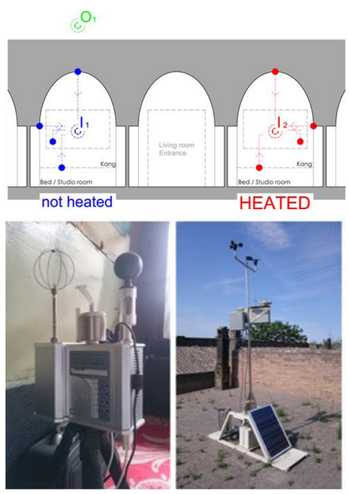
The aim of this chapter is to explain the passive strategies behind the project choices, before defining the actual energy system, presenting at the same time the software used, DesignBuilder. To do this, it is necessary to first illustrate the preliminary studies carried out by the NTNU and the SEU and then analyse the building used for the analysis: the private house.
At the same time it is important to describe how the building's energy model was created using DesignBuilder, defining the parameters and specifications used: the main steps that allowed the creation of a model as consistent as possible with the project are described.

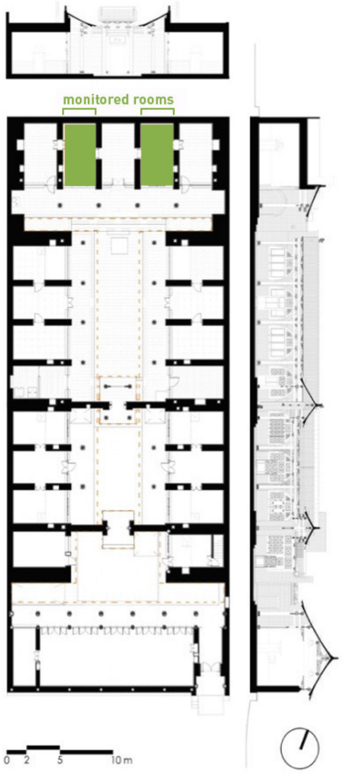
5.1 Local building energy conditions and analysis

Before proceeding with the definition, first of the passive strategies used in the design and then of the energy system used, it is necessary to clarify in which building context the project is placed and which are the local standards for the existing buildings. To do this, it is appropriate to refer to the analysis carried out, by the NTNU of Trondheim and the SEU of Nanjing on the village historical buildings, to which reference had already been made in section 3.9. As written, the studies were referred to the old courtyards, which mainly needed interventions for upgrading their energy performance and in some cases of repairing non-structural elements.
The research project that handled the aforementioned analysis, carried on by SEU and NTNU with support from the Norwegian Council of Research (NFR), was realized between years 2013-2016 and was entitled "Energy efficient up-grading of historical villages in Ping Yao area, Shanxi Province, China".
It was composed by three Work Packages (WP) :

• the first Work Package, WP1, focused on the analysis of the local building traditions, their historical and architectural values together with their technical state.
• the second Work Package (WP2) focused on anthropological studies, necessary to understand how the housing structures ordinarily were used, underlining pros and cons with regard to energy efficiency.
In detail, were analysed daily activities carried out inside and outside the existing dwellings, and how thermal comfort, daylight and ventilation were perceived and influenced activities, feeling of security, belonging and other aspects of residential life.
• the third Work Package (WP3) focused on detailed building physics investigations and energy evaluations and calculation of a building in particular. On the basis of this it was defined a chart of possible interventions that could have been applied to improve the environmental performance of the building, reducing its energy demand.
The analysis in WP3, as said, was carried out on a courtyard house in particular, the Liu Compound, which is also the biggest compound in Hou Ji.

To monitor the house, it has been installed a system denominated HBAS - Historic Building Assessment System – by SEU and NTNU with the support of the Beijing Jiantong Technology. The system aimed at monitoring the winter conditions both of external and internal environment of the house and consisted of one micro-climatic station placed outside the house and four interior thermal environment monitors.
The outside micro-climatic station, placed on the house roof, recorded air temperature values (-30~+70 ± 0.5 °C), relative humidity (0~100 ± 3%), horizontal solar radiation intensity (0.3~3.2 μm with sensitivity 7~14 mV/(kW/m^2) ± 2%), precipitations (≤8 mm/min, φ160 mm ± 4%), wind speed (0~30±1.0 m/s, start at 0.5 m/s) and direction (360° ± 5%,) (Finocchiaro L. et al., 2015).





▲ Fig. 5.3
Ground Plan of the Liu Compound with monitored rooms highlighted. (Finocchiaro et al., 2015)

The four monitoring apparatus located inside the house were placed two in the west room (unheated) and two in the east room (heated). They were able to record data of air and surface radiant temperatures, relative humidity, wet bulb temperature, black bulb temperatures, air flow speed and CO_2 concentration in PPM. They were also able to instantly calculate predicted percentage of dissatisfied (Finocchiaro L. et al., 2015).

As stated in the climate analysis, the HouJi village is located in an area with a climate that is cold-semi arid, according to Koppen-Geiger climate classification. This means that there are large temperature excursion between day and night and that during the year there is a prevalence of cold temperatures, for about six months, fairly short intermediate seasons, and a warm season about three months long with temperatures in some cases very hot; to this are added the strong cold winter winds from Siberia.
Referring to the analysis of WP2 and WP3, to overcome these problems, local homes, both in terms of conformation and construction, are built to protect themselves as much as possible from cold and wind and to disperse as little heat as possible during the cold months.
In fact the local houses use heavy walls in order to store the solar heating during the day while releasing in the night, with the walls that in traditional constructions are made by bricks of burnt loess[1], which guarantees high stability and low thermal conductivity (Finocchiaro L. et al., 2015).
At the same time, buildings are mostly characterized by the presence of an internal courtyard, towards which all the openings face: this was made in order to optimize the access of solar radiation while protecting the house from cold winds. Usually, outside the windows, wooden screens are positioned, equipped with rice paper during the cold season, in order to filter the daylight while regulate ventilation from the courtyards.
To protect the interior from solar radiation, there is a porch along each side of the buildings: this allows to shade the hot summer sun, while allowing low winter sunlight to penetrate inside.

Also from the analysis of WP2 and WP3 the following information concerning the thermal comfort during the year and to the ways for handling discomfort:

- the form and orientation of the buildings, i.e. the narrow yard distributed along the east-west direction, the deep eaves as well as the heavy mass in roof and walls, facilitate thermal comfort.
- the residents have four main measures for improving comfort:
  - by shifting between carrying out activities outside and inside
  - by using the heated kang and sometimes supplementary extra heating when necessary
  - by adapting clothing to shifting temperature
  - by using shutters, padded carpets and curtains at doors and windows.
- Local old people usually wear several layers of clothing the whole year

◀ Fig. 5.1
Section of the building with the location of the three control units. (Finocchiaro et al., 2015)

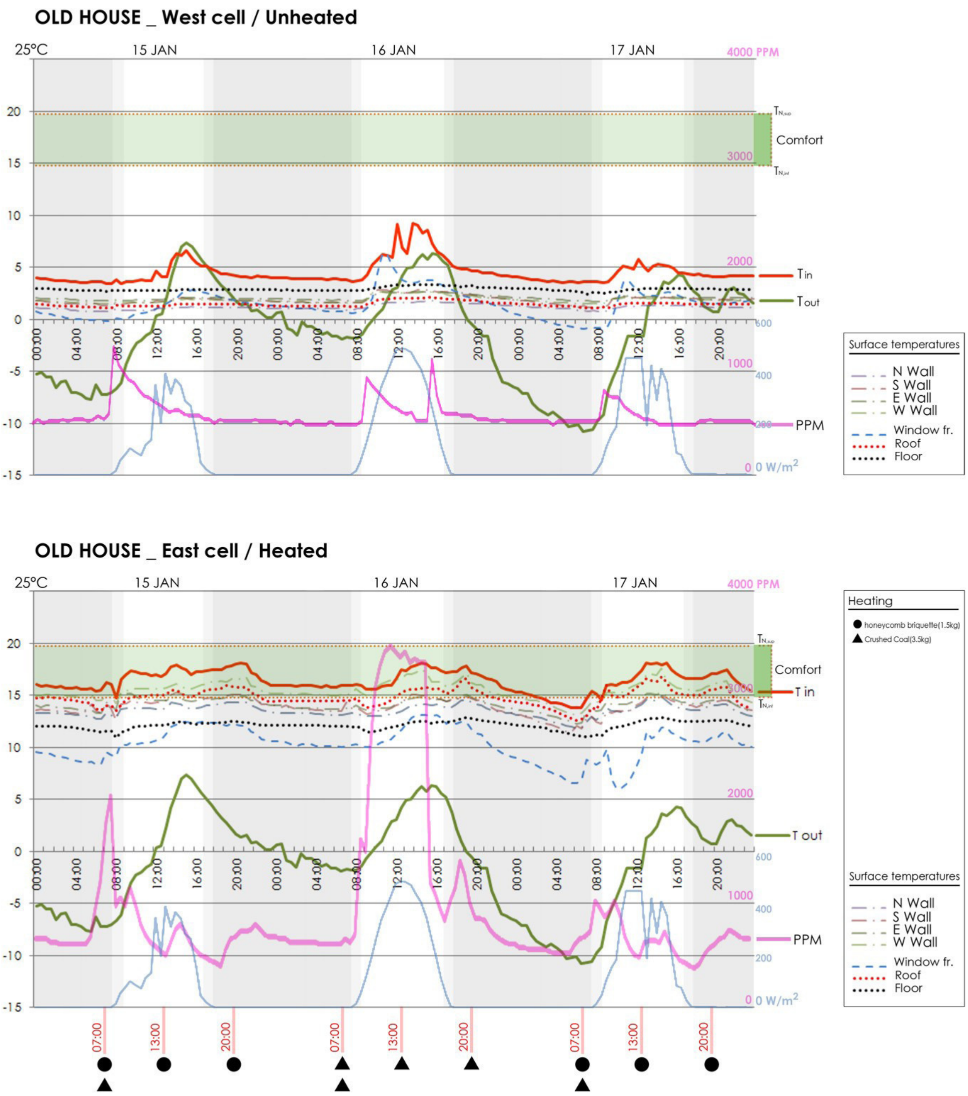
◀ Fig. 5.2
The installed control units. (Finocchiaro et al., 2015)

5.1 Aeolian sediment formed by the accumulation of windblown lime.

round, while young people seems to relate to the temperature of the season when it comes to clothing (Finocchiaro L. et al., 2015).

About the daylight handling, simple measurements were made on an overcast day with shifting sky conditions, with a Konica Minolta illuminance meter[2]. The outside illuminance was measured in the middle of the courtyard, which means that there was not full hemisphere of the sky where the measurements were taken. Inside measurements were taken on the kang close to the window, in the middle of the kang and at the edge of the kang.
Therefore the following informations emerged:

• Daylight factor, (100% x indoor illumination/exterior illumination), was calculated to be 3,5 - 4,5% by the window, 1,8 - 3,9% in the middle of the kang, 0,8 - 2,4 by the edge of the kang. In the rear of the room the values were 0,17% - 0,2%. Although these values were not so accurate, they indicated quite good daylight conditions (Finocchiaro L. et al., 2015).
In the same way the houses of more recent construction, despite having been



◀ Fig. 5.4
Results of three of the coldest days within the monitoring period. (Finocchiaro L. et al., 2015)

5.2 The Konica Minolta illuminance meter is a single element detector that measure photometric brightness falling upon a surface, i.e. the amount of light that strikes a surface, in footcandles or in lux.

built in the last fifty years, and although using more modern construction standards, seemed to have important deficiencies in terms of comfort regarding the internal air quality, air tightness, as well as isolation.

At the end of the analysis, the following results for winter conditions, were found:

- the measured transmittance values were very high for each building components, both for the wall and floors and for the fixtures, with the exception of the roof.
- temperature fluctuations indoor were reduced from an amplitude of 18 °C to 4 thanks to the effective use of heavy thermal mass
- major challenges in winter were related to air quality and differences among radiant surface temperatures, especially those of windows and floor
- the floor temperature resulted being the most stable one, with values constantly around 3 °C in the unheated room and 12 °C in the heated one
- in the west heated cell, instead, the use of the kang is able to move temperature values within the thermal neutrality range of 14-19 °C
- Significantly high values of carbon dioxide level, up to over 3000 PPM, where 1000 PM is taken as a limit, have been also recorded, during midday in the heated room because of the use of crashed coal and honeycomb briquettes in the Kang.
- there were a high predicted percentage of discomfort in the heated room, always included between 56 and 91% according to the monitoring system
- the mixture of loess and straw used for both bricks and rammed earth over the roof vaults ensured an effective insulation layer. This was confirmed by thermal resistance measures conducted on-site that revealed a low average U-value of 0,65 W/m^{2}K (Finocchiaro L. et al., 2015).

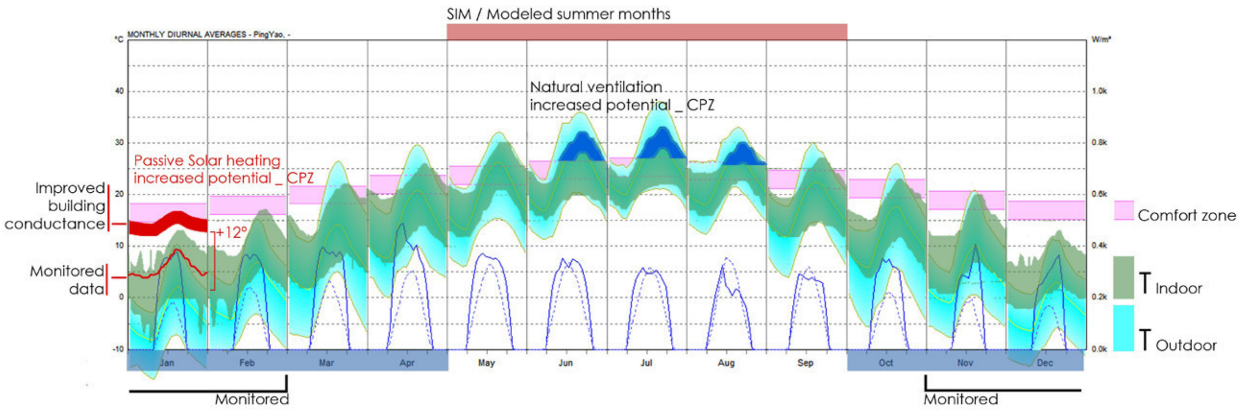
Building envelope Liu House

Component	construction / layers	d (m)	λ (W/mK)	R=d/λ (m^{2}K/W)	u-value (W/m^{2}K)
Outer walls	Ext.Surf.resistance	-		0.04	
	Bricks	0.54	1.02	0.53	
	Internal plaster	0.01	0.02	0.50	
	Int. Surf.resistance	-		0.11	
10.3 m^2				1.18	**0.85**
Internal walls	Ext. Surf.resistance	-		0.04	
	Internal plaster	0.01	0.02	0.50	
	Bricks	0.54	1.02	0.53	
	Internal plaster	0.01	0.02	0.50	
	Int. Surf.resistance	-		0.11	
20.20 m^2				1.68	**0.60**
Parapet wall	Int. Surf. Resistance	-		0.11	0.00
	Internal plaster	0.01	0.02	0.63	
	Bricks	0.41	1.02	0.40	
	Ext. Surface resistance	-		0.04	
3.85 m^2				1.18	**0.85**
Windows	wooden frame (%)	32			
	Single glazing	0.006			
	SHGC	0.860			
	Rice paper shutter	-			
6.45 m^2					**5.00**
Vaulted roof	Ext.Surf.res.	-		0.04	
	Limestone	0.02	1.30	0.01	
	Clay-straw mix	0.56	0.18	3.13	
	Bricks	0.39	1.02	0.38	
	Internal plaster	0.01	0.02	0.50	
	Int. Surf.res.	-		0.11	
28.45 m^2				4.17	**0.24**
Whole envelope	infiltration rate	2.00	ach (50pascal)		0.00
	Room conductance	63.1			
69.26 m^2					0.91109

Fig. 5.5 ▶
Building's thermal characteristics obtained from the WP3 analysis. (Finocchiaro L. et al., 2015)

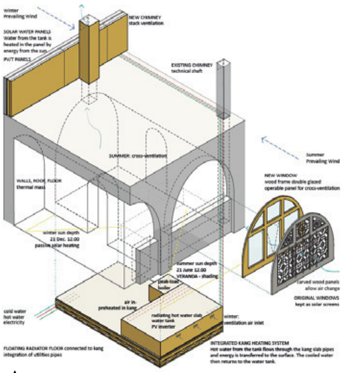
5.2 The starting point: continuity with tradition and re-interpretation

Thanks to the analysis carried out in the WP by NTNU and SEU some important design indications were obtained regarding the interventions to redevelop them on an energy and construction level, which in turn have been useful for the development of the project contained in the thesis.
Those informations were used to adequately comprehend the local buildings condition and to design the new buildings using passive strategies in the most coherent way possible using the potentialities that emerged, obviating instead the design and construction deficiencies. Nonetheless the project wanted to deviate a lot from the traditional local architecture under some points of view, while under others it was decided to use the hints obtained.
For the passive strategies management in the thesis' project, the data taken



▲ Fig. 5.6
Temperature fluctuation throughout the year and potential correction through passive strategies use. (Finocchiaro L. et al., 2015)

from the conclusions of the WP3 work, result of the studies in winter through field analysis and of the building modelling in DesignBuilder for simulating the summer conditions, were taken as reference; in this way a complete annual chart of suggestions was obtained.
Some important indications emerged, as shown in the image above:
• having an effective natural ventilation during the hot season, assuming an internal air-speed of 1,5 m/s and a ventilation rate of 10 l/s*person had a positive effect for avoiding internal overheating and using as less as possible an eventual mechanical ventilation; the effect is highlighted by the blue color in the graph.
• increasing the number of air changes per hour and inlet of fresh air through natural ventilation has increased the indoor air quality; this was made by inserting a chimney for extracting exhausted air through stack ventilation since the rooms have only one window. If more than one window is available, it is possible to avoid using the chimney using instead cross ventilation.
• having a low U-value for windows, especially those facing south, helped to decrease winter losses and increase solar gains.
For the Liu House, reducing the south window U-value to 2,5 W/m^{2}K from the previous 5 W/m^{2}K have reduced the overall conductance of the building envelope from 64.8 to 48.7 W/K, making possible to passively rise internal temperatures of the house of 12° and minimizing the use of kang to the strictly necessary for cooking and comfortable sleeping (Finocchiaro L. et al., 2015).



▲ Fig. 5.7
Exploded axonometric view of architectural upgrading interventions (Despa A.M., 2015).

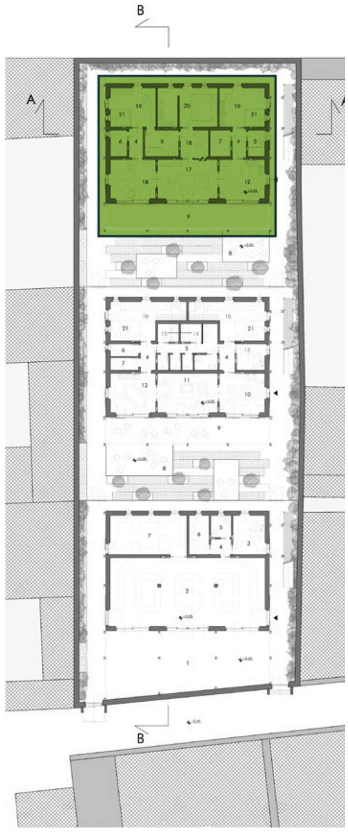
• using a modern energy system based on radiant surfaces or modernizing the kang connecting it to a floating radiator floor has had positive effects on the stabilization of the internal temperature.
• during the hot period, the heavy construction of the building in combination with porches and shutters shading led to the achievement of a temperature range close to the comfort zone, according to the simulated data. In this way, internal temperatures turned out to be more favourable than outdoors' ones.
• to improve the efficiency of the systems a good solution was to use an alternative energy sources for running the kang or the heating the house as solar thermal systems.
• not using any more system based on the coal to cook and heat, in order to reduce the high internal values of PPM, which exceeded 3000 PPM, helped to have better IAQ.

At last, according to the results, SEU and NTNU gave two ways to intervene, minimal and maximal, giving recommendations for a building energy performance upgrading and improvement of IAQ, (Interior Air Quality), with intervention respectively.
The first indicated some less expensive solutions: removing the kang to improve health security; replace fixtures with some more performing and morphologically faithful to the originals, increasing the airtightness to improve thermal performance; replace the used pipes that had leaks and add some mechanical exhaust ventilation to improve the IAQ; reconstruct the electrical system and use new and efficient luminaire for lighting.
The second indicated some more expensive solutions: use high-performance thermal-break windows, as double glazing with thermal-break aluminium frame; add a thermal insulation layer on the walls; use high insulation doors; use mechanical heat recovery system for fresh air; add stack chimney on the north wall to enhance the natural ventilation in summer; use PV/T system for electricity production and hot water, even for ground heating using the hot water.
After all these considerations, the compositional choices of the project carried out in this thesis, part of an integrated design in all parts, were positively conditioned by them, finding confirmation, from the beginning to the end of the project, in the correctness of the energy analysis. This applies to the choice of using massive walls to retain as much heating as possible in winter; the use of an outdoor shading system that allows to shield only the sun from hot periods; use well-insulated perimeter walls; use green roof, for providing excellent thermal performance to the ceiling; use radiant surfaces to heat and possibly cool; use walls painted with light colours to increase the brightness both in the courtyards and inside the buildings; use double glazed fixtures, without going any further, as they are sufficient for the local climate; adequately ventilate the interiors of buildings to avoid overheating and maintain high IAQ; favour the use of cross ventilation or mechanical ventilation, given the possible excessive complexity of inserting a chimney for ventilation in a house with high energy efficiency in a cold-arid climate, with cold outside temperatures for many months during a year.

5.3 The analysed case: *the private house*

Regarding the building object of the energy analysis, the private house was chosen, even if the choice could have fallen on each of the three planned buildings, given the almost identical construction type. The main difference is due to the diversity of functions of the three buildings: this led to the choice of a private house because in an eventual situation in which it could be decided to replicate the building typology, it would be the more suitable solution, given its residential character.
Despite this choice, the energy analysis have accompanied the entire design process of all the buildings, each time giving important feedback in relation to the design choices; some choices have therefore been confirmed by the results of the analysis, while others have been modified or removed due to their negative contribution to energy balances.

From the first steps of the project it was foreseen that the house would be divided into three different macro thermal zones, differentiated not only for the function, but also for the different management of the internal temperature setpoints for thermal comfort and for the systems activation. This, together with the aim to design a nZEB building, allows greater flexibility in the use of energy systems and allows to obtain large energy savings if used correctly.
Nowadays in fact, during the design of the energy systems and of the building itself, it is essential to implement a zoning of the interior spaces, or better to say, to divide into thermal zones, where by area it is mean a room or a group of rooms.
According to the UNI/TS 11300:2014 - part 1 the necessary condition for an area to be air-conditioned, is the presence in it of a plant terminal; at the same time, air-conditioned zones that have setpoint temperatures that differ by more than 4 Kelvin, are to be considered different air-conditioned zones.
Consequently, a non-air-conditioned zone appears to be an area not maintained at a predetermined set-point temperature. However, if the resulting temperature is within a range of 4 K of the set-point temperature of an adjacent conditioned area, it can be incorporated into the latter.
By applying these concepts to the project, theoretically it would have been possible to incorporate all the rooms within a single thermal zone, since the temperature setpoints set for achieving internal comfort range from 18 °C to 22 °C. However, to have an adaptive and performing system it was necessary to implement a clear division based on the room function.
The concept that instead refers to the non-air-conditioned rooms can be applied to those of the project: the rooms that don't need setpoints to have comfort conditions, as underused by the tenants, are the Technical room, where the systems are located, and the Storage room. However, they border on air-conditioned environments, benefiting from them: as shown by the analysis carried out, it was possible to constantly maintain temperatures during the year that differed by a maximum of 3 ° C from those of the air-conditioned rooms.



▲ Fig. 5.8
Ground Plan of the building selected for energy analysis: the private house.
Source: Author's elaboration

Fig. 5.9 ▶
Representation of the division into thermal zones of the private house.
Source: Author's elaboration

The building is thus divided as follows:

• the day zone, which is composed by kitchen, living room and study;
• the service zone consists of two bathrooms, two aisles, an additional working space, the technical room and the storage room;
• the night Zone is composed of three bedrooms

The day zone has an air-conditioned area of 58 m^2, the service zone has an air-conditioned area of approximately 29 m^2, since storage and technical rooms are not counted, and the night zone has an air-conditioned area of 58 m^2.
The three macro areas differ, in addition to the type of activity that is carried out inside, for the height of the interior spaces, as the service zone has a false ceiling to allow the presence of the systems and for the amount of glass surface, which is greater in the day zone, as it is exposed to the south, and less in the night zone, as it is mainly exposed to the north, and almost absent in the service zone, which acts more as a buffer space.
The internal contributions are also diversified among the internal environments since they host different functions, with some like bathrooms and kitchens that have a greater share of latent gains, and others like the living room or the study that have greater sensitive gains.
The division has been designed to be as modelled as possible on the actions of the tenants during the day: the rooms in the north are likely to be used during the day, unlike the south-facing rooms. Then, the building, except for the north side, has an external shielding system for solar radiation, which on the south side creates a patio that can be used both in winter and in summer. This greatly helps to achieve the internal comfort conditions, since it helps to block the hot summer radiation.

5.4 The energy modelling software: DesignBuilder

For this thesis, it was chosen to use the software DesignBuilder to carry on the energy analysis and energy simulations throughout the project, from the initial analysis without active plants up to the detailed analysis on the selected building, that will be discussed in Chapter 6.
The software DesignBuilder is the most complete user interface for EnergyPlus calculation software, and is used as a high quality instrument for energy analysis of simple or extremely complex buildings, performing dynamic energy analysis. In regard to the latter, there are currently several software for energy analysis, which differ in the way of treating the thermal properties and for the time units used, which greatly affects the accuracy of the calculation. In this sense, software can be divided into three types: "stationary", where the time unit is the heating or cooling period; "semi-stationary", where the values of temperature and solar irradiation are based on monthly averages; "dynamic", where energy analysis considers time values, defining time profiles for the occupation of a building, lights and systems, use of DHW, etc.
In this way DesignBuilder allows to obtain accurate informations and data on energy performance, comfort conditions, HVAC component sizing, natural lighting, carbon emissions, etc. of the analysed building, either by modelling it directly in DB or by importing an already made model realized with BIM. This feature is very useful, since it allows to design architectural and bio-climatic solutions aimed at providing the best levels of comfort and the lowest energy consumption even before approaching the plant choices.

DesignBuilder was born as a graphical interface of EnergyPlus, the latter developed from the U.S. Department of Energy from the union of the functionalities of two software, BLAST and DOE-2, designed between the years '70 and '80, with the aim of conducting energy simulations and thermal loads, as well as the study of HVAC and the cost analysis of life of the artefact; this characteristics are combined with the simplification of the production process of the model, which makes it possible to work with a 3D model, a feature not present in EnergyPlus, whose interface doesn't allow direct visual interaction with the object of the analysis.
Furthermore the accuracy of the simulations and analysis is due precisely to the integration of EnergyPlus within DesignBuilder's environment which allows to carry out complete simulations without leaving the interface; therefore simulation results can be effectively displayed and analysed in a comprehensive manner. Plus DesignBuilder has quality control procedures which assure the accuracy of the results in comparison the stand-alone EnergyPlus engine. Another element that ensures the validity of the software is that, as EnergyPlus, it has been tested under the comparative Standard Method BESTEST/ASHRAE STD 140[3] (Ibarra D., Reinhart C., 2009).

5.3 ASHRAE Standard 140 specifies a standard method of test for evaluating the technical capabilities and applicability of software used in calculating the thermal performance of buildings and their HVAC systems.

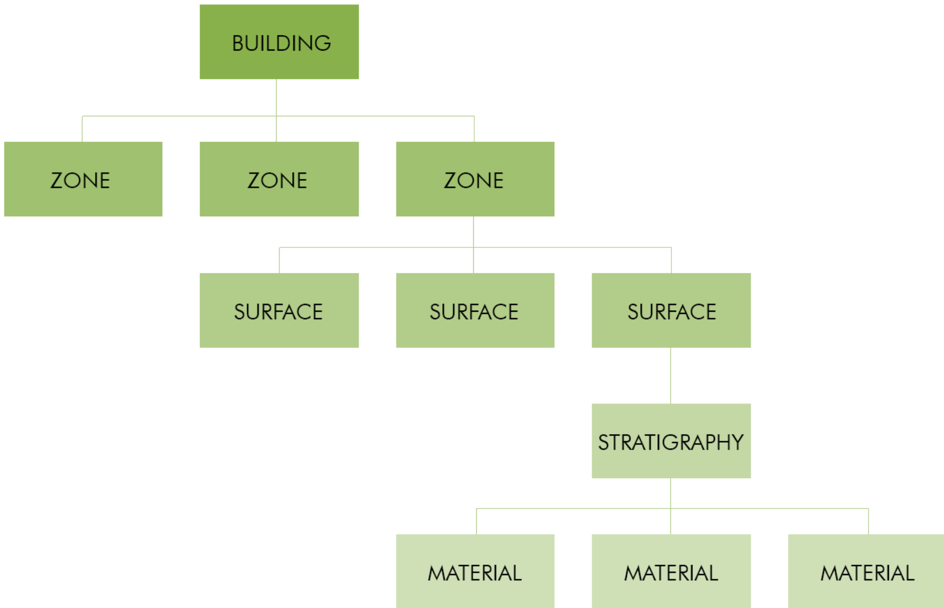


Fig. 5.10 ▶
Operating scheme of DesignBuilder.
Source: Author's elaboration

For the analysis present in this thesis, it is used the version 5.5.0.12 in association with Energy Plus 8.6.0; to this is added the possibility of using the BIM Revit software to create the model to be used for the analysis. In this sense, thanks to the interoperability between the two software and Revit, it's possible to import BIM models through the .gbXML[4] file format. This procedure allows to optimize work times, since designing the building on Revit is much quicker and easier than on DB and even more than Energy Plus (in the latter this action is not possible).
As said, DesignBuilder has a user-friendly interface that allows to model and to assign physical-thermal characteristics, such as dimensions, materials, thermal plants, and thermal loads to the building equipment and plant components, directly in the software.
The construction of the building model in DesignBuilder is possible thanks to a system based on a "hierarchical inheritance": this means that, based on the level in which the parameters are inserted, these will have repercussions in all the lower levels; this feature allows to optimize the work-time by setting the data at the general level of the building, then at the next one and so on, so that they are automatically transmitted to the lower levels; in any case when a detailed characterization is needed, it is possible to access the single level. In this sense modelling in DesignBuilder is based on the concept of "block", in fact the model as a whole, is composed of a set of blocks, which then assume the characteristic of "zones" belonging to the same building, all together constituting the outer envelope of the model. The thermal zones, that form the block, are defined by the surfaces that delimit them. To each surface is assigned a stratigraphy consisting of different materials which are in turn characterized by their thermal and physical properties.

5.4 .gbXML, acronym of green building XML, developed by Green Building Studio Inc., is a format that allows you to interchange information between a BIM model and energy analysis software

5.5 Initial data setting for energy simulations in DesignBuilder

The first actions that were carried out when it was started to use the DesignBuilder software, were to set the general functions of the software based on the objectives programmed for the analysis, as the unit of measure for example. Whereupon, it was necessary to set the information for importing the model, since modelling within DesignBuilder is very complicated and unintuitive, and it's worth doing it only in situations where few thermal zones are modelled with simple geometries. In the same way it was important to set the informations about the location and the climate file on which all the analysis are based on.

> Importing the model from Revit

The first thing to do, before inserting the model made with the BIM Revit software, is to proceed with the addition of a "New building" from the main toolbar, which in this case was then renamed as "House HouJi". This created the first level of the hierarchical structure of the energy modelling in which it was possible to import the .gbXML file.
The main advantage of this operation is that at the *Building* level it is possible to set up templates for activity, construction elements and plants that will remain in the project in case of replacing the .gbXML file, therefore automating the recalculation process of energy performance after a design change.
In relation to the case study, the interoperability between the two software made it possible to automatically recognize all the thermal zones set in the BIM model as "zones", once the .gbXML file was imported in DesignBuilder. In this case, however, thermal properties, stratigraphy of the surfaces and materials were set directly in DesignBuilder, so it was not necessary to model them in Revit. If instead they were modelled in Revit it would have been necessary to check the option "Import thermal properties" in the import box of the energy model to ensure that the properties of the materials were recognized.
Immediately after importing the model, the next step is to check if the automatic report related to the imported zones issued by the software contains any errors. Usually, the latter are related to errors in modelling, to be more precise concerning the effective closure of all the zones or the possible overlap of surfaces. In this case errors were found due to the overlap between the surfaces of the false ceilings and the service areas below them in the central area; the problem was solved by modifying the Revit file and reimporting the correct model.
In addition, it was necessary to make some modifications to the imported model, since the surfaces created in the BIM model were not considered automatically, but they must be reassigned in the imported energy model; to do that it was necessary to modify the construction template by assigning the appropriate stratigraphy to each building surface, as will be explained in the related section.

> Climate File

After importing the model, the next thing to set, when opening a new project, is the template which define the location where the project is located: this means that it's necessary to choose the climate file, having the extension .epw [5], used for the simulation.
In dynamic simulation software, climate files play a major role, since they give essential informations about the environmental conditions in which the building and the plant will have to work; they determine dispersions, leakages by infiltration considering the hygrometric conditions and solar loads.
In DesignBuilder, with detailed HVAC modelling, which is the option chosen in this thesis as will be explained in Chapter 6, climatic parameters can have a major influence on the performance of the modelled implant; for this reason it is important to work with reliable and up-to-date weather files.
For this project, the first thing done was to look for the climate file related to the city of Pingyao, which as mentioned, is the city closest to the project site. Neverthless, the Pingyao accessible climate file was missing a series of important data, causing the results to be completely wrong in some parts; therefore the choice fell back on the climate file of the other closest location, the one related to the city of Taiyuan. Taiyuan is a city located about 95 km away from the project site, but despite that, it was decided to choose it since it was the nearest city with a climate station and also because the climatic and geographical site characteristics are practically the same to that of Pingyao.
In this case, the climate file of Taiyuan, CHN_SHANXI_TAIYUAN_CSWD, is already present in the DesignBuilder database, otherwise it can be downloaded for free online.
After this have been set data related to the project site location in the village of Hou Ji, which are: 37.148926 Latitude and 112.133055 Longitude, the elevation above sea-level of 763 m and the orientation of the site, which is tilted 11 ° compared to the North-South axis, so a value of 349 has been entered.

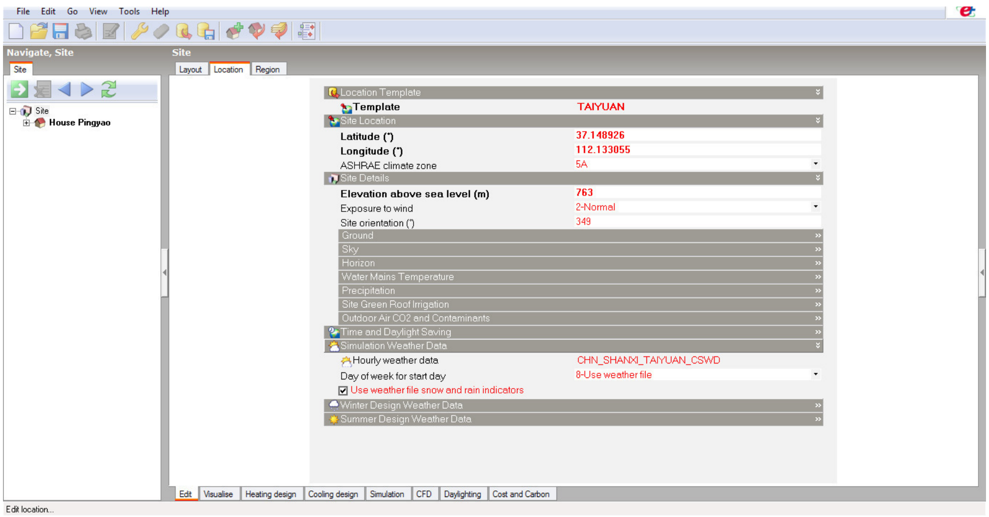


Fig. 5.11 ▶
Setting of "Location" tab in DesignBuilder.

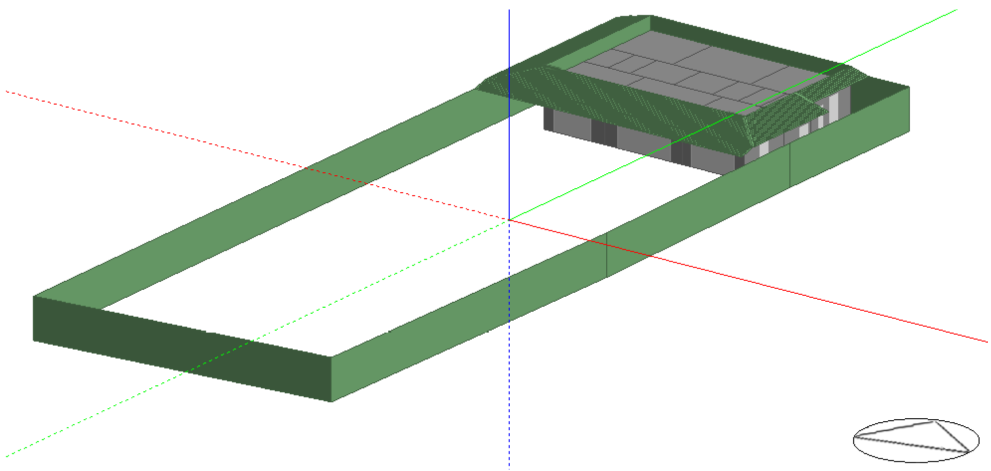
5.5 .epw means "EnergyPlus Weather Data". It is a weather file saved in the standard EnergyPlus format developed by the U.S. Department of Energy (DoE) containing weather data that is used for running energy usage simulations. It is used by EnergyPlus energy simulation software or software with EP integration and is available for more than 2100 locations in over 100 countries.

5.6 The energy model

Once the model was imported and the information on the location and climate file were set, the actual modelling of the building started. DesignBuilder, depending on the type of analysis to be performed, and the results to be obtained at the detail level, allows to define every aspect of the modelling, from the characteristics of the building, to the occupants profile, to the operation of the plants, etc. Everything can be set from the general building level up to each individual air-conditioned area and surface.
The aim of these settings is to obtain an energy analysis that is coherent with the project objectives, and at the same to verify if the design solutions work or not. The most important information to set, since the analysis is based mainly on those, refer to the definition of the following categories into the model data sheets:

• Occupancy: information regarding the occupancy profile of the tenants inside the building zones
• Activities: information regarding the functions performed and the zones occupation periods
• Construction: information on the stratigraphy of surfaces and their thermal properties
• Openings: information related to materials and stratigraphy of doors and windows
• Artificial lighting: information on the artificial light type and its schedule and control type
• Internal inputs: information regarding the set up of the operating hour profile for equipments and systems
• HVAC (Heating, ventilating and Air Conditioning): information related to ventilation, heating, cooling and domestic hot water systems

These points will be detailed appropriately within this section as they are essential to achieve a modelling as faithful as possible to the project and to obtain realistic energy analysis.
At the same time, it's necessary to select "Model Options" from the main page



◀ Fig. 5.12
View of the imported model in DesignBuilder.

of the software to define some general software settings. For example it's necessary to choose which "Timing" of the occupancy use, between "Typical workday" e "Schedules": the first defines the occupancy by a start and an end time with season variation; the second, more flexible, defines the occupancy for each day of the week and month of the year using schedules; therefore the second have been chosen.
The same concept applies to the definition method to be used for internal gains, since three different model can be chosen: "Lumped", where all the values are lumped into one; "Early" where gains can be defined separately for each room in different categories; "Detailed" where gains are defined for every single item in every zone. It was decided to use the "Early" mode, since it wasn't necessary to model in detail every equipment and using an average of the internal gains wouldn't have allowed to have a clear idea of the contributions in each environment.
For the choice of the occupation times of rooms and of the activities type, reference was made to the habits of a family of four people, father, mother and two children; the same applies to electrical appliances and their use. Anyhow, to set everything that doesn't refer to the occupation time, use, etc. European and Italian regulations have been used, as they are easier to access, and because in some cases they have proved to be more stringent than the Chinese ones. In this sense, the analysed building, according to article 3 of Presidential Decree 412/93, which divides into eight categories the buildings according to their intended use, belongs to the category "E.1, Buildings used as residences and assimilable". It in turn is divided into three sub-categories, and the analysed building belongs to the first one: E.1(1) "Dwellings used as permanent residence, such as residential buildings and rural, colleges, convents, houses of punishment, barracks" (DPR 412/93, 26 August 1993[6]).
For what concerns the environmental control, since the regulation assumes a constant internal temperature value based on the categories of intended use specified in art. 3 of DPR 412/93, and the designed building corresponds to category E.1 (1), in order to maintain the internal comfort, the regulation gives 20 °C as a value for winter air conditioning (with a tolerance of 2 °C), 26 °C for summer and 50% for relative humidity.
Regarding the duration of the heating season, i.e. the period in which it is possible to turn on the energy system for heating purposes, in Italy it is regulated according to the climatic zone; there are six categories, from A to F, where A is the hottest and F is the coldest. In this sense the city of Ping Yao, with 3100 DegreeDays, has the same values as the places located in zone "F", since the places belonging to this category, have DD ⩾ 3001; this means that the heating season has basically no limits, since it has no limits for the "power-on time" and for the "time allowed", with a variable duration depending only on the outdoor climatic conditions (DPR 412/93, 26 August 1993).

5.6 Decree of the President of the Republic August 26 1993, n. 412, Regulation laying down rules for the design, installation, operation and maintenance of building heating systems for the purpose of limiting energy consumption, in implementation of art. 4, paragraph 4, of the Law of 9 January 1991, n. 10

5.6.1 Occupancy

Defining the type of tenants and their occupancy profiles inside DesignBuilder is the most important thing to do after the initial settings mentioned in the previous pages; thus, first of all, it has been set that the house tenants are a family, composed by two adults, mother and father, and two children.
Together with that, since the type of energy simulation performed will be dynamic, it is important to set up an operating hour profile for equipments and systems, giving specific values for every hour of the day, checking at the same time that the average respects the indications of the standards, as it will be detailed further. It is important to underline that this is based on the same concept of the occupancy profile.

Therefore, since the analysis was conducted on a single building of relatively small size, it was decided to further detail the occupancy profiles of the home, so, instead of creating only a single mediated schedule to which all the systems and internal contributions refer to, different schedules have been created based on the function of the single rooms.
The first one created, at the building level, was a general schedule for the house occupancy, named *Family Occupancy HouJi*. Since the house is inhabited by a family of two adults and two children, it has been hypothesized that during the week the house is occupied until 8.00 am, not occupied until 16.00, since the parents are at work and their children at school, occupied in half until 18.00 pm and completely occupied until the following day; during the weekend instead the house is always occupied except from 14.00 to 19.00, as it can be seen in the timetable:

Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 08:00, 1,
Until: 16:00, 0,
Until: 18:00, 0.5,
Until: 24:00, 1,
For: Weekends,
Until: 14:00, 1,
Until: 19:00, 0,
Until: 24:00, 1,
For: WinterDesignDay AllOtherDays,
Until: 08:00, 1,
Until: 16:00, 0,
Until: 18:00, 0.5,
Until: 24:00, 1;

where 1 means that the house is occupied by all the family members, 0,5 by only two of them, 0 that no one is at home.
Two different timetables for the weekdays were made, one for hot period and one for the cold period, and one for the weekends.

Fig. 5.14 ▶
Occupancy rate for Weekdays and Weekend for Living Room, Study and Kitchen

Fig. 5.15 ▶
Occupancy rate for Weekdays and Weekend for Bedrooms

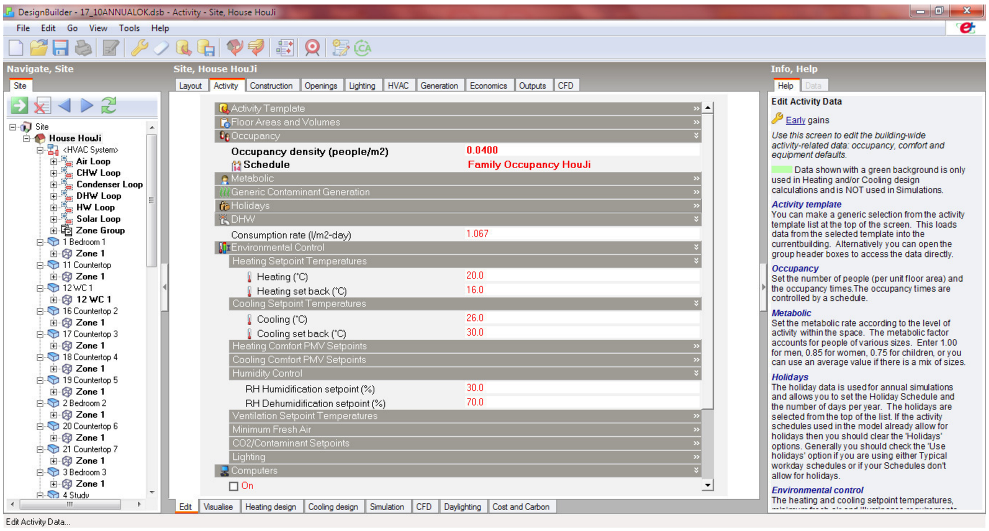
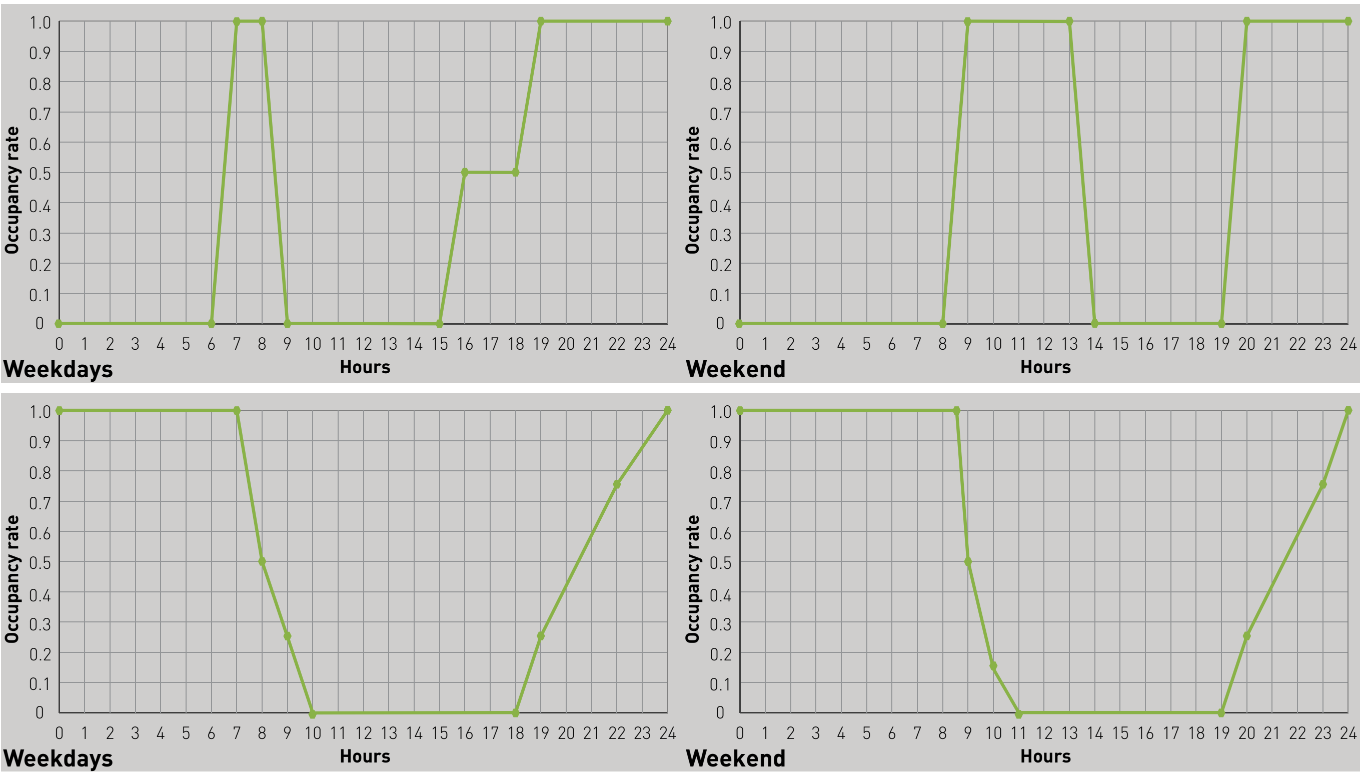


Fig. 5.13 ▶
Setting of "Activity" tab at Building level in DesignBuilder.

In this case, concerning the "Occupancy density", the values contained in the UNI10339: 1995 standard have been taken into consideration, which establishes for permanent residences, a value of 0.04 persons / m2; value entered inside the appropriate box within the software.

After this, as mentioned, it was decided to further detail the schedules related to the occupancy, creating other five variants, depending on the effective use of space:

- *S&L&K_Occ*, for Kitchen, Living Room and Study; occ. density 0.04 prsn/m^2
- *Dwell_DomBed_Occ*, for the Bedrooms; occ. density 0.04 prsn/m^2
- *WC_Occ*, for Bathrooms; occ. density 0.04 prsn/m^2
- *Tech&Storage_Occ*, for service spaces; occ. density 0.04 prsn/m^2
- *Off 24/7*, for unoccupied spaces, like countertops; occ. density 0 prsn/m^2

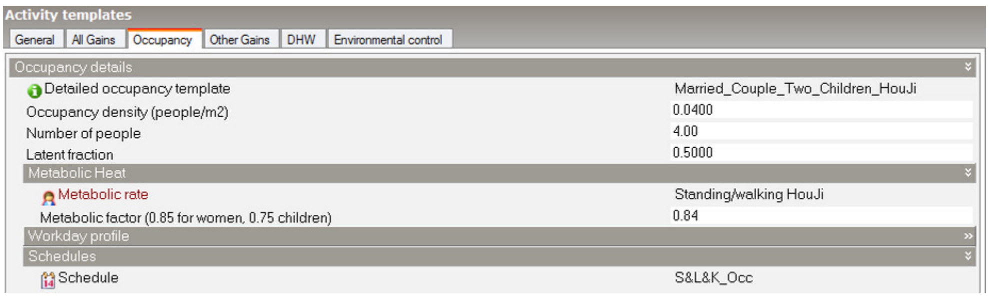


5.6.2 Activity templates

Taking into account the thermal zoning of the dwelling, which envisages the division into three “macro thermal zones”, the “day-zone”, the service zone and the “night-zone”, and being a dynamic simulation, which requires more detailed parameters variables over time, six different activity templates were used, in relation to the different usages of the rooms: one for kitchen, living room and study, the so called “day-zone”, *Activity Template_Kitchen_Living_Study HouJi*; one for the bedrooms, the so called “night-zone”, *Activity Template_Bedrooms HouJi*; one for the Bathrooms, Activity Template_Bathrooms HouJi; one for the other air-conditioned rooms used as service spaces, *Activity Template_OtherAirConditionedRooms HouJi*; one for the non-conditioned rooms, that are used, but only few times and are not usually occupied, ie Technical room and Storage room, *Activity Template_NoConditionedRooms HouJi*; one for unoccupied spaces, *Unoccupied_HouJi.* Much of the energy simulation is based on the values inserted into the activity templates to perform the calculations, so it is essential to enter some values related to: metabolic factor of the people present in the environment, the thermal contributions of the electrical equipment and their type , the operating profile of the lights, the temperatures that control both the internal conditions of comfort as well as the activation of the systems to heat or cool or ventilate; the required ventilation flow rates per person and per square meter. Each of the elements mentioned above refers to specific regulations, which provide precise data. Nello specifico:

• Activity Template_Kitchen_Living_Study HouJi

In the “Occupancy” Tab, for the occupancy profile, it was set as “Detailed occupancy template”, that only defines which type of people lives in the rooms, *Married_Couple_Two_Children_HouJi*, and as schedule the S&L&K_Occ, mentioned in the previous page, with an occupancy density of 0.04 person/m^2. For the latent fraction was assumed a default value of 0.5.
In the Metabolic Heat field, for the Metabolic rate was chosen the “Standing/walking” schedule, which defines a “Metabolic rate” per person of 120 W.
The Metabolic factor indeed, was obtained averaging those of the father, 1, mother, 0.85 and children 0.75 (multiplied for two). The mean is 0.84.
The values related to the metabolic heat were taken from ASHRAE, Handbook of Fundamentals, Chapter 8, Table 5.
In the Other Gains field, which refers to the thermal contributions due



◀ Fig. 5.16
Setting of “Occupancy” tab in the Activity Template_Kitchen_Living_Study HouJi in DesignBuilder.

to electrical appliances, nothing has been set, as the equipment such as computers, home appliances and the lighting system have been set individually for each room.

Lastly, the "Environmental control" Tab, establishes the temperature setpoint for cooling, heating and the necessary ventilation flow rates, as well as the illuminance target. The schedules related to Cooling and Heating were set starting from the following setpoints and setbacks, respectively 26 °C / 30 °C and 20 °C / 16 °C which were adapted on the three different thermal zones, with the respective activation schedules, realized after the initial analysis developed without active plants explained in this chapter; the same applies to the Mechanical Ventilation, designed after the analysis without active plants.

For the "Minimum fresh air", values from legislation UNI EN15251 related to "very low pollution building" were assumed: 10 l/s/person as minimum fresh air, 0,49 l/s/m^2, for mechanical ventilation per area which refers to airflow for building emissions pollutions.

The target illuminance has been set to 250 lux, because, according to the existing legislation, it is the average amount of required light for residential spaces.

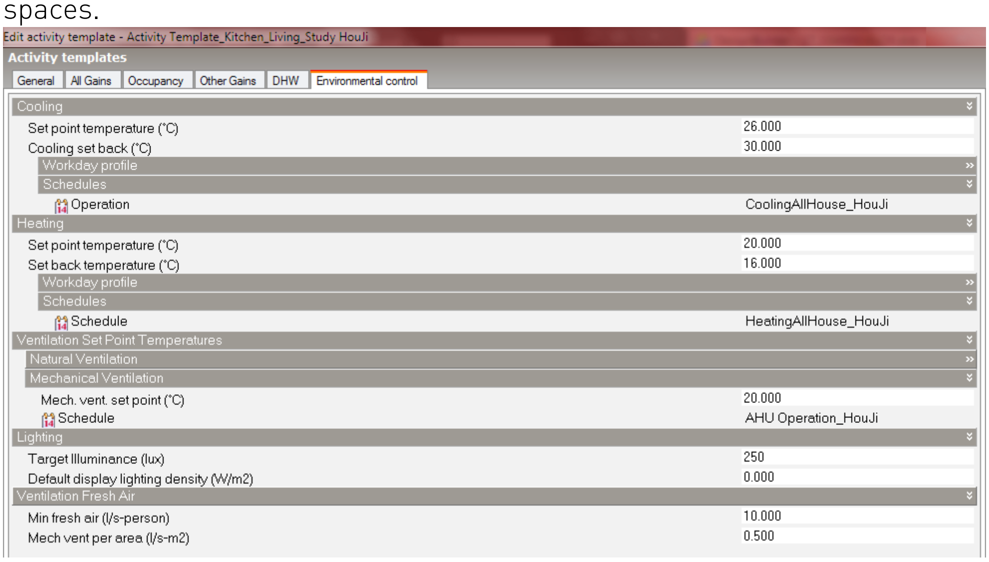


Fig. 5.17 ▶
Setting of "Environmental control" tab in the Activity Template_Kitchen_Living_Study HouJi in DesignBuilder.

• Activity Template_Bedrooms HouJi

In the "Occupancy" Tab, for the occupancy profile, in the first part the same values as in the previous template have been inserted: for "Detailed occupancy template", *Married_Couple_Two_Children_HouJi*; occupancy density of 0.04 person/m^2; latent fraction was assumed a default value of 0.5.

In the Metabolic Heat field, this time, for the Metabolic rate was chosen a "Bedroom" schedule, which defines a "Metabolic rate" per person of 104 W. The Metabolic factor is again 0.84. As occupancy schedule was chosen "Dwell_DomBed_Occ", mentioned in the previous section.

In the Other Gains field, again nothing was set because the equipment has been set individually for each room.

Lastly, in the "Environmental control" Tab, the schedules related to Cooling and Heating have been set with different setpoints and setbacks compared to the previous activity template, respectively 27 ° C / 31 ° C and 18 ° C / 16 °

C, with the respective activation schedules, realized after the initial analysis developed without active plants explained in this chapter; the same goes for the Mechanical Ventilation, designed after the analysis without active plants. Again for the “Minimum fresh air”, values from legislation UNI EN15251 related to “very low pollution building” were assumed: 10 l/s/person as minimum fresh air, 0,49 l/s/m^2, for mechanical ventilation per area.
The target illuminance has been set at 250 lux, according to the existing legislation for residential spaces.

• Activity Template_Bathrooms HouJi

This template refers to WC1, WC2, i.e. the two house’s bathrooms, that need to have different setpoint and parameters for ventilation, compared to that of the other rooms. In the “Occupancy” Tab the values set are the same of Activity Template_Kitchen_Living_Study HouJi, except for occupancy schedule, in this case “WC_Occ” has been chosen.
The same goes for the “Environmental Control” Tab, where only setpoint, setback and air changes were changed, specifically: Heating setpoint and setback are respectively 22 - 18 °C; Cooling setpoint and setback are respectively 26 - 30 °C. For the ventilation, legislation UNI EN15251, Tab. B5, states that bathroom, in very low pollution residential buildings, need to have 20 l/s as minimum fresh air, and 0,49 l/s/m^2, for mechanical ventilation per area

• Activity Template_OtherAirConditionedRooms HouJi

This template refers to Additional working space and Aisles, but in the “Occupancy” Tab, the same values of “Activity Template_Kitchen_Living_Study HouJi” have been set.
The same happens in the “Environmental control” Tab, where only different setpoint and setback values were set, as the spaces are less used: Heating setpoint and setback are respectively 18 - 16 °C; Cooling setpoint and setback are respectively 28 - 31 °C.

• Activity Template_NoConditionedRooms HouJi

This template refers to the technical room and storage room, which, unlike other rooms, does not require active heating and cooling systems, being used for short periods of time. The set values are the same for all the Tab, except for the occupation schedule, set this time on “Tech & Storage_Occ” and the “Other Gains” field, where it has been added the mean of the internal gains along all the week for rooms that are not kitchen or living room, which is 3 W/m^2 (UNI/TS 11300 part 2). As said, no setpoint were needed for Heating and Cooling since there is no active system.

• Activity Template_Unoccupied HouJi

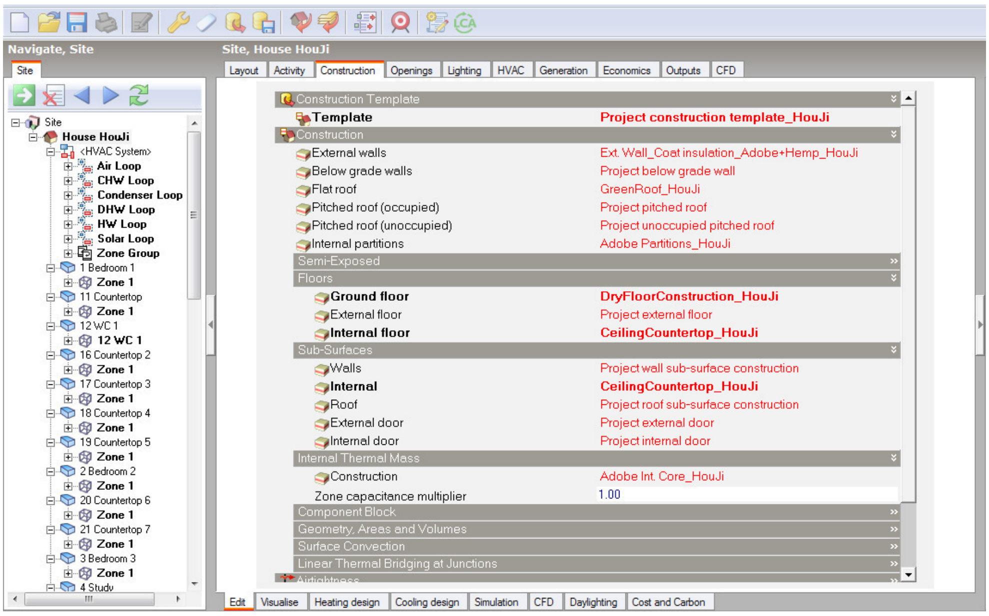
This template refers to the countertops, which are, obviously, the only part of the house that is not occupied. For this reason everything related to the production of thermal contributions in the schedule is set to "Off", so that this part of the house can take part in thermal exchanges with the internal environments, but that does not produce heat contributions due to active systems or tenants or does not have a system of active ventilation.

	Kitchen_ Living_Study HouJi	Bedrooms HouJi	Bathrooms HouJi	OtherAir Conditioned Rooms HouJi	No Condi-tionedRooms HouJi
Occupancy schedule	S&L&K_ Occ	Dwell_ DomBed_ Occ	WC_Occ	OtherAir Condi-tioned_Occ	Tech & Storage_ Occ
Occupancy density [m^2]	0.04	0.04	0.04	0.04	-
Metabolic rate [W]	120	104	120	120	120
Metabolic factor	0.84	0.84	0.84	0.84	0.84
Heating setpoint/ setback	20 / 16 °C	18 / 16 °C	22 / 18 °C	18 / 16 °C	-
Cooling setpoint/ setback	26 / 30 °C	27 / 31 °C	26 / 30 °C	28 / 31 °C	-
Minimum fresh air [l/s]	10	10	20	10	-
Mech. ventilation per area [l/s/m^2]	0.49	0.49	0.49	0.49	0.49
Target illuminance [lux]	250	250	250	250	250

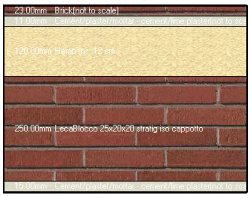
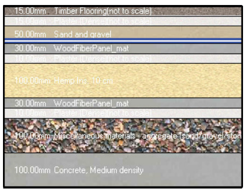
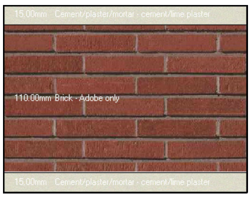
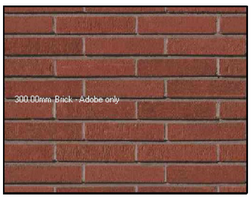
Tab. 5.1.1 ▶
Summary table of the Activity Templates set in DesignBuilder.

5.6.3 Construction templates

The "Construction" tab allows to define the stratigraphy of the building envelope components, assigning to each surface of the model specific thermal and physical properties, defining all data related to the construction and airtightness. To do that, it is possible to assign to the surfaces predetermined stratigraphy or new ones, using the materials already present in the software library or creating new ones. The fastest method to complete this step would be to create and assign the stratigraphies directly within the Revit software, and then import the .gbXML model with them already assigned; however in this case it was preferred to model them directly within DesignBuilder to have a more accurate definition of the characteristics of the materials used.
This step in modelling is very important, since DesignBuilder uses construction components to model the conduction of heat through walls, roofs, ground and other opaque parts of the building envelope.
The thermal properties of the construction are calculated based on layers, each layer having a material reference and thickness; the combination of thickness and material gives the thermal characteristics of the layer.
For this analysis, in this field, the first thing was done to create the "Project construction template_HouJi", through which the stratigraphies of the surfaces related to floors, walls and roofs were assigned. At the same time the airtightness of the building is requested, which in this case, using the default infiltration software template, has been set to "Excellent", since an excellent air tightness is expected.
A value of infiltration rate equal to 0.1 ac / h was then assigned.
In detail, in the "Building" level project template, five main types of stratigraphy have been set, referred to: internal floor, external wall, internal partitions, internal core and green roof. Added to this was the definition of the sub-surface referred to the countertop surfaces in direct contact with the thermal zones of the central service area. In this sense, the stratigraphies used for the analysed building in the DesignBuilder model are listed in the following page.



◀ Fig. 5.18
Setting of "Construction" tab at the Building level in DesignBuilder.

Component	Stratigraphy	S [cm]	λ [W/mK]	U [W/m²K]
 External wall	Lime/mortar plaster	2	0.8	
	Expanded clay block 25x20x20	25	0.21	
	Hemp insulation	12	0.04	0.226
	Reinforced plastering	0.8	0.8	
	Brick cladding	2.3	0.72	
 Green Roof	Extensive soil mix	25	0.31	
	Filter membrane	0.8	0.19	
	Drenage system	3	0.49	0.225
	Sand sloped creed	5	0.25	
	Wood fiber insulation	10	0.038	
	Wood protection board	7	0.13	
 Ground Floor	Bamboo pavement	1.5	0.14	
	Gypsum fiber panel	1.5	0.5	
	Dry sand	5	0.25	
	Wood fiber panel	3	0.05	
	Gypsum fiber panel	1	0.5	0.235
	Hemp Insulation panel	10	0.04	
	Wood fiber panel	0.8	0.05	
	Granulated volcanic rock mineral	10	1.3	
	Concrete subgrade	10	1.35	
 Internal Wall	Plaster	1.5	0.8	
	Compressed earth bricks	12	0.7	2.13
	Plaster	1.5	0.8	
 Internal Core	Earth compressed blocks 295x140x90	30	0.7	1.45
 Countertop	Gypsum Plasterboard	1.3	0.25	2.67
	Gypsum Plasterboard	1.3	0.25	

Tab. 5.1.2 ▶
List of stratigraphies used in the DesignBuilder model

5.6.4 Other internal inputs

The internal contributions, that include any form of energy generated by internal sources other than the heating system, are determined on the basis of the category of building. The sources of thermal energy inside a closed space are generally due to occupants, waste water, electrical, lighting and cooking equipment; the internal gains deriving from the presence of these sources can be obtained, relying on the values shown in Section 13.1.2.2, Table 14 of the UNI/TS 11300 part 1 regulation, which refers to residential buildings.

Giorni	Ore	Soggiorno e cucina $(\Phi_{int,Oc} + \Phi_{int,A}) / A_f$ [W/m²]	Altre aree climatizzate (per esempio stanza da letto) $(\Phi_{int,Oc} + \Phi_{int,A}) / A_f$ [W/m²]
Lunedì – Venerdì	Dalle ore 07:00 alle ore 17:00	8,0	1,0
	Dalle ore 17:00 alle ore 23:00	20,0	1,0
	Dalle ore 23:00 alle ore 07:00	2,0	6,0
	Media	9,0	2,67
Sabato – Domenica	Dalle ore 07:00 alle ore 17:00	8,0	2,0
	Dalle ore 17:00 alle ore 23:00	20,0	4,0
	Dalle ore 23:00 alle ore 07:00	2,0	6,0
	Media	9,0	3,83
Media		9,0	3,0

$(\Phi_{int,Oc} + \Phi_{int,A})$ è il flusso termico dalle persone e dalle apparecchiature, in W;
A_f è la superficie utile di pavimento.

◄ Tab. 5.1.3
Temporal profiles of thermal inputs from occupants and equipment
Source: Section 13.1.2.2, Table 14, UNI/TS 11300-1:2014, Energy performance of buildings - Part 1: Evaluation of energy need for space heating and cooling

Starting from this division, it was important to set different thermal contributions inside DesignBuilder, for kitchen and living room and for the other air-conditioned rooms, otherwise the thermal calculations would consider oversized (or undersized) internal inputs, returning inexact results.
Within DesignBuilder, from the "Activity" tab, it's possible to set the values of the internal contributions based on their category; it's possible to choose between: "Computers", "Office Equipment", "Miscellaneous" which allows to indicate an average of the internal gains in environments such as the bathroom where there are several sources, "Catering", which refers to the kitchen, and "Process " which refers to rooms with machinery, such as factories.
For the two bedrooms the Computers tab was selected, setting a power density of 5 W/m^2, with an activation schedule that foresees its use for 1 hour and 30 minutes per day.
For the two bathrooms the Miscellaneous tab was selected with power density of 3 W/m^2, using the same schedule as the occupancy of the room.
For the study, the Office Equipment tab was selected, with a power density of 5 W/m^2 and an activation schedule that foresees its use for 1 hour and 30 minutes a day. For the living room the Miscellaneous tab was selected with a power density of 5 W/m^2, using the same schedule as the occupancy of the room. For the kitchen, the Catering tab was selected setting a power density of 8 W/m^2, foreseeing for its use for two hours on average per day.
For the technical room, the Miscellaneous tab was selected, setting a power density for internal supplies of 3 W/m^2, due to the plants inside.

5.6.5 Artificial lighting definition

Inside DesignBuilder, the electrical input to lighting appears as heat that contributes to zone loads or to return air heat gains. This heat is divided into four different fractions: three of these are given by the input fields Return Air Fraction, Radiant Fraction and Visible Fraction; a fourth, defined as the fraction of the heat from lights convected to the zone air, is calculated by EnergyPlus as:

Convected Fraction = 1.0 – (Return Air Fraction + Radiant Fraction + Visible Fraction)

These fractions depend on the type of lamp and luminaire, which in DesignBuilder are divide into: suspended, surface mount, recessed, luminous and louvered ceiling, return-air ducted.[7]

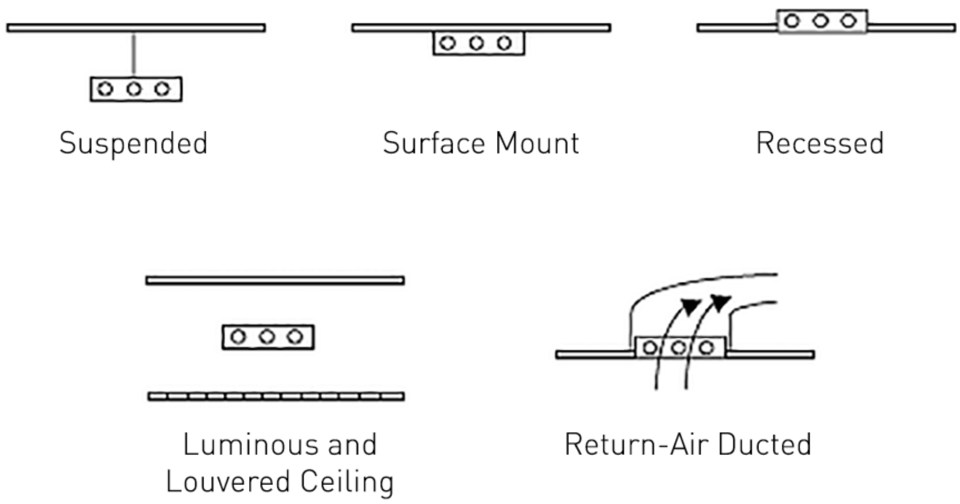


Fig. 5.19 ▶
Luminaire types in DesignBuilder.

In this project, since it was decided to favour energy efficiency for the new equipment installed, combining good performance with low consumption, it was chosen to use the LED light. At the same time, among the types of lamp, it has been chosen the "Suspended" type for "day-zone" and "night-zone", while for the "service-zone" it has been chosen the "Recessed" type, since all the rooms in this part of the house have a countertop, making it easier to install.
For the above mentioned LED types , the software gives these default values:

Tab. 5.1.4▶
Properties of the two types of lamps chosen inside DesignBuilder

	Suspended lamp	Recessed lamp
Power density [W/m^2]	5	5
Return air fraction	0	0
Radiant fraction	0.42	0.37
Visible fraction	0.18	0.18
Convective fraction	0.4	0.45

5.7 https://designbuilder.co.uk/helpv1/Content/_General_lighting.htm

Talking about the required light for internal spaces, in this analysis, since it is related to a residential building, it is considered a value of 250 lux, taken from the existing legislation UNI 12464. It is the mean of the required illuminance for different internal rooms: "Areas with traffic and corridors [...] storage spaces" 100 lux; "Homes" 150 lux, "Normal office work, PC work, study library [...] kitchens" 500 lux

Inside the software it has been decided to divide the lighting use into four different schedules, following the zone function, as it happened for the occupancy profiles.
In this sense, for the "General Lighting" profile for the most used rooms, Living Room, Kitchen, Study, it has been created a schedule, called "LightingHours S&L&K_HouJi", which uses an operation profile that plans to turn on the light averagely for five hours a day. For the Bedrooms it has been created "LightingHoursBedrooms_HouJi", that plans to turn on the light averagely for two and a half hours a day. For the Bathrooms, it has been created "LightingHoursBathrooms_HouJi", that plans to turn on the light averagely for two and a half hours a day. These three schedules were combined with the target illuminance setpoint of 250 lux that allow to turn on the artificial light when there's not enough natural light during the day, therefore modulating consumption based on the time of year and the related quantity of solar inputs. For the less used rooms, Aisles and Additional working space, it has been created "LightingHoursLessUsedRooms_HouJi", that plans to turn on the light averagely for one hour a day. For Storage room and Technical room, , which are the least used rooms, has been created "LightingHoursNotUsedRooms_HouJi" which plans to turn one the lights for 15 minutes a day of average.

5.6.6 Openings

After the considerations aimed at choosing the type of glass and the materials that make up the frame developed in chapter four, which led to the choice of low-emissivity double-glazed windows with a wooden-aluminium frame, the relevant data were set in DesignBuilder. First of all the glazing template called "Glazing template_HouJi" was created, in which the selected glass and its solar shading were set. About the glass, it has the following characteristics:

- Solar transmission g 0.65
- Light transmittance LT 0.82
- Transmittance value $U_g = 1.1\ W/m^2K$
- Glass-cavity-glass dimensions : 4 mm - 20 mm - 4 mm
- The cavity is filled with Argon gas.

The frame instead is made of wood and has the following characteristics:

- Transmittance value $U_f = 1.327\ W/m^2K$
- Frame thickness 7 cm
- Inside - outside projection 2 cm

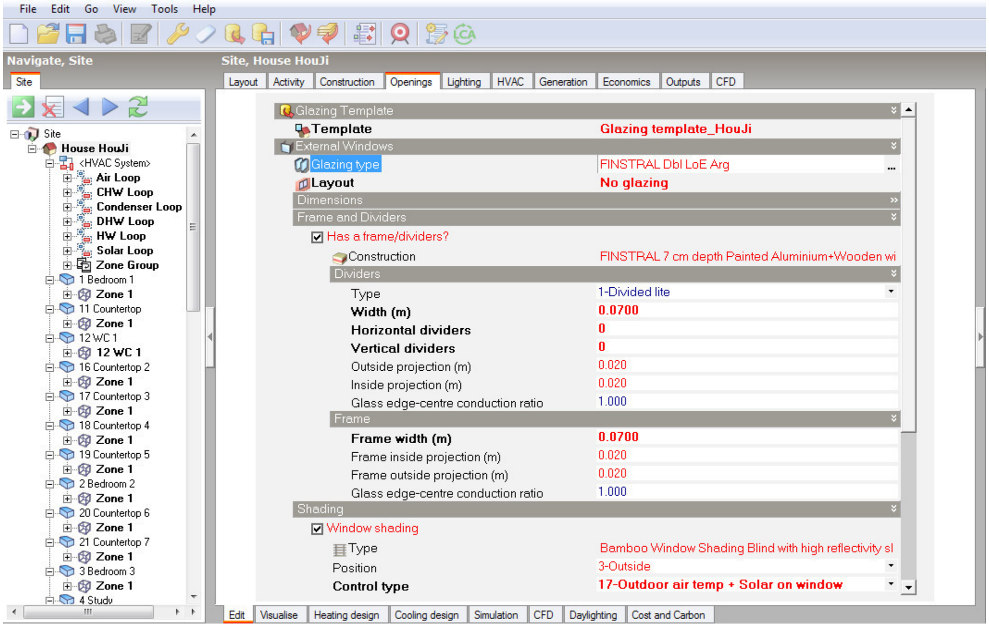


Fig. 5.20 ▶
Setting of "Openings" tab at the Building level in DesignBuilder.

Instead, vertical or horizontal dividers have not been set, because the fixtures foreseen for the project do not have any, having only the classic frame that runs along the entire edge of the window.
Furthermore, within the Openings Tab it was necessary to check the "Layout" section, in which the software automatically assigns a value of transparent surface equal to 30% of the total surface. This is not correct, therefore it was necessary to choose the voice "No glazing" among the possible choices, so that DesignBuilder does not insert further transparent surfaces, adding to those already present, that would cause an alteration of the results of the energy simulation.
The bamboo shading system position instead was set as "Outside", and its activity schedule was set as "Always on" during the day when temperature exceeded 30 °C and when the solar radiation reaching the inside of the building is excessively high, exceeding 150 W/m^2.
In this sense, the sliding shadings work with little frequency because, thanks to the external porches composed of wood and recovery beams, the solar radiation cannot reach the internal spaces of the building during the hot season.

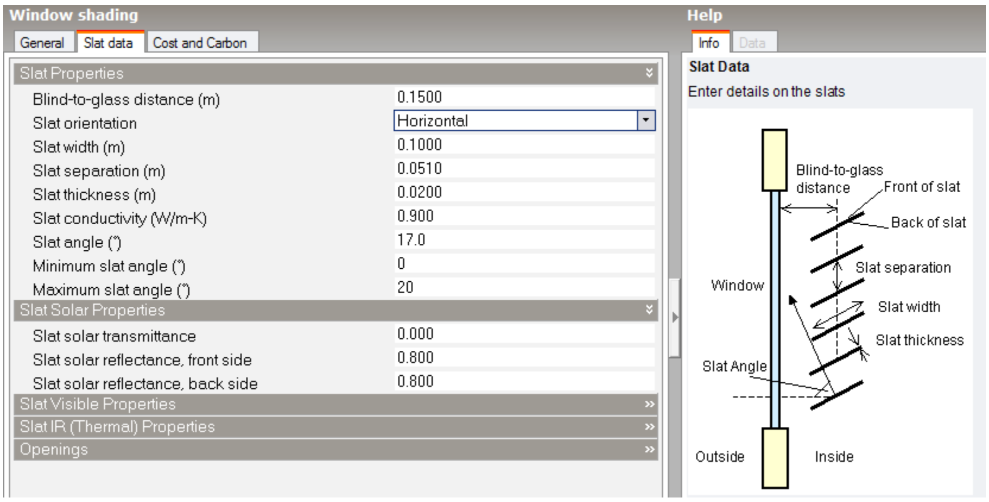


Fig. 5.21 ▶
Setting of the window shading system used in the DesignBuilder model

5.6.7 Domestic Hot Water demand

Lastly, it was possible to set the tenants' domestic hot water consumption rate in DesignBuilder, estimating at the same time the overall level of DHW consumption, and its annual energy need. For a residential building, like the one analysed, it's possible to obtain the required domestic hot water demand referring to the UNI/TS 11300 part 2. At the same time, it's possible to calculate the volume of requested water V_w [l/s] as:

$V_w = a \times S_u + b$ [l/day]

a parameter obtainable from table 30 [liters/m^2 day]
b parameter obtainable from table 30 [liters/day]
S_u house useful area [m^2]

Superficie utile S_u [m^2]	S_u <= 35	35 < S_u <= 50	50 < S_u <= 200	S_u > 200
Parametro *a* [litri/(m^2 x giorno)]	0	2,667	1,067	0
Parametro *b* [litri/giorno]	50	-43,33	36,67	250

◄ Tab. 5.1.4
Values for parameters a and b used to obtain daily requested water volume for residential buildings.
Source: Prospectus 30, section 7.1.2 UNI/TS 11300-2:2014, p. 37

In this case we have the necessary data: knowing the house useful area, that is 155 m^2, it's possible to get from the table the values for a and b related to useful surfaces S_u between 50 and 200 m^2 ($50 < S_u \leqslant 200$).
Therefore *a* is 1.067 [liters/m^2 day] and *b* is 36.67 [liters/day].
It's now possible to obtain the value of hot water demand, substituting these values in the above mentioned formula:

$V_w = 1.067 \times 155 + 36.67 = 202.055$ l/day

After this step, it can be calculated the required thermal energy Q_w for domestic hot water, which is obtained in relation to the water flow rates for the various uses and to the difference between the supply temperature and the cold water intake temperature on the basis of the reference data defined by the UNI / TS 11300 part 2. It is given by the following formula:

$Q_w = \rho_w \times c_w \times \Sigma i \, [V_{w,i} \times (\theta_{er,i} - \theta_0)] \times D$ [kWh]

ρ_w is the water density, which can be assumed to be 1000 [kg/m^3]
c_w is the specific heat of water, equal to 1,162 * 10^{-3} [kWh/(kg × K)]
$V_{w,i}$ is the daily water volume for the i-th activity or requested service [m^3/day]
$\theta_{er,i}$ is the water supply T° for the i-th activity or requested service [°C]
θ_0 is the cold water inlet temperature [°C]
D is the number of days for the calculation period considered [d]

$Q_w = 1000 \times (1.162 \times 10^{-3}) \times [0.202 \times (45-15)] \times 365 = 2570.22$ kWh

Then it can be calculated the annual energy need of DHW for surface unit:
$Q_w = 2570.22/155 = 16.58$ kWh

5.7 How passive strategies help to reach comfort conditions

Following the setting of all the characteristics of the building, it was necessary to conclude in DesignBuilder the analysis on the building without active systems carried out since the beginning of the design process; this was made in order to clarify the final contribution to the project of passive strategies for maintaining comfort conditions, and to give a solid basis before the actual active plants definition and their energy simulations, that will be discussed in the next chapter.
In order to analyse the building performances in the best possible way, data have been extrapolated, referring to:
• indoor and outdoor temperature and indoor humidity RH_{in}, comparing the first two to see how many and what kind of variations occurred inside the building and the related temperature profiles.
• solar gains, to assess how much solar radiation entered the building both in the winter period, evaluating the coldest month, January, both in the summer period, evaluating the hottest month, July; with the same approach the contribution of the outside shading system for maintaining comfort conditions acceptable was evaluated.
• walls and roof U-value, comparing them with construction standards commonly used in traditional building, to assess their contribution to internal comfort.
Except the analysis on shading system, green roof and wall where values referring to the average of the entire building were used, the profiles of two rooms in particular, the Living Room and the Parents Bedroom were used: the first one is the room with the best solar exposure, facing south; the second one is the room with the worst exposure, facing north and having windows that look only towards that direction.
As analysis periods were used:

- Coldest Month: January and its most critical days

- Hottest Month: July and its most critical days

- Hottest Months: June to August Coldest Months: December to February

It was decided to mainly evaluate the data for two months in particular, January and July, and for hottest and coldest months, as it was thought to be the most representative way to understand the building conditions. On the one hand, carrying out an evaluation on an annual scale would have meant making the reading of the data more complex; on the other hand analysing the most critical periods of the year it was possible to evaluate the building performance during the worst climate conditions of Hou Ji village area.
In the same way, when analysing the building performance with active energy systems it is necessary to use fixed days to understand the maximum load that the system can have in the most stressful situations.

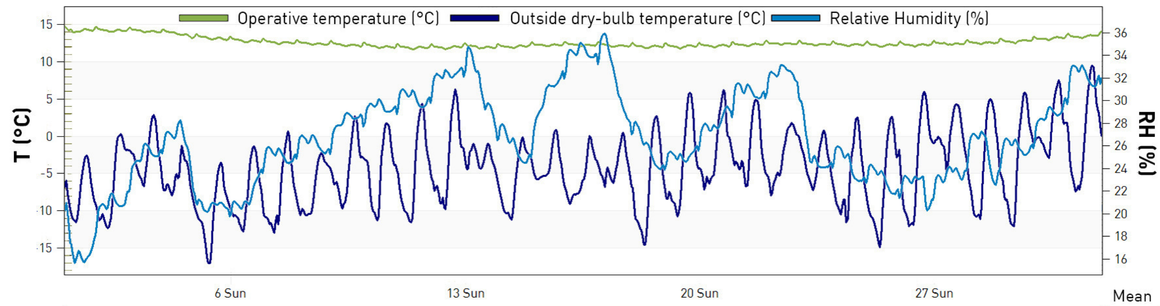
• *Operative temperature profiles without active systems (July and January)*

In this section, the analysis for the hottest month, July, and the coldest month, January, are performed, taking as a reference for the simulations the Parents Bedroom and the Living Room. It can be seen how the building, although without active systems, maintains average internal temperatures near to the comfort zone, thanks to the passive strategies and the type of building designed.
In the graphs, the variations of internal temperature T_{in} were analysed in relation to solar radiation and the outdoor temperature T_{out}, as well as the relative humidity values RH_{in} inside the building, in order to assess the general design choices adopted.

> January

First, two charts were created for the month of January both for the Parents Bedroom and for the Living Room, in order to evaluate simultaneously T_{out}, T_{in} e RH_{in}.
From the first graph it can be seen that the bedroom maintains a constant internal temperature, with an average of 15 °C more than the outside, settling at a total average T_{in}=12.53 °C, despite having outside values even at -15 °C. This shows that an heating system is needed, in order to reach the necessary comfort conditions when the building is occupied.
The living room, on the other hand, as can be seen in the second graph and in

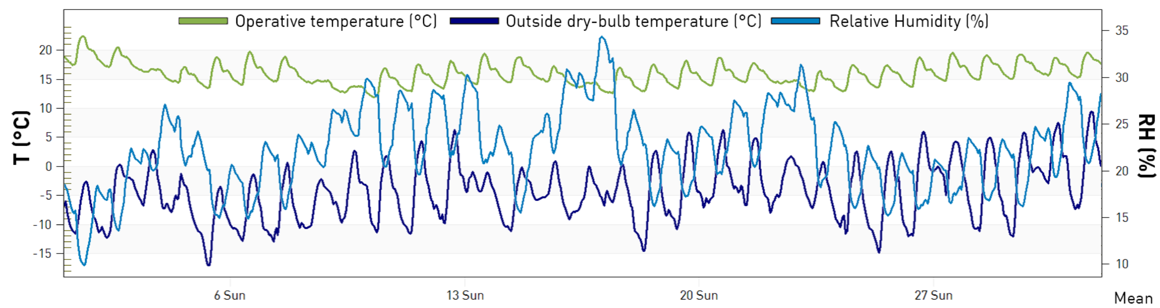
› Parents Bedroom_Temperature and Relative Humidity 1st - 31st January



											Mean
T_{in} (°C)	13.98	12.90	12.20	11.91	12.32	12.56	12.13	12.43	12.20	12.64	12.53
T_{out} (°C)	-2.05	-1.45	-5.09	-8.19	-5.77	-7.00	0.08	0.58	-3.48	-11.92	-4.42
RH_{in} (%)	25.11	22.15	28.88	32.00	28.79	27.09	29.49	24.11	23.11	26.05	26.70

◄ Fig. 5.22 Comparison between operative temperature, outside temperature and relative indoor humidity of the Parents Bedroom during January.

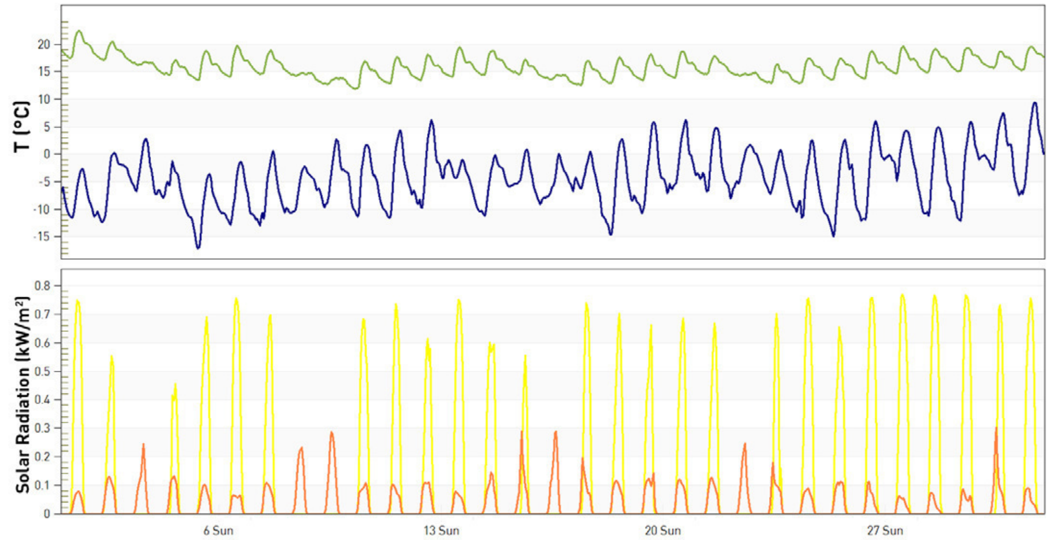
› Living Room_Temperature and Relative Humidity 1st - 31st January



											Mean
T_{in} (°C)	16.71	19.14	13.13	13.52	15.34	14.67	16.53	15.43	17.82	15.12	15.74
T_{out} (°C)	-2.05	-1.45	-5.09	-8.19	-5.77	-7.00	0.08	0.58	-3.48	-11.92	-4.42
RH_{in} (%)	20.81	15.61	25.79	27.70	23.87	25.81	21.96	19.01	16.28	21.34	21.90

◄ Fig. 5.23 Comparison between operative temperature, outside temperature and relative indoor humidity of the Living Room during January.

› Living Room_Temperature and Solar Radiation 1st - 31st January

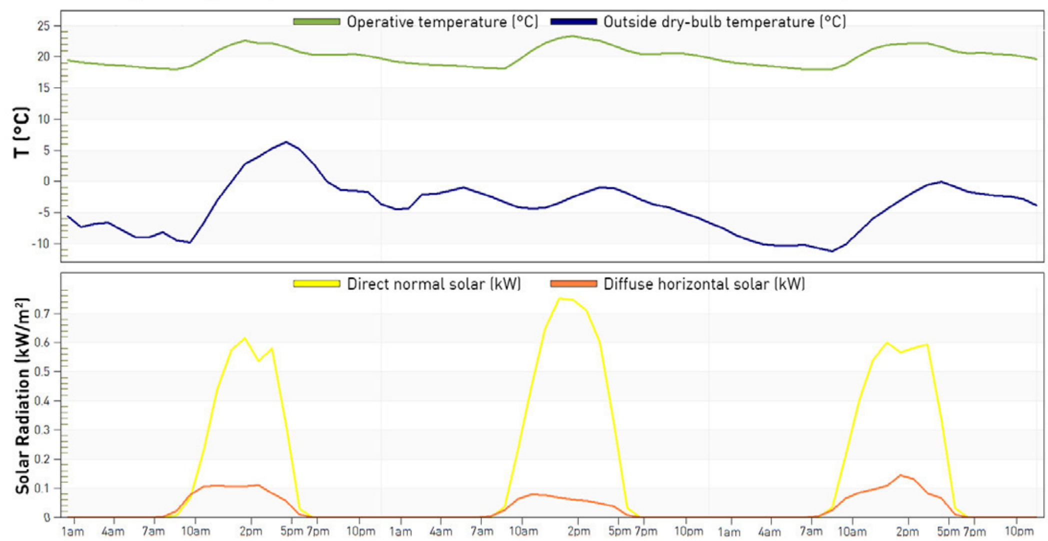


											Mean
T_{in} [°C]	16.71	19.14	13.13	13.52	15.34	14.67	16.53	15.43	17.82	15.12	15.74
T_{out} [°C]	-2.05	-1.45	-5.09	-8.19	-5.77	-7.00	0.08	0.58	-3.48	-11.92	-4.42
Direct [kWh/m²]	0.00	0.57	0.00	0.00	0.00	0.00	0.00	0.10	0.62	0.00	0.43
Diffuse [kWh/m²]	0.00	0.06	0.24	0.00	0.00	0.00	0.00	0.08	0.11	0.00	0.13

Fig. 5.24 ▶
Comparison between operative temperature, outside temperature and solar radiation of the Living Room during January.

the graph above, benefits a lot from the solar radiation being exposed to the south, and maintains an average T_{in} = 15 °C with peaks of almost 20 °C; it can also be noted the considerable increases in temperature that occur due to the increase in solar radiation, reaching peaks of 18-20 °C. In fact, the solar radiation reaches peaks of more than 0.7 kW/m^2 for the direct radiation and averagely 0.13 kW/m^2 for the diffuse radiation.
The RH_{in} instead, settles at low values in both rooms, with an average of 26.70 % in the bedroom and 21.90% in the living room.
Whereupon a zoom was made on the living room to better highlight how the solar radiation affects the building's internal temperature during the winter, thanks to the rooms facing south. They have not been performed on the bedroom as being exposed to the north it is not possible to take advantage of direct solar gains. In the graph below it can be seen, combining temperatures

› Living Room_Temperature and Solar Radiation 12nd - 13rd - 14th January



											Mean
T_{in} [°C]	18.19	22.57	20.34	18.72	20.98	20.92	19.30	18.02	22.17	20.38	20.16
T_{out} [°C]	-8.98	2.78	-1.43	-1.96	-4.34	-1.88	-7.49	-10.74	-1.70	-2.46	-4.53
Direct [kWh/m²]	0.00	0.62	0.00	0.00	0.45	0.03	0.00	0.00	0.58	0.00	0.42
Diffuse [kWh/m²]	0.00	0.11	0.00	0.00	0.08	0.01	0.00	0.00	0.13	0.00	0.11

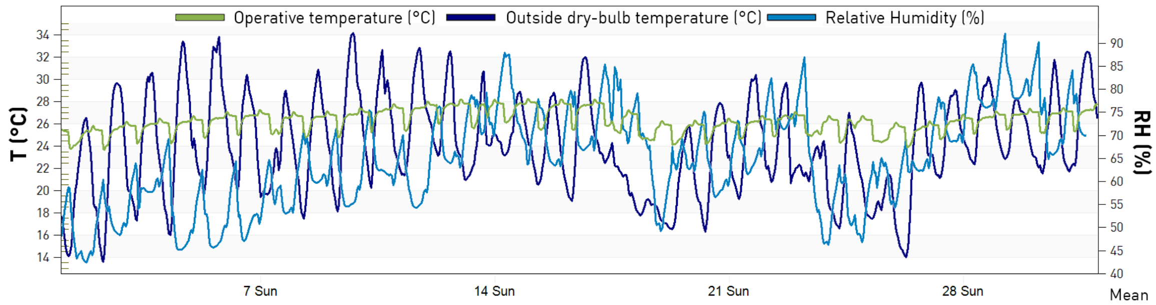
Fig. 5.25 ▶
Comparison between operative temperature, outside temperature and solar radiation of the Living Room during 12th -13th -14th January.

and solar radiation profiles, both direct and diffuse, profiles, is highlighted as in the days 12nd-13rd- 14th January, solar contributions are exploited very well.
It can be seen that in the winter days when there is a good solar radiation, as happens in the three days chosen, it is adequately exploited thanks to the windows facing south and allows to reach very good T_{in}, equal to an average T_{in}=20.16 °C, with peaks of almost 23 °C. This happens thanks to the large amount of solar radiation, which reaches values of 0.7 kW/m^2, with an average of 0.42 kW/m^2.
In the same way the external walls, the floor and the green roof designed, as well as the use of double glazed window allow to keep the heat losses of the building to a minimum, thus keeping the internal temperature higher: this allows to greatly reduce the heating loads of the installed energy system, since it will have to satisfy lower energy requirements to maintain the comfort conditions. In this sense, the solar radiation that reaches internal spaces during daylight hours when temperature rises, from 8.30 AM to around 14.00 PM, makes possible to increase the T_{in} from 2 to 4 °C.
It is also important to highlight how the internal temperature is always higher than the outside temperature of about 20 degrees.
These considerations on the analysis without systems show how the project choices are adequate up to now, and have allowed to maintain acceptable internal conditions, up to bringing the internal temperature to 20 °C without the use of active systems.

> July

Again in July, living and bedroom were analysed, with particular attention to the living, since it is south-exposed and more prone to overheat. As can be seen from the first graph, the bedroom maintains a constant temperature despite the strong external temperature changes, moving between 24 and 28 °C; it exceeds 28 °C shortly only in the middle days of July, maintaining a total mean temperature of about 26.19 °C.
The same concept applies to the Living Room, whose temperature never exceeds 30 °C, maintaining a T_{in} between 24 and 29 °C throughout July. This means that the appropriate design choices makes possible to keep T_{in} within the limits of adaptive comfort, i.e. 28 °C, despite the room has the worst

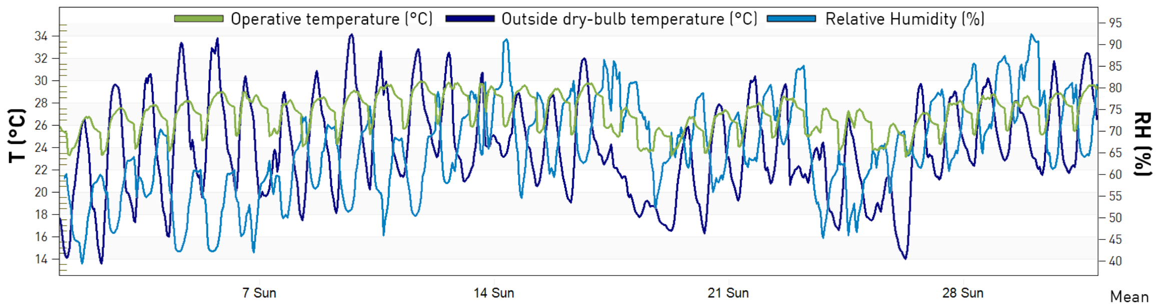
› Parents Bedroom_Temperature and Relative Humidity 1st - 31st July



											Mean
T_{in} (°C)	25.99	26.76	26.50	25.99	27.93	27.23	26.06	25.21	24.75	25.52	26.19
T_{out} (°C)	27.73	28.75	27.17	23.29	21.99	19.76	27.19	23.59	23.72	23.35	24.65
RH_{in} (%)	58.82	50.26	54.81	76.39	72.62	68.80	58.85	53.84	64.25	83.62	64.22

◀ Fig. 5.26
Comparison between operative temperature, outside temperature and relative indoor humidity of the Parents Bedroom during July.

› Living Room_Temperature and Relative Humidity 1st - 31st July



											Mean
T_{in} (°C)	27.86	28.38	27.34	26.11	28.54	27.33	27.19	25.66	24.84	25.55	26.88
T_{out} (°C)	27.73	28.75	27.17	23.29	21.99	19.76	27.19	23.59	23.72	23.35	24.65
RH_{in} (%)	58.67	51.29	54.47	79.08	71.73	78.20	58.81	53.60	64.97	85.61	62.64

Fig. 5.27 ▶
Comparison between operative temperature, outside temperature and relative indoor humidity of the Living Room during July.

summer-exposure being south-faced. The Living Room in fact maintains an total average T_{in}=26.88 °C.

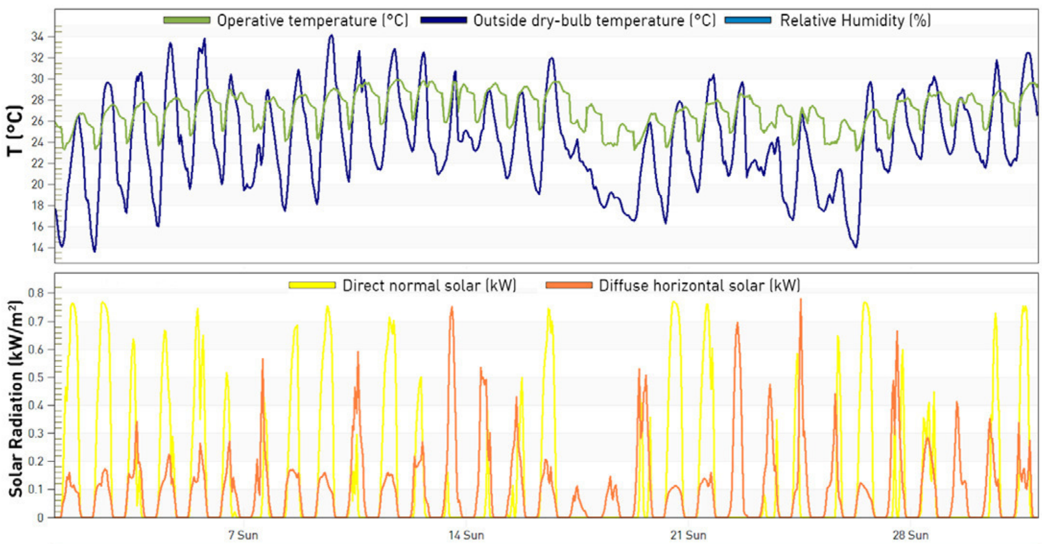
Therefore it can be inferred that for few days, when the temperature stays above 29 °C during the day, it will be necessary to use a cooling system, not excessively powerful, but that can allow to overcome without problems the eventual overheating problems.

In both rooms quite good RH_{in} values are registered, between 45 - 80% for most of the time to be precise, with the highest peak at 90% and the lowest at 40% for both rooms; the total RH_{in} average for the bedroom is 64.22% while it is 62.64% for the living room. This means that a dehumidification system will be needed in order to improve the indoor air quality and to avoid the combination of high temperature and high humidity.

In the graph below instead it can be seen that inside the living room, temperatures vary according to solar radiation. Differently from the analysis carried out on January, in July the diffuse radiation is double, while the direct radiation has similar values; despite that, la T_{in} stays below 29 °C, even when outside peaks of 34 °C are combined with direct radiation of 0.60 kWh/m^2.

In the same way it is possible to notice that in the night time, the temperature

› Living Room_Temperature and Solar Radiation 1st - 31st July



											Mean
T_{in} (°C)	28.36	29.01	27.90	29.64	29.10	27.85	27.75	25.93	25.08	28.20	27.58
T_{out} (°C)	27.73	28.75	27.17	23.29	21.99	19.76	27.19	23.59	23.72	23.35	24.65
Direct (kWh/m²)	0.00	0.00	0.60	0.00	0.00	0.00	0.04	0.00	0.73	0.00	0.45
Diffuse (kWh/m²)	0.02	0.14	0.15	0.12	0.00	0.00	0.03	0.25	0.12	0.08	0.25

Fig. 5.28 ▶
Comparison between operative temperature, outside temperature and solar radiation of the Living Room during July.

goes down very much, thus reducing possible cooling loads: constant decreases of about 4 degrees occur, never falling below 23 ° C, but that allow to have internal night temperatures within the comfort range.

To analyse in more detail the building performance during July, following the previous analysis it is clear that for the Bedroom there are no particular criticalities and the temperatures are acceptable, in particular because it is exposed to the north and not subject to overheating.

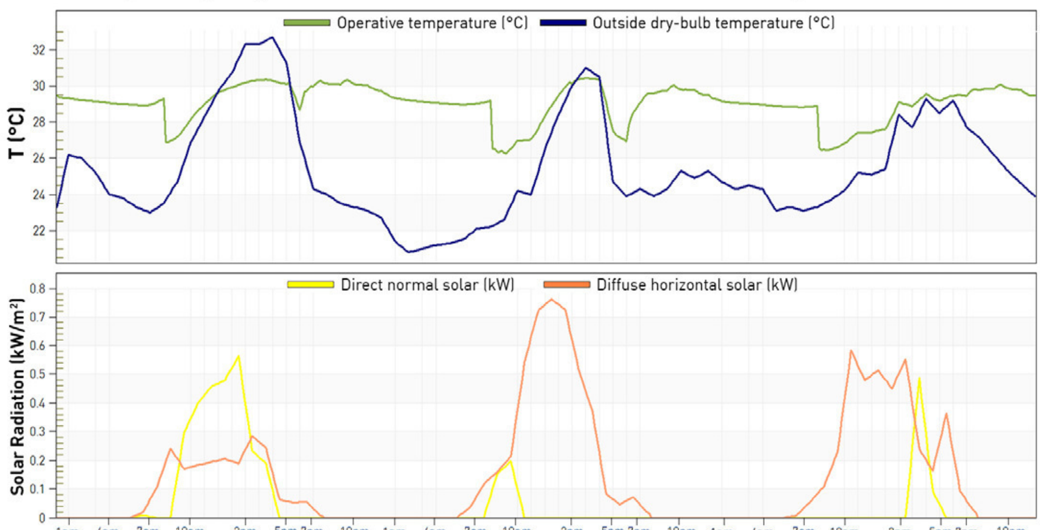
Instead regarding to the room with the most critical sun-exposure, that is the living room, to evaluate the internal conditions, it was decided to create two focuses lasting three days, to analyse the building performance when two types of criticality occur. The first is due to a peak of temperature and solar radiation in which there is generally a low relative humidity, in which it is necessary to understand at what temperature the internal environment arrives; to do this the days 12nd -13rd - 14th July were chosen. The second is caused by a peak of humidity and high temperatures, which occur on 27th - 28th - 29th July.

Between 12nd and 14th July it can be noted that T_{in} reaches at most 30 °C during the sunniest hours, when solar radiation also increases; the latter settles on total average values of 0.42 kW/m^2 for the direct and 0.36 kW/m^2 for the diffuse, with peaks 0.8 kW/m^2 regarding the latter.

From the graph it is also possible to notice the drop in temperature that occurs around 7.30 AM, the time in which the windows are opened to ventilate the interior spaces, which consequently dispose of part of the heat. In the same way, a drop occurs around 18.30 PM, time in which the building is again occupied by all the tenants, who can ventilate the internal environments. This could be verified thanks to the setting of all the schedule mentioned in the section 5.6.1.

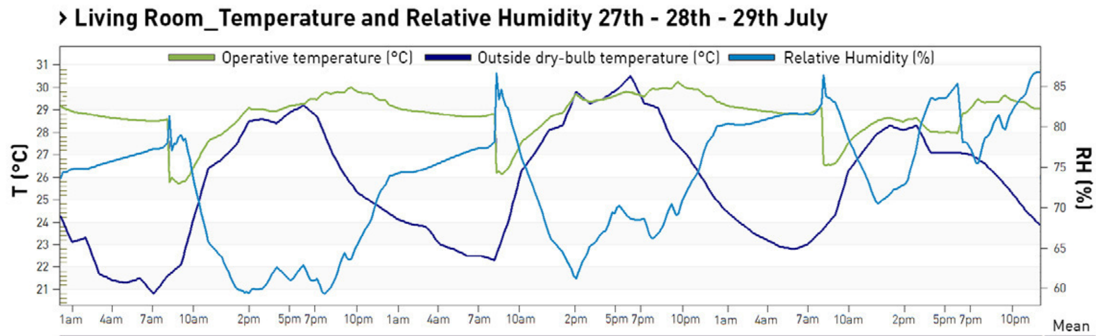
From this it can be deduced that it may be necessary to ventilate more during

› Living Room_Temperature and Solar Radiation 12nd - 13rd - 14th July



											Mean
T_{in} (°C)	28.93	29.92	30.29	29.21	26.35	30.42	30.02	28.96	27.13	29.17	29.04
T_{out} (°C)	23.15	30.70	24.15	20.80	22.40	31.00	24.80	24.30	24.70	28.50	25.45
Direct (kWh/m²)	0.01	0.52	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.05	0.42
Diffuse (kWh/m²)	0.02	0.20	0.01	0.00	0.16	0.44	0.00	0.00	0.58	0.26	0.36

◀ Fig. 5.29
Comparison between operative temperature, outside temperature and solar radiation of the Living Room during 12nd-13rd-14th July.



											Mean
T_{in} (°C)	28.93	28.83	30.19	29.39	26.54	29.80	30.68	29.36	28.27	28.42	29.00
T_{out} (°C)	21.15	27.40	27.95	23.90	23.15	29.30	27.40	23.20	26.70	27.10	25.72
RH_{in} (%)	76.96	60.12	59.33	74.39	84.61	65.17	69.20	80.91	76.54	83.55	73.08

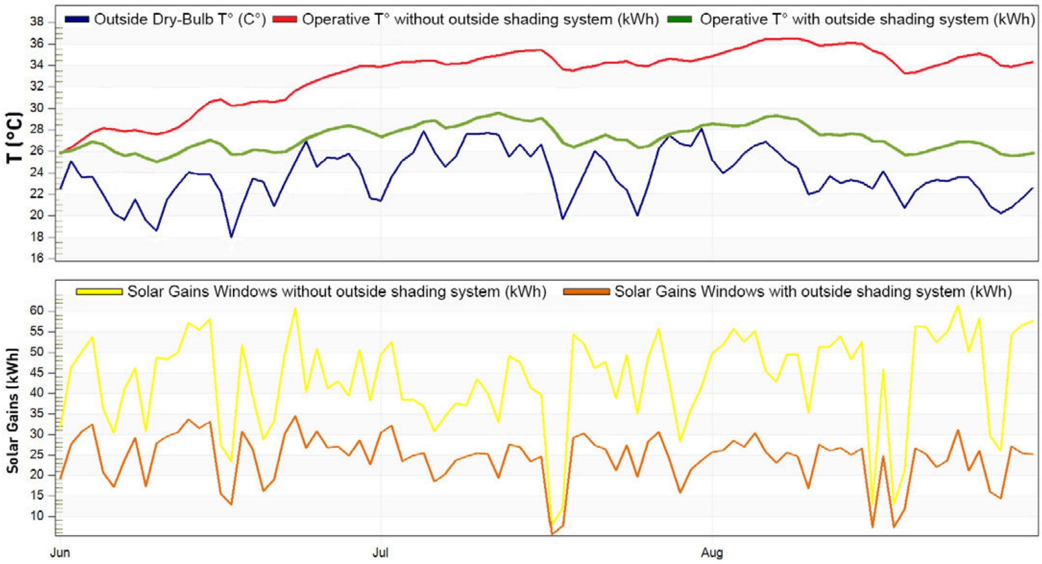
Fig. 5.30 ▶
Comparison between operative temperature, outside temperature and relative indoor humidity of the Living Room during 27th-28th-29thJuly.

the night hours through natural ventilation, since there are some degrees of difference between internal and external that can be exploited.
Between 27 and 29 July the worst internal conditions regarding the combination of RH_{in} e T_{in} happen, as temperatures of almost 30 ° C are combined with humidity ranging from 60 to 80%. The RH_{in} has a total average value of 73.08%, that exceeds the 65% taken as a reference as a upper limit for the comfort related to the human. The analysis carried out on these days shows how the building, despite being the hottest and most humid days of the year, has a T_{in} almost always below 30 ° C, keeping in line with outside temperatures during the hottest hours. In this case it may be necessary to an active system to cool, but these are short periods of time; not to mention that the strategies adopted make it possible not to switch on cooling systems during the night, maintaining temperatures in the range of adaptive comfort, which is 28 ° C. This happens because during the night the air cools down a lot, since high temperature changes occur, with the T_{out} which decreases even up to 10 °C.
Thanks to the data obtained, it is possible to demonstrate that the passive project strategies allow to adequately control the internal temperatures keeping them below 30 degrees even in the hottest days in the living room, which is exposed to the south. They become critical when combined with high relative humidity.

• *The shading system*

To evaluate the contribution as a passive strategy element of the external shading system, two different analysis were performed using the same model, with the difference that in one case the shading system was not present.
From the graph in the next page some important information emerge regarding the presence of the outside shading system, which, being the main constructive element for the protection from solar radiation, is a very important passive strategic element to maintain comfort conditions.
The analysis was carried out in the summer months, from June to August, to assess how much radiation is actually blocked in the hottest period, since it is the primary cause of overheating inside the buildings. It can be seen that the presence of the porches allows to considerably reduce the solar heat gains: they are reduced by 35% in June until they reach a reduction of 45-55% between July and August, when the sun is hotter. This happens because the

› Whole building_Temperature and solar gains comparison 1st June - 31st August



												Mean
T_{in} (°C)	28.69	31.58	32.89	34.85	35.27	34.37	34.66	36.20	36.58	34.03	35.52	34.05
T_{Out} (°C)	20.37	21.10	25.77	22.45	26.45	18.53	21.63	23.52	21.11	19.56	19.72	21.84
Sol.G.Win.(kWh)	46.21	27.61	40.33	52.56	43.63	12.04	48.74	55.72	51.43	21.08	29.70	39.00
T_{in} (°C)	26.63	27.82	28.02	29.03	30.33	30.60	29.16	30.44	31.36	29.60	28.11	27.04
T_{Out} (°C)	20.37	21.10	25.77	22.45	26.45	18.53	21.63	23.52	21.11	19.56	19.72	21.84
Sol.G.Win.(kWh)	29.32	15.65	26.81	32.34	25.56	6.78	28.36	28.61	27.64	11.71	16.08	22.62

◀ Fig. 5.31
Comparison between operative temperature, outside temperature and solar radiation in the all building from 1st June to 31st August.

sun is higher in the sky and has a much higher angle of incidence: in this way the shading allows to block it. In winter, on the other hand, the reverse occurs, with the sun having a low angle of incidence, which allows the sun-rays not to be blocked by the external bamboo and metal shading and to penetrate into the building.

In the same way the average internal temperature profiles of the building undergoes an important variation: without the porches the T_{in} touches peaks of 37 °C, with T_{in} averagely between 31 °C and 36 °C; with the use of the porches instead the T° decrease from 2 °C at the beginning of June up to 7 °C between July and August, not allowing to overcome practically never the 30 ° C.

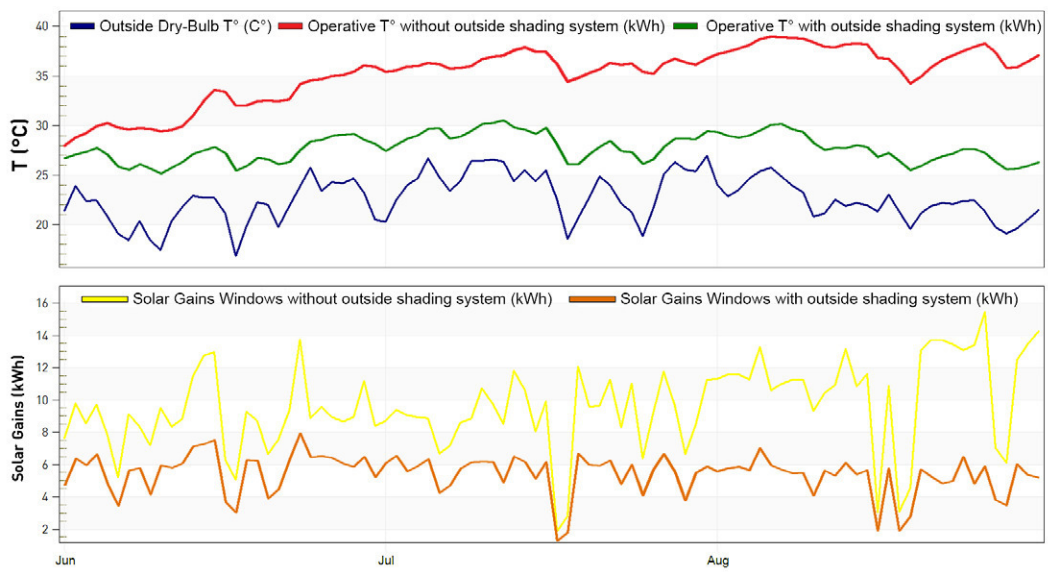
The total average internal temperature for the overall period without shading system is 34 °C, while with them it is 27 °C, therefore finding 7 degrees of difference between the two solutions.

On the following page, instead, a focus was made in the same period on the living room to assess how the environment most prone to overheating problems performed in the summer period.

La living room with the presence of the shading, maintains a T_{in} lower in a value range from 4 °C to 12 ° C of difference with the T_{out} during the whole summer period, with an average T_{in} =28.72 °C, compared to the T_{in}=35.19 °C without the use of shading. The solar radiation in the same way is almost halved, with a total average of 8.10 kWh without the system, and 4.67 kWh with the system.

In this way it is possible to understand how much helps the shading system to reach the internal comfort, reducing eventual cooling loads during the summer period, thus reducing energy consumption.

› Living Room_Temperature and solar gains comparison 1st June - 31st August



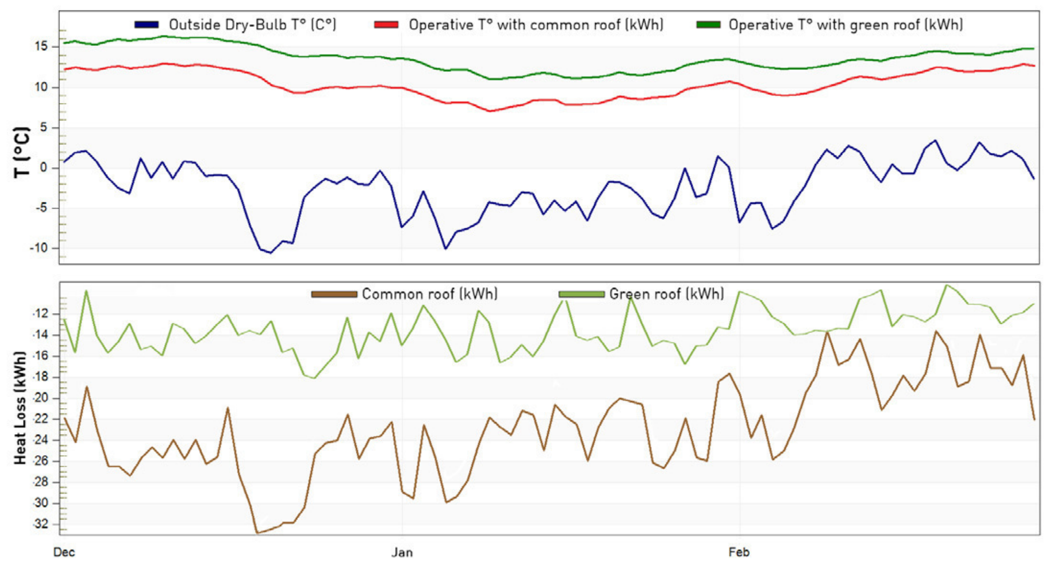
												Mean
T_{in} (°C)	29.76	33.43	34.56	35.59	36.72	34.41	35.25	37.80	37.96	34.24	37.39	35.19
T_{Out} (°C)	20.37	21.10	25.77	22.45	26.45	18.53	21.63	23.52	21.11	19.56	19.72	21.84
Sol.G.Win.(kWh)	8.33	6.29	8.84	9.39	10.70	2.81	9.20	11.56	10.44	4.54	7.04	8.10
T_{in} (°C)	25.66	26.77	27.97	27.64	29.71	25.65	26.17	28.34	27.12	25.04	25.93	28.72
T_{Out} (°C)	20.37	21.10	25.77	22.45	26.45	18.53	21.63	23.52	21.11	19.56	19.72	21.84
Sol.G.Win.(kWh)	5.54	3.42	6.21	6.30	5.93	1.51	5.42	5.61	5.39	2.50	3.57	4.67

Fig. 5.32 ▶
Comparison between operative temperature, outside temperature and solar radiation in the Living Room from 1st June to 31st August.

• *The green roof*

To evaluate the contribution as a passive strategy element of the green roof, two different analysis were performed using the same model, one with the designed green roof and the other with a common roof. In this sense, in the analysis below, the actual contribution in terms of decrease of heat dispersion thanks to the use of the green roof, was evaluated; to do this an analysis was conducted in the coldest months of the year, from December to February.

› Whole building_Temperature and heat loss comparison 1st December - 28th February

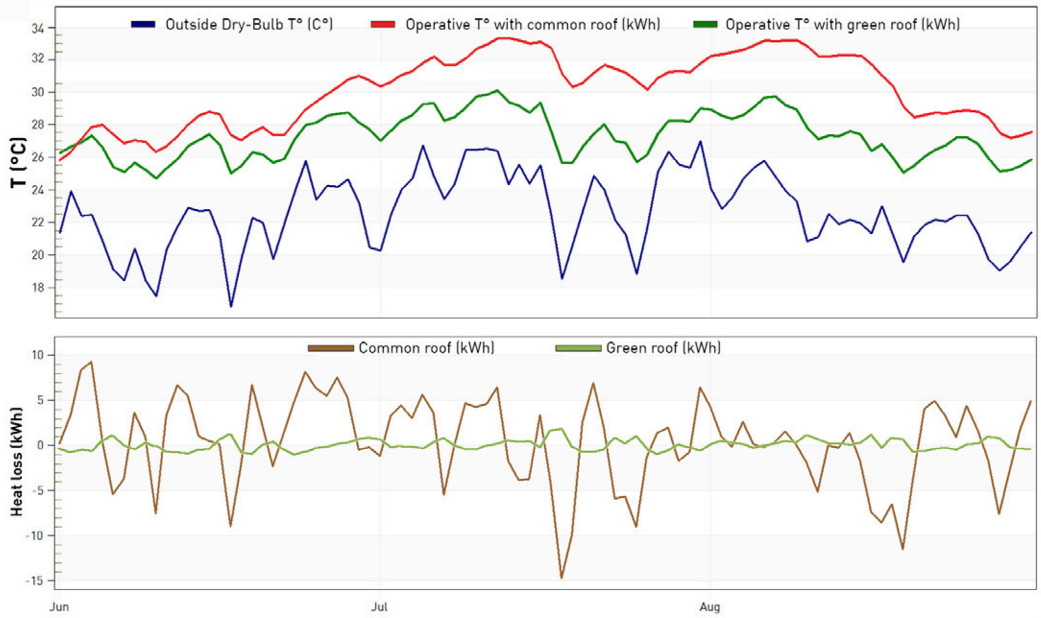


												Mean
T_{in} (°C)	12.50	12.29	9.72	9.94	7.08	7.89	8.84	9.86	10.52	12.07	12.53	11.32
T_{Out} (°C)	1.22	-0.91	-2.35	-7.36	-4.18	-4.15	-6.18	-4.38	1.21	2.44	2.16	-1.23
C.Roof (kWh)	-23.47	-18.66	-22.99	-26.67	-19.63	-20.26	-24.42	-21.55	-14.64	-15.45	-16.58	-20.39
T_{in} (°C)	15.93	15.70	13.92	13.58	11.01	11.16	11.96	12.87	12.94	14.32	14.51	13.72
T_{Out} (°C)	1.22	-0.91	-2.35	-7.36	-4.18	-4.15	-6.18	-4.38	1.21	2.44	2.16	-1.23
G.Roof (kWh)	-13.05	-9.79	-15.79	-12.70	-10.50	-11.82	-12.20	-7.97	-11.05	-10.46	-9.87	-11.38

Fig. 5.33 ▶
Comparison between operative temperature, outside temperature and heat losses for the whole building, comparing the designed roof solution with a common roof, from 1st December to 28th February.

The green roof has a U-value=0,22 W/m^{2}K , while the roof used for the comparison, which is an energy code standard medium weight flat, has a U-value=0,486 W/m^{2}K in line with the average transmittance values of a common roof built in this period in China.
The compared wall is composed by 10 cm of concrete in the inner side, 8 cm of XPS insulation, 1 cm of fibreboard and 2 cm of bitumen coating.
The use of the green roof makes it possible to greatly reduce heat loss and more easily maintain the comfort conditions inside the building, while providing a green space for the tenants in a space that wouldn't be used..
As can be seen from the graph, the use of the green roof allows to have inside the building a temperature without active systems higher than 3 °C to 4 °C, compared to the use of a traditional roof. This can be seen in the same way from the difference in dispersion between the two solutions: the use of the green roof makes it possible to halve the dispersed kWh, thus helping to maintain a higher internal T°. This has the same effect in the summer season, with the green roof helping to maintain a lower internal temperature. In this way the green roof helps to reduce the energy consumption of the energy plant.
Similarly, an analysis was also carried out for the summer period from 1st June to 31st August. From the graph emerges as the solution with the common roof has an average heat loss of -0.90 kWh, having an average T_{in}= 30.13 °C; the green roof solution instead has 0.22 kWh as heat loss average value but the T_{in} = 26.91 °C. Therefore it can be deduced how the use of green roof in summer allows to reduce the T_{in} of the building averagely of 4 °C compared to the use of a common roof, maintaining the same constant internal temperatures, acting as thermal mass and having an average high inertia. Likewise, the

› Whole building_Temperature and heat loss comparison 1st June - 31st August



												Mean
T_{in} (°C)	27.08	28.64	28.92	30.62	32.66	31.17	30.17	32.46	32.19	29.09	28.44	30.13
T_{Out} (°C)	20.37	21.10	25.77	22.45	26.45	18.53	21.63	23.52	21.11	19.56	19.72	21.84
C.Roof (kWh)	3.67	0.13	8.20	3.23	4.27	-14.71	-1.25	-0.08	-5.14	-11.48	-1.57	-0.90
T_{in} (°C)	25.66	26.77	27.97	27.64	29.71	25.65	26.17	28.34	27.12	25.04	25.93	26.91
T_{Out} (°C)	20.37	21.10	25.77	22.45	26.45	18.53	21.63	23.52	21.11	19.56	19.72	21.84
G.Roof (kWh)	-0.43	0.64	-0.71	-0.19	-0.35	1.87	-0.35	0.28	0.66	0.70	0.93	0.22

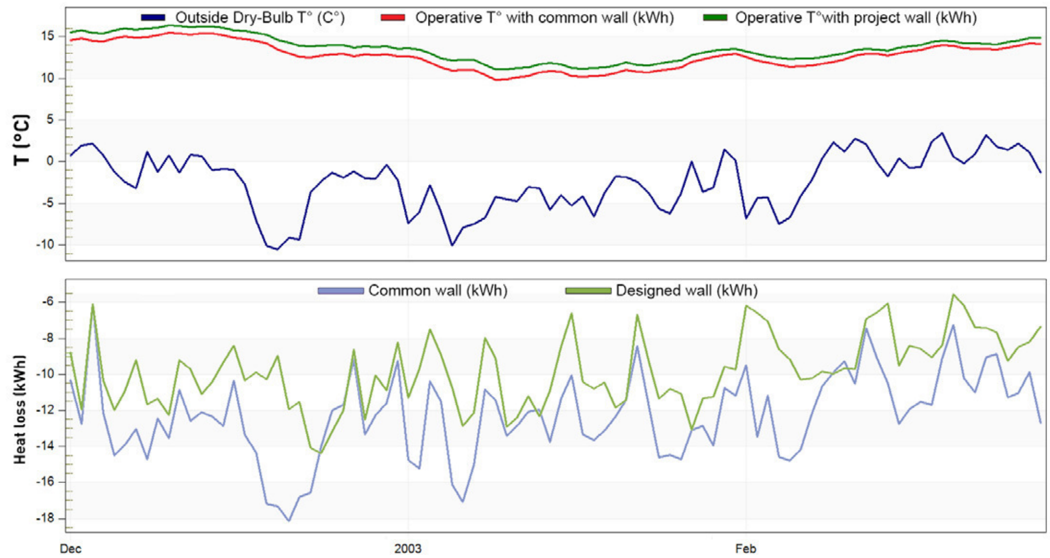
◄ Fig. 5.34
Comparison between operative temperature, outside temperature and heat losses for the whole building, comparing the designed roof solution with a common roof, from 1st June to 31st August.

green roof allows to reflect a large part of the radiation that affects the roof, preventing it from entering the building.
Therefore, in summer the use of the green roof allows to have a lower internal temperature than the outside maintaining constant the heat balance and avoiding above all particular temperature changes between day and night, as instead happens in the comparative case.

• *The wall assembly (earth blocks/hemp insulation)*

With the analysis below,it was evaluated the actual contribution to the thermal balance, as a passive strategy, of the designed wall assembly. It has a U-value = 0.22 W/m^{2}K, and a high thermal inertia, thanks to the use of 25 cm earth blocks joined to the 12 cm hemp insulation. An energy code standard medium weight wall was used for the comparison, which has a U-value = 0.35 W/m^{2}K in line with the average transmittance values of a common wall built in this period in China. The wall is composed by two rows of bricks of 10 cm, of which the inner face is plastered, with a layer of XPS insulation in between of 10 cm. The analysis was conducted in the coldest months of the year, from December to February to assess the heat losses.
As can be seen in the graph, the use of the designed wall allows to constantly maintain an average T_{in}=13.45 °C compared to 12.58 °C. It can be registered at least one more degree inside the building along all the three months, while the heat losses are reduced from 2 to 5 kWh; averagely along winter with the designed wall about 1.20 kWh less are dispersed than with a common wall assembly.
This allows to have better conditions of internal comfort and using less energy to heat the system during the cold period.

› Whole building_Temperature and heat loss comparison 1st December - 28th February



												Mean
T_{in} (°C)	14.98	14.85	12.72	12.64	9.85	10.21	11.12	12.15	12.30	13.73	13.88	12.58
T_{Out}(°C)	1.22	-0.91	-2.35	-7.36	-4.18	-4.15	-6.18	-4.38	1.21	2.44	2.16	-1.23
C. wall (kWh)	-14.73	-10.35	-14.02	-14.75	-11.43	-13.34	-14.48	-13.47	-9.29	-11.71	-11.04	-12.60
T_{in} (°C)	15.93	15.70	13.92	13.58	11.01	11.16	11.96	12.87	12.94	14.32	14.51	13.45
T_{Out}(°C)	1.22	-0.91	-2.35	-7.36	-4.18	-4.15	-6.18	-4.38	1.21	2.44	2.16	-1.23
D. wall (kWh)	-13.05	-9.79	-15.79	-12.70	-10.50	-11.82	-12.20	-7.97	-11.05	-10.46	-9.87	-11.38

Fig. 5.35 ▶
Comparison between operative temperature, outside temperature and heat losses for the whole building, comparing the designed wall solution with a common wall, from 1st December to 28th February.

Chapter 6

Active Technologies, Energy System and Analysis

The purpose of the following chapter is to define the last part of the project path developed in the thesis, which is the one related to the energy active system and energy simulations. Since the beginning of the design process, the goal has been to use a type of system that could be as modern as possible, identified in this case by the hybrid compact system: it will be detailed below its operation hand in hand with the energy analysis carried out with the DesignBuilder software, all related to one of the three planned buildings, the private house.

6.1 Pre-dimensioning the system: Heating and Cooling Design

The first step made in order to define the energy system, was to carry out calculations inside DesignBuilder, called "Heating design" and "Cooling design". These two functions of the software precede the actual simulations on the project, as they allow to calculate the peaks of heating and cooling loads, using the worst conditions that can occur; based on the values obtained in kW it is possible to adequately size the power of the energy production equipment necessary to reach the comfort conditions.

• Heating Design

With this function it is possible to size the heating equipment needed to 'balance' the coldest winter design weather conditions that can happen at the project site. In this way it is possible to have an appropriate basis to achieve the conditions of indoor thermal comfort in winter conditions.
Another important thing to underline, is that this analysis is a *steady state* analysis, which means that timing is not taken in consideration.
The heating design simulation uses, as said previously, EnergyPlus to carry on this type of analysis, having the following characteristics:
• Constant (Steady-state) external temperature set to the winter design external temperature, taken from the climate file, that in this case is -14.9 °C
• Wind speed and direction set to design values
• No solar gain
• No internal gains, as lighting, equipment, occupancy, etc.
• Heated zones are heated constantly to achieve the heating temperature set point, that is 20 °C, using a simple convective heating system
• Heat conduction and convection between zones of different temperatures are considered
• Schedules are not used for Heating design calculations, since they are based on a steady state analysis which does not account timing[1]

For the calculations during the Heating Design, the setpoint and setback temperature values must be set within DesignBuilder, in order to communicate the comfort temperature that must be maintained. Therefore the following ones were used:

• Heating Setpoint 20 °C
• Heating Setback 16 °C

The software, in order to calculate the heating capacities required to maintain the temperature set points in each zone, displays at the same time the total heat loss of the analysed building, dividing it in the following categories:
• Glazing

6.1 http://www.designbuilder.co.uk/helpv5.2/#_Heating_design_simulation.htm

- Walls
- Partitions
- Solid floors
- Roofs
- External infiltration
- Internal natural ventilation, displayed in dark green (i.e. heat lost to other cooler adjacent spaces through windows, vents, doors, holes)
- External ventilation, displayed in light green (i.e. the air changes)

At the end of the simulation, the total heat loss in each zone is multiplied by a Safety factor, which is 1.5 by default, to give a recommended Heating Design Capacity.

> Heating Design graph_Temperature and heat loss analysis

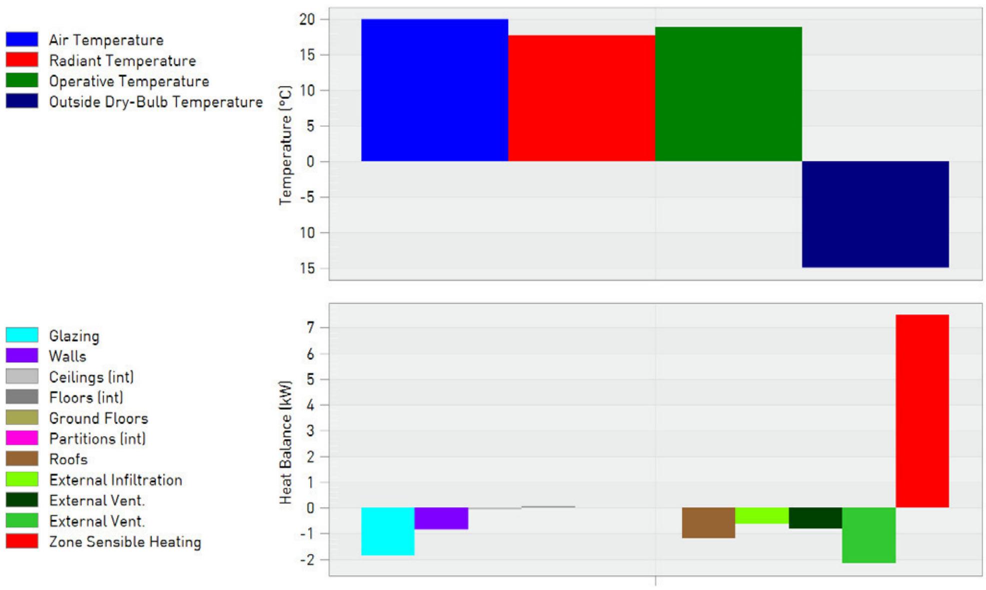


Fig. 6.1 ▶
Bar graph of temperature and heat losses obtained from Heating Design for the analysed building.

> Heating Design table_Temperature and heat loss analysis

Air Temperature [°C]	20.00
Radiant Temperature [°C]	17.71
Operative Temperature [°C]	18.86
Outside Dry-Bulb Temperature [°C]	-14.90
Glazing (kW)	-1.86
Walls (kW)	-0.85
Ceilings (int) (kW)	-0.06
Floors (int) (kW)	0.00
Ground Floors (kW)	0.06
Partitions (int) (kW)	0.00
Roofs (kW)	-1.18
External Infiltration (kW)	-0.63
External Vent. (kW)	-0.82
External Vent. (kW)	-2.14
Zone Sensible Heating (kW)	7.48

Fig. 6.2 ▶
Values related to temperature, heat losses and Zone Sensible Heating required for the analysed building, obtained from Heating Design.

Thanks to this analysis, it was obtained a total "Zone Sensible Heating" of 7.48 kW. It can be noted that the higher heat losses values are those of the "External Vent.", which is referred the zones air changes, and it is equal to -2.14 kW and those of the windows, equal to -1.86 kW. On the contrary, the Ground Floor registers a gain of 0.06 kW, due to the temperature difference between the ground (about 13 °C) and the outside air (-14.9 °C).
Knowing this data, it was possible to choose a system that had a power higher than that amount, in order to cover the heating needs of the building in the worst design conditions.

• Cooling Design

The "Cooling Design" uses the same approach of the Heating Design, but with opposite temperature conditions at the site location. The calculations are carried out using the hottest summer design weather conditions likely to be encountered, in order to determine the required capacity of mechanical cooling equipment for the designed building. For the zones which are not mechanically cooled, free-floating temperatures are calculated including the effects of natural or mechanical ventilation if these options are selected on the zone HVAC tab.
The cooling design simulation uses, as said previously, EnergyPlus to carry on the analysis, having some predefined key criteria behind:

• Periodic steady-state external temperatures, calculated using maximum and minimum design summer weather conditions, are used
• No wind is considered
• Solar gains through windows and scheduled natural ventilation are included
• Internal gains from occupants, lighting and other equipment are included
• Consideration of heat conduction and convection between zones of different temperatures is included

Talking about the period of time used for the calculations, for buildings situated in the Northern Hemisphere, the software uses the month of July while for buildings in the Southern Hemisphere uses January; therefore for this analysis, being HouJi part of the second category, July was used; at the same time it was set up July 21st as SummerDesignDay, i.e. the reference hottest day used for the calculations related to cooling.
After starting the simulation, the software calculates half-hourly temperatures and heat flows for each zone and determines cooling capacities required to maintain any cooling temperature set points in each zone. The setpoint used for the analysis were the following ones

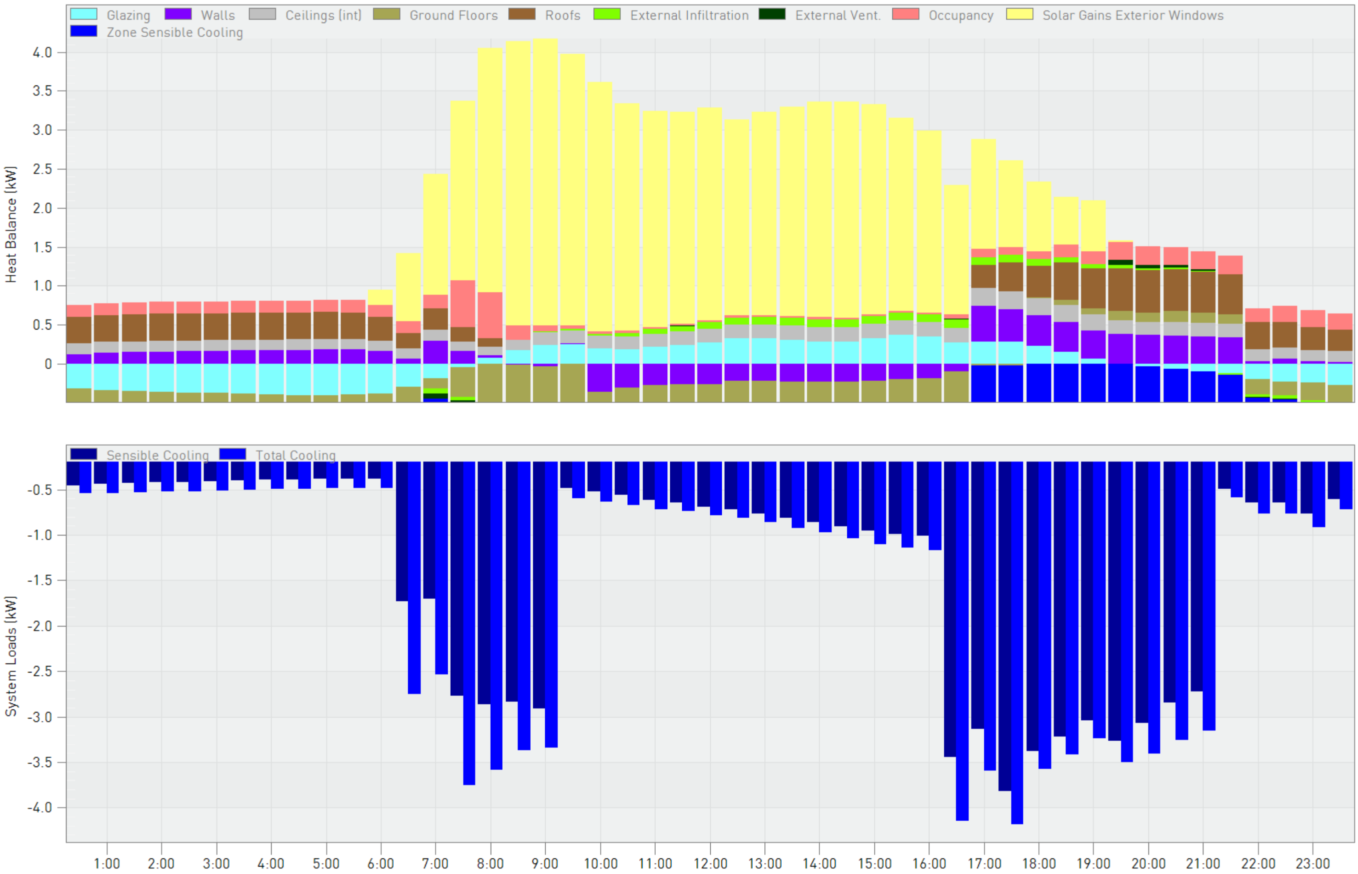
• Cooling Setpoint 26 °C
• Cooling Setback 30 °C

The simulation continues until temperatures and heat flows in each zone have converged, and if convergence does not occur then simulation continues for the maximum number of days as specified in the calculation options, which were set from June to September.
At the end of the simulation, the maximum cooling load in each zone is multiplied by a Safety factor that is 1.3 by default, in order to give a Design Cooling Capacity, expressed in kW. To find this value, it is necessary to choose the peak load in the "Total Cooling" line in the end simulation table, which in this case was -5.10 kW.
Therefore it was necessary to choose a plant with a power higher than this value.

Fig. 6.3 ▶
System cooling loads on 21st July for the analysed building obtained from Cooling Design.

Fig. 6.4 ▶
Temperature and heat gains obtained from Cooling Design of the analysed building.
The highlighted value represents the maximum required cooling peak, to which refer for the system definition.

> Cooling Design_Heat balance and system cooling loads on 21st July



Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Glazing (kW)	-0.36	-0.39	-0.38	0.07	0.19	0.28	0.28	0.35	0.23	-0.04	-0.20
Walls (kW)	0.15	0.17	0.16	0.04	-0.36	-0.26	-0.23	-0.18	0.39	0.37	0.03
Ceilings (int) (kW)	0.14	0.13	0.13	0.11	0.16	0.18	0.18	0.19	0.22	0.17	0.15
Ground Floors (kW)	-0.17	-0.17	-0.21	-0.77	-1.08	-0.85	-0.95	-0.89	0.01	0.12	-0.20
Roofs (kW)	0.35	0.35	0.31	0.11	-0.27	-0.29	-0.26	-0.16	0.40	0.54	0.35
External Infiltration (kW)	-0.08	-0.09	-0.09	-0.02	0.03	0.08	0.10	0.09	0.08	0.03	-0.03
External Vent. (kW)	-0.03	-0.04	-0.04	-0.02	0.00	0.00	0.00	0.00	0.00	0.05	-0.01
Occupancy (kW)	0.15	0.15	0.15	0.59	0.03	0.03	0.03	0.03	0.10	0.24	0.18
Solar Gains Exterior Windows (kW)	0.00	0.00	0.20	3.14	3.20	2.73	2.77	2.34	0.89	0.00	0.00
Zone Sensible Cooling (kW)	-0.42	-0.39	-0.38	-2.86	-0.52	-0.69	-0.86	-1.00	-3.38	-3.07	-0.64
Sensible Cooling (kW)	-0.42	-0.39	-0.38	-2.86	-0.52	-0.69	-0.86	-1.00	-3.38	-3.07	-0.64
Total Cooling (kW)	-0.52	-0.50	-0.49	-3.58	-0.63	-0.78	-0.98	-1.16	-3.59	-3.40	-0.76

As can be seen from the images, the greatest cooling loads occur around 8 to 9 AM and after 16.30 PM up to about 21 PM; in the second case the highest values are registered, up to 4 kW. This happened because, using the occupancy schedule set at the building level, which foresees the presence of people until 9 am, and from 4.30 PM onwards, the software for the non-occupied hours refers to the setback temperature, which is 28 °C; in this way the cooling loads are lower. While the greatest loads occur at the times when the building is occupied, i.e. when the 26 °C setpoint is active.
Clearly these values are not to be taken as definitive, but as indicative of the building performance, since different external contributions are not considered and at the same time the calculation is carried out in steady state. However, it can be said that up to this point the building has shown good performance in terms of energy, with relatively low consumption forecasts.

6.2 Identification of the most effective energy system

Defining an adequate energetic system that could be integrated inside a nZEB (nearly Zero Energy Building) building design, is a kind of "minefield", since when a designer approaches to a design of an energy system, there's the chance to choose between a quite big variety of installations, whether they are single, combined or hybrid systems; each one of them has valuable features, so it is important to understand which one of them meets better the needs of the project, keeping in mind the environmental standards and the economic and environmental sustainability to reach.
Clearly, the aim is to find the best solution for the energy system, supported by realized examples giving tangible results on which could be the final outcome, that is to design a building that could be at the same time sustainable in its materials and construction systems and sustainable in its energy systems. Different solutions were taken in consideration with the purpose of finding the most suitable solution to the project and to the idea of dwelling that the thesis aims to achieve.

The project area is located in a territory, as stated in the previous chapters, characterized by a cold semi-arid climate. In this kind of climatic situation, the design need to focus more on what could be the heating loads and how to give comfort inside with stiff temperatures outside. Whereas it is necessary to consider eventual cooling loads, as when the summer arrives, quite high temperature are registered, especially in July and August, with peaks sometimes of 40 degrees; thus, it's important to choose a system that can help to reach comfort conditions in the hottest period.
In this sense, as seen in the previous chapter, the constructive solutions designed contribute in a decisive way to maintain the internal comfort conditions, helping in winter to reduce the heating loads, thanks to the use of green roof, well insulated walls, well-designed floors and double-glazed windows, with the latter, together with the porches that don't shade from the low winter sunrays, that allow for high solar gains.
In the summer period, on the other hand, the porches and the external shading systems of the windows considerably shield the solar radiation, thus reducing the phenomena of overheating and the following possible cooling loads. The building envelope, however, having a good thermal inertia, allows to maintain the internal temperature around 28 °C maximum throughout the house in the summer period, except for the three rooms facing south, where during few days of July in the hottest hours 30 °C are recorded; to cope with these possible cooling loads, a small system is sufficient, if used alone, to cover the needs otherwise, to use a single system, it is possible to use a radiant floor that works in reverse summer, cooling the rooms, i.e. free-cooling.
An integrated building design in all its components, which is exactly the aim of the thesis, is only possible with project ideas as the ones written above: make a project that has a strictly relation between architectural design, environmental design and energy systems design, makes the realization of

a nZEB pilot building possible. But it is important to know the starting point of the reasoning behind the choice of the energy system: first of all it was decided that the element on which it should have been based was the heat pump. This technology, regardless of the type that is applied, nowadays is the most suitable solution for nZEB buildings; obviously it needs to be integrated with other technologies, in order to achieve the objectives set, i.e. having a building with very high energy performance, having at the same time a high environmental standard.
All the reasoning and examples are intended to explain deeply the chosen solution with the heat pump at the center, after having clearly explained its operating mechanism. But first of all it is necessary to describe why these type of systems has been chosen for the project in the Hou Ji Village, which is the topic that will be discussed in the following pages. Inside that it's also important to give an explanation of what is and how does it work a heat pump, that, as said, will be the core of the best-case scenario system, motivating the choice made with examples of realized buildings.
For the designed building, which is planned for a single-family of 4 people and develops on a 155 m^2 plan, it has been chosen, for the best-case scenario, a hybrid system, which integrates inside itself different components, a Heat Pump (HP), a Controlled Mechanical Ventilation (CMV) with a Heat Recovery Ventilation (HRV), a radiant floor and a Photovoltaic and Solar System.
The fundamental discriminating factors in the choice of the plant were the climate of the area and the will, as already mentioned above, to create a performing building that combines very low energy consumption and low heat losses with a high environmental respect.
For the distribution of heat/cold a radiant floor has been chosen, having the ability to distribute better the temperature and give greater comfort; at the same time, having low cooling energy needs, it is possible to use the same radiant floor for cooling the rooms in summer, reversing its cycle, thanks to the free-cooling.
The heat pump has been combined with the CMV, with integrated HRV, which starts up to perform the necessary air changes for the rooms, recovering energy both in winter and in summer to be reused in energy processes.
The on-site electric production has been entrusted to photovoltaic panels integrated with the porches on the south side, whit a power of 4.5 kWp; they are used to supply the heat pump, the CMV and the whole house electric system. Solar thermal panels are also installed in the same place, with the aim of covering the domestic hot water needs. Both systems will be detailed in the final sections of the chapter. At the same time, the application of two solar thermal panels has been designed to help the heat pump to cover all the hot water requirements needed by the system for heating the rooms.
Thus, together with the energy system based on the heat pump, it was necessary to think of an alternative solution that can be realized with less investment; in fact a heat pump-based systems has a high initial cost of installing, therefore in lack of funds or with a low budget, it can be very difficult to employ. An alternative solution could be a radiator system connected to the local district heating system.

6.3 The hybrid system

Nowadays, energy production and consumption are travelling towards a hybrid future, where less and less energy is used for buildings, which must be as performing as possible; for this reason, the current regulatory framework leads to the use of multiple technologies interconnected in a smart way to ensure maximum levels of energy efficiency and sustainability.
In this sense, nowadays hybrid and flexible systems are the best result of the mix of different energy sources, thus their flexibility allows the selection and implementation of renewable and traditional sources that best suits individual needs, guaranteeing the best performance of the plant and avoiding dependence on a single energy source.
The choice may be different on a case-by-case basis so must be taken into account the trend in the cost of primary energy, the non-programmability of renewable sources (above all some, such as solar) and the growing spread between primary and secondary energy.
Among the energy systems the hybrid one is, therefore, the most technological, since a single plant takes care of the overall consumption, looking constantly for the best compromise to save energy consumption: for doing this, it is no longer the single machine to realize the performance but its correct positioning and interaction in the system.

But, what does a *hybrid* choice translate in practice?

Currently the most significant developments are represented by hybrid systems composed of a heat pump, combined with a Heat Recovery Ventilator (HRV) or an Air Handling Unit (AHU), joined with a photovoltaic plant; it's important to underline that, in a high energetic performance building, the controlled mechanical ventilation is almost inevitable to not frustrate energy savings with natural ventilation.
It's also common to use a boiler to support heat pump's heat production, but this goes against the sustainable approach that it is used, since in any case it uses fossil fuel; eventually it is sufficient to use a solar thermal system to cover the energy needs.
These combinations fit to any climatic situation: in particular the combination of heat pump and photovoltaic system provides a full renewable energy contribution on sunny days and in those not particularly cold, while HRV and AHU take care of indoor air quality and comfort conditions reusing at the same time hot or cold air produced.
It is important to notice that the heat pumps used in hybrid systems meet the heating, cooling and domestic hot water requirements and interfacing with other technologies - above all solar energy - allow to increase efficiency levels and the use of a substantial renewable share (Scotuzzi M., 2016).
But what are actually the advantages of a hybrid heating and cooling system that uses a heat pump, whether it is air-water, air-air or geothermal?
It can be possible to point out the following ones:

• increased comfort: unlike the heating generators with burner, the heat pump provides a constant flow of hot air or hot water, depending on the type. During indoor cooling, heat pumps also have a good level of cooling, unlike many traditional air conditioners.
• high energy savings: compared to traditional systems, hybrid heating/ cooling systems can save from 30 to 50% in fuel costs. In addition, heat pumps consume much less energy since they work in a moderate temperature range compared to traditional burners.
• reduction of CO_2 emissions: using less fossil fuel to heat and cool a building, allows to reduce emissions considerably, ensuring at the same time that the tenants become more "conscious" about a sustainable use of resources.
• cost: although the initial costs, these type of systems can allow to have a substantial reduction in bills without suffering a negative impact on comfort.

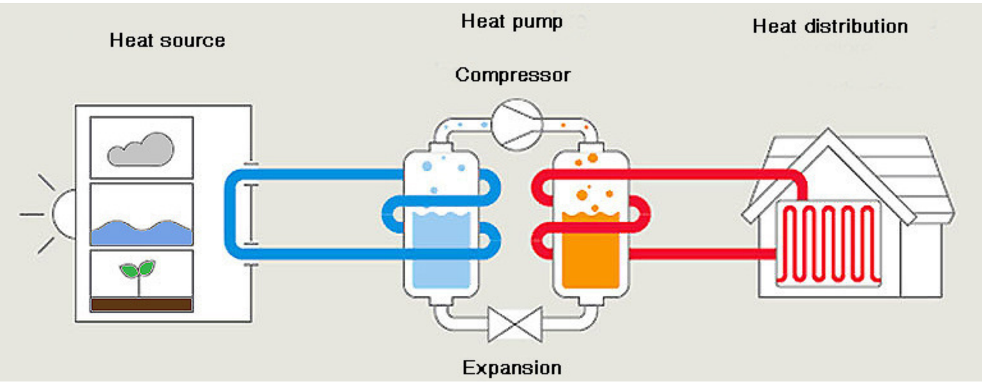
However, the design of a hybrid system requires good accuracy, as the feeling of comfort is highly subjective, in order to be appropriately designed to maximize the overall comfort of the occupants.
The main disadvantage of hybrid heating and cooling systems is the higher indicated cost of the initial installation, but it's clear that, after a high expense for the first installation, it results in long-term savings that will certainly make the difference on the budget. Hybrid conditioning systems can therefore maximize comfort inside the home, minimizing the cost of bills.
But the main component, as mentioned, within a hybrid system that aims to have a very low environmental impact and a high performance compared to its consumption, is the heat pump; the correct functioning of this system is based on it, so it is important to choose, according to the place of planning and the local climate, the correct type.
In this sense a heat pump installation is fundamental nowadays for achieving a total or partial independence from gas or diesel fuel and to use the thermal potential available free of charge in the air, in the ground or in the water.
Talking about the air for example, even when its temperature is below zero degrees, it inherently contains potential heat. A heat pump system allows to concentrate this heat and transfer it to the water in the house. The hot water produced can be used to power a radiators system or a floor heating system, or it can be used as domestic hot water, for shower, kitchen and sanitary ware. During the summer, the heat pump system can be used in the reverse way to cool spaces.
The same concept applies to water and ground, since energy can be extracted from those for heating/cooling water inside the system: but the main difference between the ground and the air is that the first one maintains a constant temperature throughout the year, while the air no, being subject to seasonal changes or variations between day and night. In the second case, these variations mean that the electric consumptions for the operation increase a lot. For the water pump, the discourse is more complex, since although it has very similar properties to the soil in terms of temperature, for its operation it must have the certainty that there is an aquifer beneath the building and that it can be used, but in most cases this is not possible.

6.3.1 The heat pump functioning

The main components of a heat pump system are the following: a compressor, an expansion valve and two heat exchangers, respectively an evaporator and a condenser.
Its operating principle, when it's used for heating purposes, is the same as a refrigerator, but working in a reverse way:

• the ambient air is taken inside the heat pump system, or the water in case of ground or water heap pump, where it meets the evaporator.
• the evaporator is connected to a closed system that contains a fluid that can pass to the gaseous state at very low temperatures. When the outside air or the water come into contact with the evaporator, the refrigerant fluid passes from the liquid to the gaseous state exchanging energy.
• then the gas enters in the compressor, where the compression process make it release more heat and returns the gas to the liquid state.
• the heat generated is collected through the heat pump system condenser that feeds it into the house's heating system.

Since this cycle is repeated continuously, it allows the accumulation of hot water, therefore it is usually a good choice to connect a boiler to the heat pump for storing the hot water produced by the system. Inside the heat pump, the water used for sanitary purposes (kitchen, taps, shower, etc.) can be heated up to 60-65 °C, depending on the setpoint chosen and is therefore available when needed.
This process of exploiting the potential heat of an inexhaustible natural source is the key to the efficiency of heat pump systems and the savings related to it. In fact, using a traditional system with gas or oil boilers, there is a 1:1 ratio between the energy input and the energy that can be obtained; i.e. for each kWh of energy with which the system is powered, approximately one kWh of supplied energy is obtained.
In the case of a heat pump, instead, for each kWh consumed by the system, used to power the components, at least 3 kWh of energy are generated, with the best performing ones that generate up to 6 kWh.
So, if the heat pump heater is connected to a photovoltaic or solar-thermal system, this would allow to become totally independent from the supply of gas or fossil fuel, using the solar radiation as a energy source instead.



◀ Fig. 6.5
Heat pump functioning scheme.

6.3.2 The choice of the heat pump type

When it's time to choose which type of heat pump (combined with other systems) to install, as said before, it's possible to choose between three types: air-air, air-water and geothermal. Each one of them has advantages and disadvantages, so it's important to know deeply their characteristics.
In the current project site the most suitable solution, for different reasons, is the geothermal heat pump.
First of all, it was excluded the air-water heat pump, because there's no chance to know if under the project area there's an aquifer, and since no study has been done about it, deciding to use this type of heat pump could be very risky during a design process.
The same thinking has been applied to the air-air heat pump, thanks to a quite simple reason: in this project it has been used a bio-climatic approach to the design, which considers not only the building itself, but also all the natural elements, like sun, temperatures through the year, wind, etc.; in this sense, thanks to the climate analysis it was possible to know that for a large part of the year, more than six months to be precise, there are cold conditions outside (since the area is in a cold-semi arid climate); therefore, using an air-air heat pump isn't a good solution, because with very cold outside temperatures this kind of heat pump works very badly and highly increases electric consumptions when it's time to withdraw air from outside to supply it in the system; without mentioning condensation problems that can occur inside the machines.
Therefore, as said, a geothermal heat pump represents the most suitable solution in this project: its energy source is the ground, whose temperature is constant throughout the year and therefore always provides the same amount of energy, reducing the energy costs of the heat pump: at 100 meters of depth, the temperature is about 13 °C constant during the year and rises about 1 °C every further 33 meters of depth.
At the same time, the geothermal heat pump, is theoretically usable in almost every place, as long as the building does not lay on rocky terrain, which would make drilling the ground to install the underground system of spiral pipes very difficult and expensive; but in the case of Hou Ji the problem is not present.
In addition, the geothermal heat pump is the one with the highest efficiency, having the highest CoP[2] among them, reaching values of 6 kWh of energy compared to 1 kWh consumed.
For its installation, it requires an underground system of spiral pipes that exchanges heat with the ground, thanks to a convector fluid that passes through them. There are two types, one vertical and one horizontal.
In the case of a vertical geothermal circuit, the geothermal probe is made with pipes installed inside perforations of variable depths between 50 and 150 m, sealed with special mixtures of cement and bentonites.
Alternatively, a horizontal or surface geothermal circuit can be used, whose

6.2 Acronym of "coefficient of performance" is a coefficient used to measure the heat pump efficiency; it is given by the ratio between the energy delivered (heat transferred to the environment to be heated) and electricity consumed; the higher the COP, the more efficient the machine is.

exchange circuit uses pipes installed in contact with the ground at a depth of about 2-3 meters maximum. The problem with this last solution is the lack of space in the project lot: each of the buildings has a limited external space, while a horizontal circuit needs a large space for the pipes, about twice the air-conditioned surface, making this system inapplicable. Therefore vertical probes are the best choice for the project.
At last, the geothermal heat pump allows to work very well with radiant floor panels that work with a lot of fluid (and therefore high thermal capacity) but at a low temperature (35 - 45 °C) which significantly reduces the thermal jump to be carried out by the heat pump and therefore increases its CoP.
At the same time, in a building that has at the centre of its design the achievement of high environmental standards, it is important to combine a heat pump system with a photovoltaic system for the production of energy, whether photovoltaic or solar thermal. The photovoltaic system and the heat pump are complementary: the first produces electricity exploited by the second to produce hot water even more efficiently, cleanly and economically; a photovoltaic system combined with a heat pump are able to produce electricity and heat, being able to satisfy all the energy needs; so surely the two plants will be installed in a complementary way in what will be the completed building.
This could be combined with an accumulator of electricity, but currently the investment is not worth the so-called "savings in the bill", with extremely long payback times. Consider that, for example concerning Italy, there's a return time estimated in 8/10 years compared to an expense of a few thousand euro, in very sunny areas and with a Mediterranean climate; as well as a guaranteed life of the item around 3-5 years. It is easy to understand that in a project area like the one in Hou Ji, where a colder climate prevails, this investment is not particularly convenient. The advantage, however, is that it can also be installed years after the construction of the photovoltaic system; therefore, a future intervention can be envisaged in this sense, if the market prices of the products should decrease (as it seems to happen)(AA VV, 2013).

6.4 Project's choice: the hybrid compact system

The hybrid compact system is a plant that, in a compact form, having the dimensions of a fridge, can at the same time handle indoor air conditioning, air exchange needing and warm water production with reduced power and consumption. It is usually composed by three elements working in series: a heat pump, a mechanical ventilation machine and a storage boiler. In the latest versions of this system they are all enclosed in a sort of cabinet, which can be positioned in a technical room, in a cupboard or in a kitchen.
The main advantage is represented by the fact that in general it's not necessary to realize the classic thermal power plant, rather to get the best performance the ideal solution in this case is to use a radiant floor, both in heating and in cooling, with a geothermal heat pump; in fact heating and cooling processes

▲ Fig. 6.6
Example of a Hybrid Compact System

are carried out by thermal distribution typical of the radiant floor after the water passed underground and then from 'plant-core'. Nevertheless, to be able to use all the advantages offered by this system, it's necessary that the building has a very low consumption and that it has a perfect airtightness, as the one designed. In fact, this type of system, initially designed for passive buildings, is indicated for use in nZEB buildings, as long as they are well insulated, and respect the concepts of passive design, in terms of winter solar gain and summer solar shading of glazed surfaces, following provisions of the regulations. Outside this area, the expressed powers are not able to meet the required air conditioning requirements: if there's no integrated building-plant design, there is no efficiency.
The integration must be done using the best available technologies, for example, using as said the ground as an additional heat source, and producing on-site energy. The normal application of this system is for single real estate users, like villas, apartments, single-family houses, etc. where generally the installation is foreseen inside the house, near an external wall or in a technical room (Orsini F., 2018).

In the type of system chosen for the private house, in the cold period, the geothermal heat pump heats the water making it flow in the underground pipes and entering it in the radiant floor system to heat the rooms. Simultaneously the controlled mechanical ventilation takes care of the indoor air quality, activating if pollution levels are too high or if the radiant floor system needs a help to maintain the internal comfort conditions when the house is occupied.
At the same time an integrated heat recovery ventilator help to lower the energy consumptions for conditioning the building, working in this way: first it extract energy from exhausted air, which is passed through a counter-current exchanger, which allows to recover a large part of the heat; once this heat has been recovered, almost free of charge, it can be re-entered into the system for heating the water or air introduced into the rooms by the mechanical ventilation or the radiant floors, or using it for sanitary production.
During the hot period instead, the geothermal heat pump works with a reverse cycle, with the fluid that cools passing inside the ground pipes, and flowing into the radiant floors. At the same time the mechanical ventilation take under control the indoor air quality eventually cooling and dehumidifying the air while the heat recovery ventilator can still extract heat from the exhausted air, reintroducing it in the system, with total recovery.
The potential of this system is that it can also be integrated with a more capacious additional boiler, a post-heating battery, photovoltaic systems and solar panels, etc. evaluating case by case feasibility and economic expenditure. In this case the hybrid system is connected with photovoltaic and solar thermal plants, with the latter that is used for heating domestic hot water, thus helping to lower more the overall energy consumption.
The reduction of occupied spaces makes this system solution more delicate than others, but constitutes, together with the high silence and efficiency, one of its main strengths; thanks to this it was possible to locate all the systems inside the technical room.

6.4.1 Hybrid compact system references

a. House in Bollate (Milan, Italy) by BLM Domus

The first building, taken as a reference, is located in Bollate, a city just outside Milan and is realized by BLM Domus company, which operates in the passive house construction field in Italy.
The house was designed according to the standards defined by the *Passivhaus Institut* in Darmstadt, appropriately adapted to the local specifics and legislation, obtaining a *passive Mediterranean* standard.
The building, inserted within a residential context, was built for a single-family, and it is divided on three levels, one of which is underground, for a total area of 185 m^2. The building has large openings facing outwards on the south side to catch the sun-rays, thus contributing to the thermal balance, shaded by electric remote controlled lamellae.
The structure is completely constructed of wood, with the load-bearing structure, equipped with static bracing and a layer of internal insulation in wood fiber (total thickness 27.5 cm), to which is added an additional outer layer of wood fiber (6 cm).
The building is powered by a 6 kWp photovoltaic system, in polycrystalline silicon modules, installed on the roof, which ensure energy independence. The plumbing and heating systems provide heating and cooling thanks to an air-water heat pump (power 6.9 kW), which is also responsible for the production of domestic hot water.
The mechanical ventilation system (exchange 350 m^3/h) is centralized in correspondence of all the environments served: it allows the recovery of a large part of the energy contained in the air, transmitted to the incoming air in order to perform the thermal pre-treatment. In the technical room there is also an accumulator (500 liters) for domestic hot water.
The prefabrication level of BLM Domus is limited to the realization in the workshop only of structural parts, leaving to construction site activity the installation of systems and all the finishes, which allows to shorten the construction time.[3]

◀ Fig. 6.7
External view of the house in Bollate.

◀ Fig. 6.8
House's technical room.

6.3 https://www.ilgiornaledeltermoidraulico.it/pompa-di-calore-e-vmc-per-la-casa-passiva-in-legno/

b. *Casa Gold* in Fagnano Olona (Varese, Italy) by BLM Domus

Casa Gold is a passive house located in Fagnano Olona (Varese, Italy) entirely designed and built by BLM Domus company. It is divided in three floors (day, night and basement) with a hanging garden on the roof, occupying an area of 375 m^2. The house is completely built in wood, with the exception of the perimeter cavity and the masonry foundation slab.
The house uses natural energy sources such as the sun-rays that penetrate through the large windows positioned on the south side, the passive heat deriving from appliances in operation and occupants; to support these sources, a 10 kW photovoltaic system for the production of electricity and solar panels for domestic hot water were installed on the roof. Thanks to this system the house has a negative balance in the generation of carbon dioxide.
Regarding heating and cooling systems, a vertical geothermal system helps the heat pump to heat the house in the winter months, cooling the house at no cost (*freecooling*) in summer. In addition, all electrical and thermal systems converge in a single technical room located in the basement.
Thanks to all these features, house consumption can be quantified in 0.8/1 lt of diesel per m^2 compared to about 7/10 lt per m^2 of a traditional house built with standard materials and assembly.
Specifically, the main building features, are the following:
• a 10 kW photovoltaic system and solar panels, is installed on the roof.
• a vertical geothermal plant with two 80 m probes, is used for floor cooling in the summer and as a support for the heat pump during the winter.
• it is used a coating in wood fiber (from 12 to 24 cm) with density of 240 kg/m^2, for insulation.
• it is used a mechanical ventilation system that has air vents in the various rooms.
• a roof garden, a quite big green area that ensures regular climatic conditions, also encouraging the efficiency of PV panels, retaining fine dust.
• the technical room is located in the basement where all electrical and thermal systems converge: 1,000 liters storage for domestic hot water, heat pump, mechanical ventilation system.[4]

Fig. 6.9 ▶
External view of Casa Gold.

Fig. 6.10 ▶
Casa Gold's technical room.

6.4 (http://blmdomus.com/index.html)

c. *nZEB House* in University of Sannio (Benevento, Italy)

In the beginning of 2018 have been inaugurated in Benevento, Italy, in an area owned by the University of Sannio, a nZEB house, an almost zero-energy experimental building for the Mediterranean climate.
The main characteristics of the building are the following:
• X-Lam panel technology with wood fiber insulation for masonry
• Air conditioning system consisting of a heat pump unit that covers the needs of heating, cooling, domestic hot water production
• Mechanical ventilation with thermodynamic recovery and electronic filtration
• Geothermal field with horizontal probes placed at about 2 meters of depth used to pre-treat the intake air to be entered in the system or to operate in free-cooling in summer; all these combined with advanced home automation technologies that allow to monitor energy and environmental performance throughout the day.
This was one of the first tests of its kind in southern Italy and it allowed the system to be developed with innovative methodologies for design, construction and plant engineering; this project is closely linked to sustainability, reduction of energy consumption and optimization of the casing-plant system and it is part of the Smart Case Program realized by the STRESS technological district, under the scientific coordination of Giuseppe Peter Vanoli of the University's Engineering Department of Sannio University.
The building is completely monitored through advanced home automation technologies, with the aim of providing the occupants with tools for optimal use of environments and configuring a sort of *Living Lab* for detailed monitoring of energy and environmental performance.
The heart of the system is a hub connected to the Internet, remotely controllable via web or through a smartphone application with which it's possible to control windows, temperature, humidity and anti-flooding sensors, turning off and on lights and electrical outlets, manage the air conditioning and lighting system.
The theme of buildings with low energy needs has been an object of study and experimentation in Italy for many years and starting from 31 December 2020, all new buildings, with some exceptions, have to meet nZEB requirements.[5]

◀ Fig. 6.11
External view of the nZEB house in University of Sannio.

◀ Fig. 6.12
House's technical room.

6.5 www.unisannio.it

d. SURE House at Solar Decathlon 2015 by Stevens Institute of Technology (New Jersey, USA)

SURE House, name derived from the fusion of the initials of words SUstainable and REsilient, was the winner of the 2015 edition of Solar Decathlon[6]; it was designed by a student group of the Stevens Institute of Technology, from New Jersey, USA.
The initial aim of this project was to realize a building that had at the same time a very low energy consumption and was able to adapt to climate change. It was a prototype for coastal homes and a building that, in addition to being zero net energy, was totally powered by solar energy, using 90% less energy comparing to dwellings of the same square footage. (Karpasto V., 2015)
The building design was based on three principles, which are, use less energy through smart design, generate all energy needed through renewable solar electric and be capable of providing power during electrical outages.
For reaching these purposes, the design focused on simple and experimental solutions, starting from envelope and window frames insulation, then moving to the energy system: a high efficiency heat pump system was chosen for air conditioning, heating, cooling and dehumidifying the rooms.
For the distribution, a zonization kit was chosen with the chance of controlling temperature in each room. To this was added a CMV (Controlled Mechanical Ventilation) system with heat recovery, which features reduced power and high heat recovery, combining low consumption with improved air quality.
For the production of domestic hot water is used a boiler powered by electricity, produced by the Photovoltaic system, all taking up little space and requiring little maintenance.
Fully integrated solar panels were installed on the roof, producing all the necessary energy for the house over the course of a year. The building also incorporates photovoltaic panels in the blinds, which, as said, feeds the electrical system that produces hot water.
These simple measures, combined with LED lighting and other high efficiency appliances, have given rise to a house that needs a very little energy to guarantee comfort (Karpasto V., 2015).

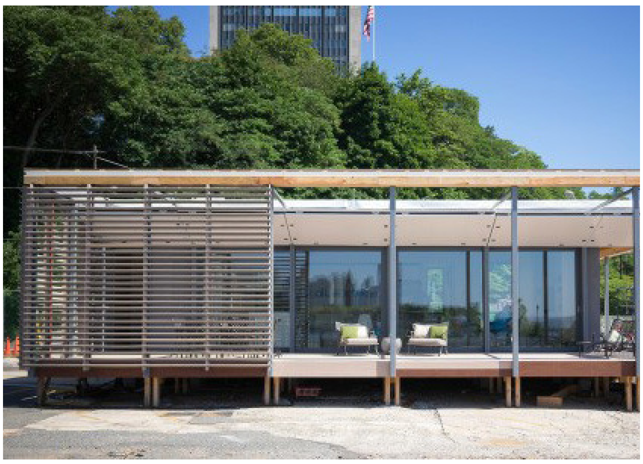


Fig. 6.13 ▶
External view of the SURE House.

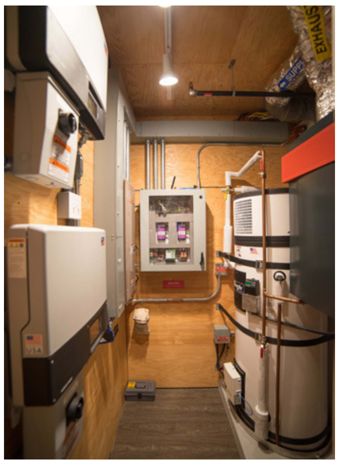


Fig. 6.14 ▶
SURE House's Technical Room.

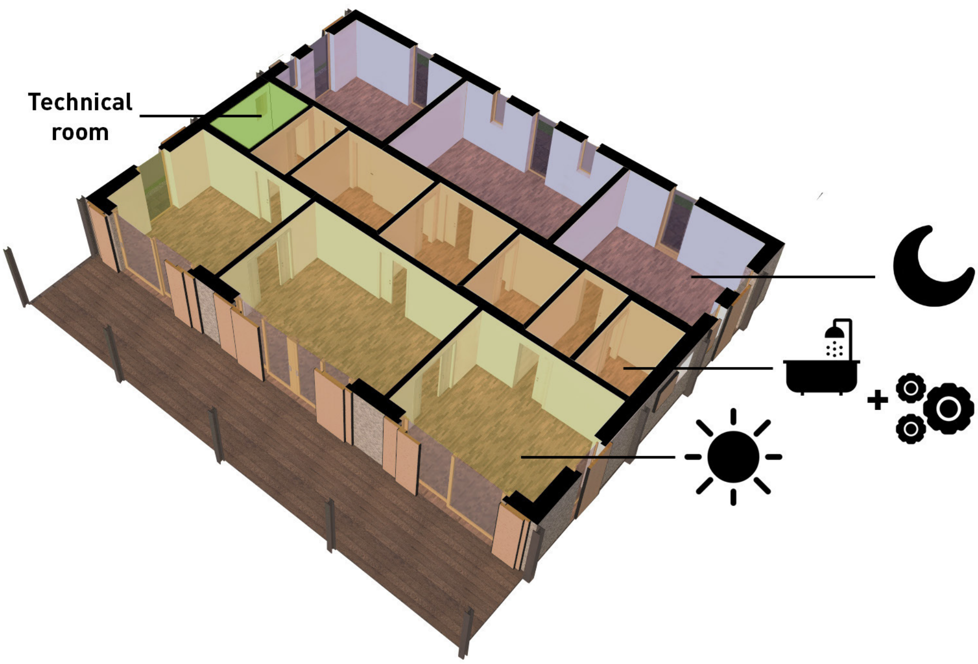
6.6 International competition which brings together low-energy buildings proposal designed and built by universities-teams chosen for participation.

6.5 The components of the designed hybrid system

The energy system designed as the main solution in this project, namely the hybrid system, is formed by three fundamental components, the geothermal heat pump (GHP), the radiant floor and the controlled mechanical ventilation system (CMV); to maintain the comfort inside the home the heat pump takes care of the heating and cooling part, while the CMV takes care of maintaining air quality and humidity control, starting to heat and cool the interior only in exceptional cases.

• Controlled Mechanical Ventilation + Heat Recovery

A house, like the designed one, that has a high airtightness and is well insulated for minimizing the energy losses, requires a constant exchange of air that can hardly be guaranteed by the manual openings, which are also inconvenient in winter because they cause a high heat loss; therefore a controlled mechanical ventilation system, which can at the same time recover heat from internal air, is a (almost) forced choice.
The thermodynamic controlled mechanical ventilation consists in a double flow ventilating machine combined with the heat pump and, as said, is used to maintain the indoor air quality and the comfort temperature if needed; it reuses at the same time the energy present in the exhausted air before it is expelled for heating the air it emits into the environment, in order to obtain very high yields. On one side the air is drawn in from the building and passes through a pump that extracts all the heat before expelling it at a temperature of about 3 °C. On the other side, the air is drawn in from the outside and, before being introduced into the building, it is heated by the heat pump up to 37 °C. Therefore, the thermodynamic controlled mechanical ventilation, as



◀ Fig. 6.15
Division of the building in the three thermal zones, day-zone, service-zone, night-zone

well as allowing a change of air inside a building without the need to open the windows, also allows to heat all or part of the house when needed.
Thanks to the principle of the heat pump it is also possible to reverse the cycle and cool the building in the summer, using the freecooling method. The machine also has filters that avoid entering bad odours or dust inside the building. It is therefore fundamental to save energy and create a sustainable housing unit, with an installation of this type of system combined with the heat pump (Vio M., 2017).

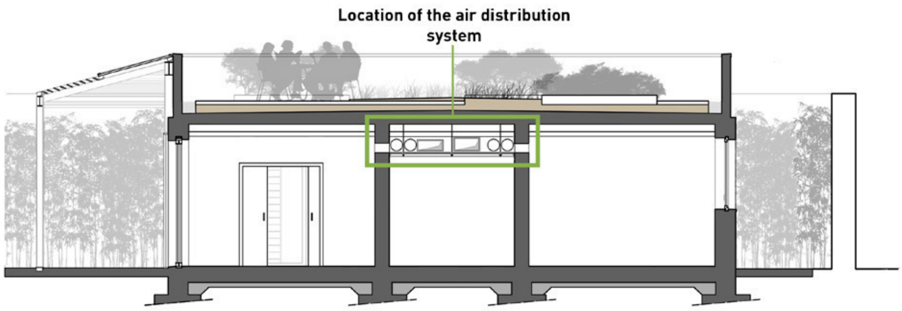


Fig. 6.16 ▶
Location of the air distribution system.

The ventilation system designed for the project is located inside the technical room and was planned to supply the three distinct thermal zones of the house, day zone, service zone and night zone.
Its distribution system is allocated within the false ceiling of the service zone rooms, which is 0.60 m high, and runs along its entire length, for a total of 14 meters: in this way it was possible to distribute the air through nozzles positioned in the upper part of each room allowing to completely hide all the pipes and at the same time limiting the overall dimensions; in the same way the rooms of day zone and night zone, that are the most used, have maintained their full height without the need of a false ceiling, while the service zone rooms, that are the least used, despite having false ceilings, have maintained a height of 2.40 m.

To calculate the required ventilation flow rate, the UNI/TS 11300 refers to other regulations in order to carry out a more detailed calculation suitable for users: since the CMV is used mainly for keeping under control the indoor air quality, the UNI EN 15251: 2008[7] is used. It indicates a project ventilation rate determined on the basis of two contributions: the ventilation required by the occupants (bioeffluents) q_p and ventilation required for the pollutants of the system and construction components q_b.
According to the building category, which is residential, the following values have been chosen, specific for "very low pollution building":

$$q_p = 10\ l/s/person \qquad q_b = 0.5\ l/s/m^2$$

The infiltrations through the envelope are instead specified by the standard

6.7 UNI EN 15251: 2008, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

based on the permeability of the envelope: as this is a building designed to have a low air permeability, it assumes a rate of 0.1 h^{-1}.
Regarding the heat recovery, in order to reduce energy consumption related to the treatment of outdoor air, the evaluation of the use of static or dynamic heat recovery devices is always recommended.
Following the provisions of UNI EN 15251: 2008, the heat recovery devices must comply with the following requirements:
• they must be protected by adequate filters, compliant with current regulations, which reduce dirt and facilitate cleaning both on the exhaust and fresh air side.
• in the case in which the use of free-cooling is foreseen, the heat recovery system must necessarily be equipped with a by-pass damper or equivalent solution, with automatic actuation under regulation. (UNI EN 15251: 2008)
As in this case, for air systems with both summer and winter operation it is convenient to adopt dynamic recovery systems, that favour annual savings, as they are more efficient in mid-seasons and in general with temperatures of external air close to the project expulsion air. (UNI EN 15251: 2008)

• Radiant Floor Heating System

The radiant floor, like the CMV, has been designed to serve the three different thermal zones, with separate water management systems. The environments that were decided not to heat were the Technical Room and the Deposit, as well as all the false ceilings of the service zone, which are used to house the air systems.
In an building designed to be nZEB, the "vehicle" of heat produced by the heat pump can be of different types, from air conditioning, to radiators to floor heating: in this case, using a geothermal heat pump, the radiant floor heating system turns out to be more advantageous.
The principles according to which the panels can transmit heat to the entire domestic environment are irradiation combined with convection. Thanks to these properties, the heat spreads homogeneously from the ground up to the ceiling, letting the radiant floor heating exceeds the limit of traditional heating systems, that is to tend to concentrate the heat in the areas closest to the emission source, as happens with the radiators. In this way it is possible to have an improvement in the well-being conditions inside the house, which will be heated evenly. Another good feature of this heating system is that low water temperatures (at least compared to radiators) are sufficient to operate well. The hot water of a floor heating has in fact a temperature between 30 and 40 °C, which is about half the 70 °C of traditional radiator systems. Therefore, it works well combined with a heat pump system, since it has a much lower water heating demand, thus requiring much less energy.
Regarding the operational functioning of the radiant floor, it is foreseen to install thermostats in each air-conditioned zone, from which it is possible to decide supply and the temperature that the room must reach, starting however from the setpoints foreseen in the design phase, as highlighted from the figure above. To do this, it is necessary to install a manifold for each

Fig. 6.17 ▶
Division of the radiant floor system and related setpoints.

zone: dividing the three zones in this way was the logical choice, as each zone becomes autonomous and has its own water circuit; at the same time it is possible the have an on-off control of the rooms, maintaining the planned tripartite layout of the system.
To clarify how it works, if for the night in winter different temperatures are required in the bedrooms between one room and another, it is possible to set separate settings without having the heating activated for all areas anyway; or it is possible to activate the system for two rooms while for another no. The thermostat will never raise the delivery temperature but will be able to close the chamber line to a certain temperature.

Regarding the expected water temperature in the radiant floor, the maximum and minimum T allowed for the rooms interior surfaces derive from considerations of comfort or superficial condensation. The UNI EN 1264[8] standard, based on the results of the UNI EN ISO 7730 standard for environmental comfort, suggests maximum temperatures for the floor, wall and ceiling in heating mode.
For the radiant floor in heating mode, the UNI EN 1264 provides a maximum temperature for the occupied area of 29 ° C, while for the perimeter areas the maximum allowable temperature is 35 ° C (with air temperature is of 20 °C). For the bathroom, the maximum surface temperature should not exceed 9 °C with respect to the ambient temperature (around 24 ° C) (UNI EN 1264-4[9]).
It should be noted that the maximum water temperatures must take into account the material in which the pipes are inserted; for example, for a plasterboard sheet it is advisable not to exceed 50 °C of the water , but for this project, since the pipes are positioned under a wooden floor and the water temperature is always lower than 50 °C no problems are foreseen.
For the cooling mode instead, it was designed that the radiant floor systems

6.8 UNI EN 1264:2009, Water based surface embedded heating and cooling systems.

6.9 UNI EN 1264-4:2009, Water based surface embedded heating and cooling systems - Part 4: Installation.

cool the rooms through the free-cooling mechanism, which use the geothermal pump in a reverse cycle during the hot period: the water passing through the pump underground pipes transfers energy to the ground and when it re-enters in the heat pump, it can be introduced into the circuit at a temperature between of about 18 °C.
It is important to considered that if a surface is colder than the ambient dew-point temperature, a condensation layer may form on the surface itself. This phenomenon should be avoided, since it could ruin structures, cause accidents (think of a slippery floor) and make air moldy. Therefore it is advisable to always keep the surface at a temperature higher than the dew temperature.

Then there's a note about the initial purchase costs of the system; they are in fact superior (even 50%) compared to those classic heating systems. But the expense usually is amortizable within a limited period of time thanks to the energy savings achievable with it. It's possible to estimate that, thanks to a quantifiable energy saving in the order of 25% per year, in the entire life cycle of a type of product, the total savings that the user can achieve - even net of any incentives of the law - could reach 35% of the total costs for the period.

• Geothermal heat pump

The heart of the designed system, as mentioned, is the geothermal heat pump, which in this case is the most correct solution to compose a system suitable for a nZEB building that has the objective of having the highest possible energy savings.
The first question that may be related to the choice of this type of system, however, is relative to the installation cost. It is true that the geothermal pump has a relatively high cost, but it is good to clarify that nowadays, the expense is very similar to that for a modern good quality gas or diesel heating system. For a living area of around 150 square meters in Europe, such as that of the house analyzed (even less by subtracting the non-air-conditioned premises, in total about 146 m^2), and for which with a higher cost than the Chinese market, the investment it is around 20 thousand euros for installation and system supply.
But for the same inhabited area the construction costs of the plant are completely similar in the case of a geothermal heating system with horizontal probes; if, on the other hand, the solution with vertical probes is chosen, the figures tend to rise, but in any case they can be amortized over a short period of time, namely few years, after the installation of the system.
For the planned buildings the geothermal pump with vertical probes was chosen, due to the availability of space and the highest yield. Each of the buildings has a courtyard of about 120 m2 which is used as vegetable gardens and greenery, so the two purposes of use would have entered into conflict; at the same time a much larger space is needed to position the pipes: unlike the vertical probes, the horizontal ones are positioned at a maximum between two and three meters deep and therefore are less efficient since the more superficial layers of soil are more affected of external climatic variations.

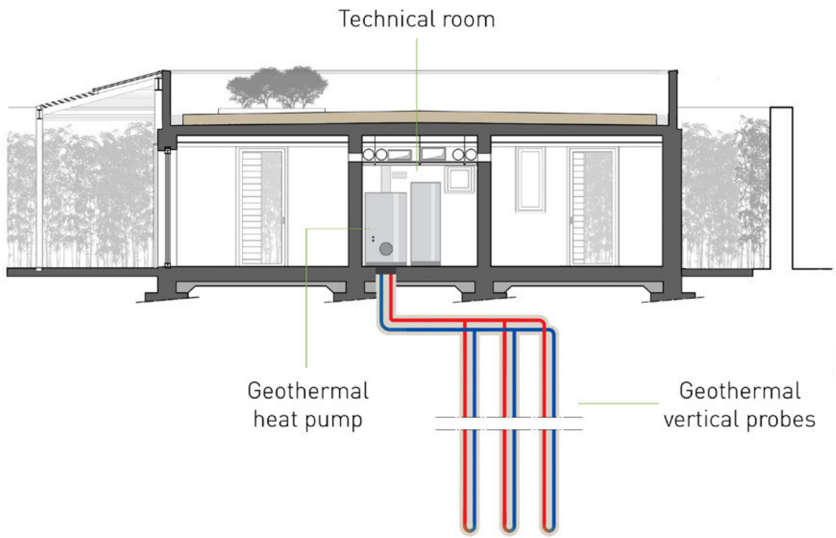


Fig. 6.18 ▶
Schematic section of the geothermal heat pump system.

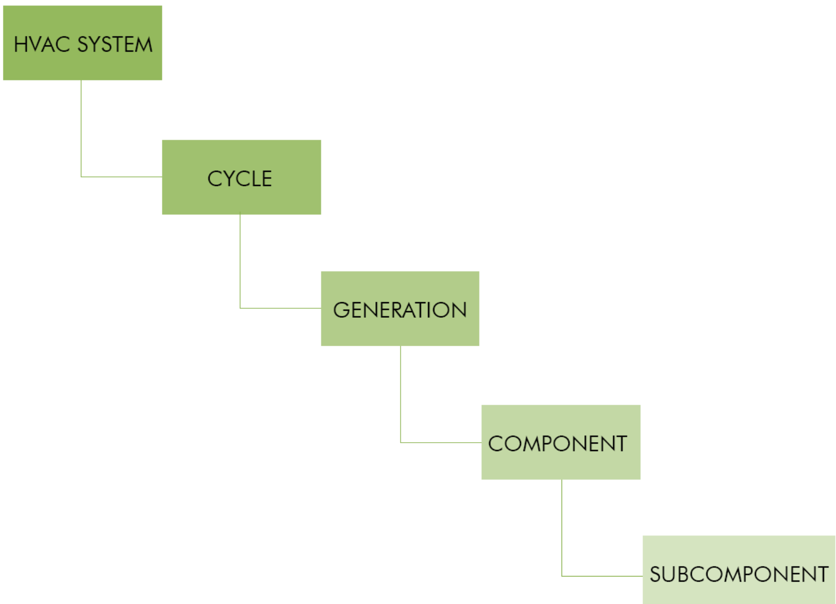
Furthermore, on average, it is required a space up to twice the surface to be air-conditioned, which in this case is missing.
At last, on average, despite having a higher cost, for the vertical probe system the consumption savings compared to, a traditional methane heating system for example, is around 60%; this percentage is even higher compared to diesel or LPG systems. In fact the geothermal pump, in addition to using the heat of the ground, which is a free and unlimited source of energy, has a considerable energy gain: for every kW of electricity consumed, it produces the equivalent of at least 3 kW of energy for the system.
Moreover this type of pump allows both to heat and to cool, since, thanks to the free-cooling mechanism, it can work in reverse cycle in the summer months, to supply water at low temperature to the radiant floor, after passing it through the ground, which has a lower temperature and absorbs part of the energy contained in the water, lowering its temperature.
Finally, a geothermal system does not entail expenses related to its periodic maintenance: it has a very long life compared to traditional heating systems, estimated at around 15-20 years for the heat pump, while for the probes the duration rises to about a century .

For the house, it was used a heat pump which, based on the indications contained in the UNI EN 14511[10] standard, which regulates the air conditioners, the liquid chilling packages and heat pumps sectors, has a useful power of 7.64 kW, a cooling capacity of 6.13 kW and an electrical power consumption of 1.62 kW. Since the pump is connected to the photovoltaic system, electricity consumption becomes very low.
The heat pump, as can be inferred from low power consumption, has a high coefficient of performance (CoP)v, given by the ratio of energy delivered to the heated environment and electricity consumed, equal to 4.71.
The pump then has a maximum delivery temperature of 25 °C, while a minimum delivery temperature of -10 °C.

6.10 UNI EN 14511:2018, Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors

6.6 The energy system configuration inside DesignBuilder

Inside the software DesignBuilder, the "HVAC" tab, which stands for Heating, Ventilation and Air Conditioning, refers to the heating, cooling and air ventilation systems inside the designed building; therefore, in this section all the characteristics of the system regarding generation, distribution and recovery of energy, type of system, etc. can be modelled.
In this modelling part it is necessary to set each feature of the system directly inside DesignBuilder, since the BIM model in .gbXML format, imported from the Revit software, does not consider the elements that make up the energy system, and the related information and parameters, of the building during the import process, even if designed.
Also for energy systems, the software is based on the same type of hierarchical system, already described in chapter 5, used throughout the rest of the modelling. In this sense, starting from this hierarchical order, it is necessary to first set the parameters at the "Building" level, and then move on to each individual thermal zone affected by the system.



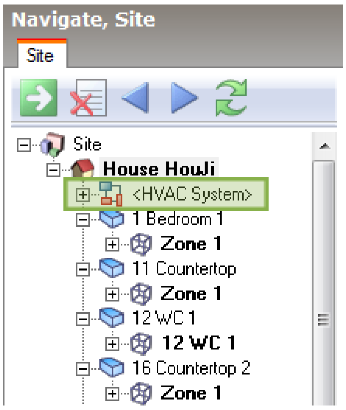
◀ Fig. 6.19
HVAC functioning scheme inside DesignBuilder
Source: Author's elaboration

Generally speaking, the software allows to choose between three different types of energy plants modelling:

• Simple HVAC, where the heating/cooling system is modelled using basic loads calculation algorithms.
• Compact HVAC, where the heating/cooling systems are defined in DesignBuilder using moderately basic HVAC descriptions
• Detailed HVAC, where the HVAC system is modelled in full detail using EnergyPlus air and water-side components linked together on a schematic layout drawing.

Starting from the complexity of the combination of systems, the "Detailed

HVAC" mode was selected for this project. Thanks to it it was possible to adequately detail all the aspects of the plant, starting from the system activation setpoints, to the energy generation systems, such as heat pumps, solar thermal panels, etc.
With this mode it is also possible to establish the thermal zones with active systems, as well as the type of terminal present inside; in the same way it is possible to set the rooms connected to the water system.



▲ Fig. 6.20
Creating the HVAC System entry within the DesignBuilder model.

First of all, to create a new HVAC system, it is necessary to set it to "Detailed" in the Model Option dialogue, in this way it automatically appears a new <HVAC System> node in the Navigator tree list of the model.
It is important to know that HVAC system models in DesignBuilder are assembled by placing a number of pre-defined air and water distribution loops together with groups of zones which are then connected to form complete systems.
Knowing this, the next step is to compose the system, choosing among the above mentioned loops the most appropriate for the analysis, connecting them through pipes or ducts to form distribution systems. It is therefore possible to modify each loop individually or to add any additionally required components and then connect them to associated components in other loops.
These loops carry with them setpoint managers, who tell the systems when to activate; they may be modified or eventually it is possible to add new ones when it is necessary to control more than one element with the same loop, for example in the case of the Air Handling Unit which controls relative humidity and temperature inside the building.
Regarding the rooms, DesignBuilder uses a system that allows great flexibility in the design process: they are arranged in "zone groups", so as to group those with the same systems, or different activation setpoints of the systems for example; from here it is then possible to modify individually the equipment properties of each room.
After placing loops, zone groups and setpoint managers and completing the required loop connections to associated equipment, an EnergyPlus simulation can be conducted for the combined building and HVAC system model[11].

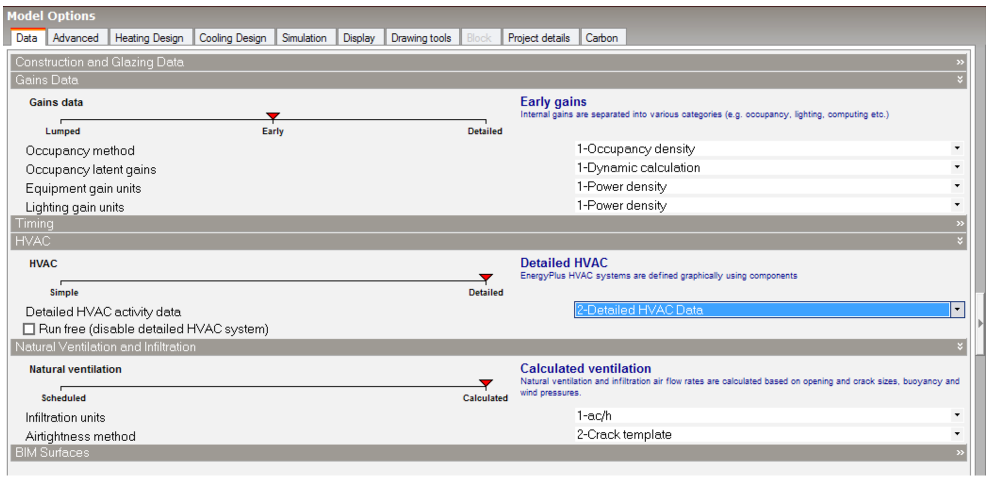


Fig. 6.21 ▶
Setting the HVAC within the software settings before modeling the building's energy systems.

6.11 https://designbuilder.co.uk/helpv3.4/Content/Detailed_HVAC/Detailed_HVAC.htm

From the “Simulation” tab, in the main DesignBuilder window, energy analysis can therefore be carried out, which for this project have been developed out with a dynamic, therefore not stationary or semi-stationary, situation; in this way it was possible to obtain hourly values using specific time intervals, such as specific days, weeks or months.
Moreover, with this type of simulation it is possible to better control parameters related to thermal inertia, ventilation, sun radiation, etc. which can greatly influence thermal balances, especially in nZEB projects such as the one developed in this thesis, in which a building that uses passive strategies combined with modern energy systems was designed.

As mentioned, during energy simulations it is important to decide the period of time in which the building performance is to be simulated and visualized, following the inputs entered so far by modelling.
Within DesignBuilder it is possible to choose the simulation time interval between the following: Annual, Monthly, Daily, Hourly, Sub-hourly.
For this project, in order to give accurate and precise data on the building performance, it was decided to carry out the simulations throughout the year, thus using the “Annual” interval; this allowed to obtain all the data necessary to define the actual energy consumption of the building, with particular reference to the plant system, up to an effective energy consumption per square meter of the house.
At the same time, analysis were carried out for all months of the year as well as in the same periods of passive design studies, with particular reference to summer and winter seasonal analysis, which allowed, during the design process, to make improvements whenever were necessary.
After the completion of the simulation, DesignBuilder generates output data, such as graphs and tables, which can be displayed for the entire building or for each individual zone, so as to identify any critical issues that may arise in the analysis, such as excessive dispersion or consumption for example, identifying at the same time the critical zone and modifying the parameters which negatively affect it.

Fig. 6.22 ▶
Graphic rendering of the hybrid energy system designed within DesignBuilder.

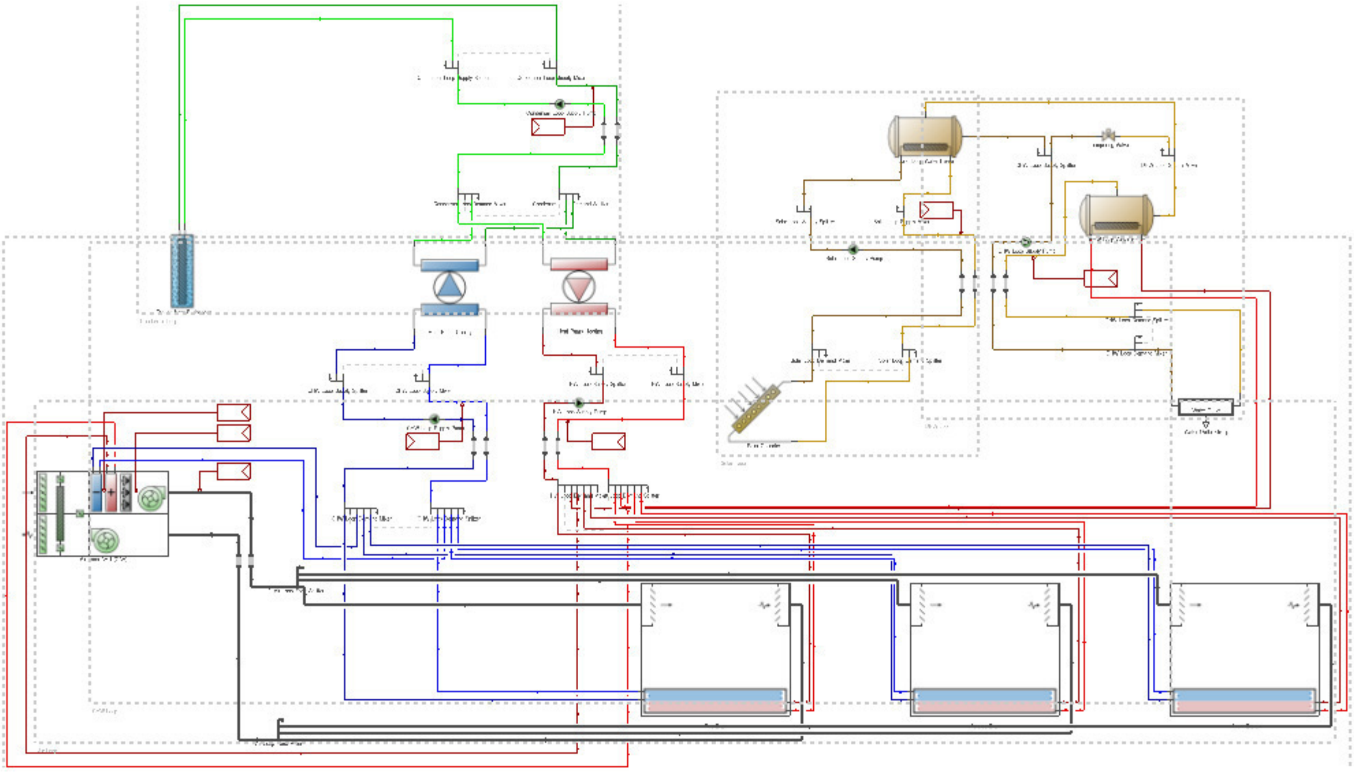
The following system solution was proposed and analysed:

• a hybrid system based on a geothermal heat pump with a radiant floor system, used both for heating and cooling, and a mechanical ventilation system with heat recovery

Solar thermal and photovoltaic panels have been used for, respectively, the domestic hot water production and household's and active system's electricity consumptions.

The choice of the system was influenced by the usage characteristics of the building, suited for a family of four-five people and based on high efficiency components.

6.7 The hybrid system inside DesignBuilder

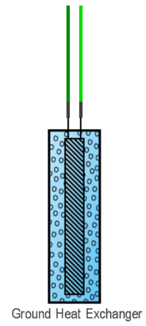


The first design solution involves the use of a geothermal heat pump, with vertical probes, used both for the heating and cooling part (freecooling), combined with a controlled mechanical ventilation system.
As can be seen from the figure above, the image gives an idea of an extreme complexity of the system, but this is not the case: being the system divided into three zones, day-zone, service-zone, night-zone, during its modelling separate connections were needed with the hot water loop and chilled water loop of the heat pump and with the ventilation system. The latter in turn requires a separate connection with the heat pump loops.
Aside, there is the domestic hot water loop combined with that of the solar thermal system.
In the real project instead, the systems are centralized in the technical room, in which the hot water boiler connected to the solar thermal panels, the connections with the photovoltaic system, the ventilation and thermal generation systems are located: hence the coils for radiant floors and air pipes are distributed, and the latter are positioned in the false ceiling of the service zone.
Below the components of the energy system model designed on DesignBuilder are listed.

- **Condenser Loop_Geothermal Heat Pump**

The Geothermal heat pump, called Condenser Loop in DesignBuilder, it was modelled after the analysis carried out on the building without any active

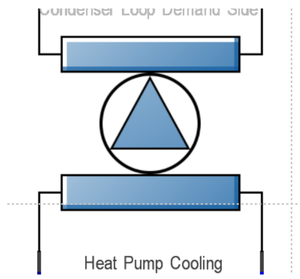
plant; in this way it was possible to obtain the required kW to heat and cool the interior spaces of the house: from the analysis it was required to use a pump that had a power greater than 6.75 kW for the heating part, and about 6 kW for cooling. The favourable element of the heat pump coupled with the heating floor is that the same circuit is used both for heating and cooling, but a reverse cycle, without needing an additional system.
In DesignBuilder the heat pump, called Ground Heat Exchanger, is connected to the two loops for hot and cold water, and refers to them for its activation, both to heat and cool the water, and has splitters and mixers positioned before the actual connection with them.



▲ Fig. 6.23
Ground Heat Exchanger inside the DesignBuilder model.

• CHW (Chilled Water) Loop_Cooling part of the system

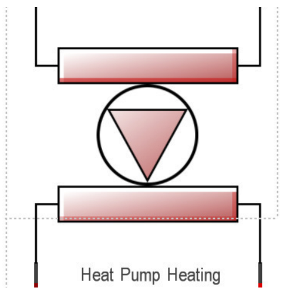
The CHW Loop deals with everything related to the cooling loads. It is divided into two parts, one called CHW Loop Supply Side and the other called CHW Loop Demand Side; the first deals with what the system produces, the second with what is required to cool the rooms; the circuit is connected to the three different zones of the building, and its activation depends on the schedules and the temperature activation setpoints.



▲ Fig. 6.24
Heat Pump Cooling system inside the DesignBuilder model.

• HW (Hot Water) Loop_Heating part of the system

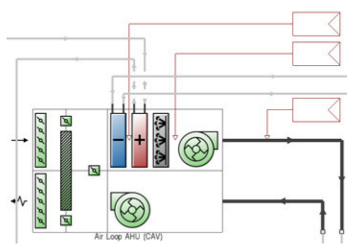
The HW Loop deals with everything related to the heating loads. It is divided, like the CHW Loop, into two parts, one called HW Loop Supply Side and the other called HW Loop Demand Side; the first deals with what the system produces, the second with what is required to heat the rooms; the circuit is connected to the three different zones of the building, and its activation depends on the schedules and the temperature activation setpoints. The loop is also connected to the Domestic Hot Water loop, since the heat pump works in conjunction with the thermal solar panels for the production of hot water.



▲ Fig. 6.25
Heat Pump Heating system inside the DesignBuilder model.

• Air Loop_Controlled Mechanical Ventilation

The Air Loop deals with the ventilation loads and the air quality control within the model. It is divided into two parts, as well as the HW and CHW circuits (this time obviously related to the air), one in and one outgoing. As can be seen from the image on the side, starting from the left, inside the Air Handling Unit there are: the fans for introducing and extracting air from outside towards inside the circuit; the heat recovery system, which takes heat from the outgoing air and reuses it; the Heating Coil and Cooling Coil, which, if the system is active, heat or cool the air whenever the radiant floor is deactivated or the comfort conditions are not met; the Steam Humidifier, which deals with the humidification or dehumidification of the internal air; the Supply Fan and Extract Fan, which are the fans for supplying and extracting air inside the zones.
The system works according to the activation schedules of the ventilation system, which is set to have the same schedules as the ones set for the


▲ Fig. 6.26
Controlled Mechanical Ventilation system inside the DesignBuilder model.

occupation of the three zones. At the same time setpoints have been set to indicate to the humidifier when to activate: they have been in order to keep humidity level between 40% and 60%, with a tolerance of +/- 5%, when the rooms are occupied.

• Zone Groups_Air conditioned zones

In the model, as mentioned, three different zones have been created, one referring to the day zone, one to the night zone and one to the service zone, so as to have a system that works in a functional manner with different set points depending on the function of the rooms. As can be seen from the image below, each air-conditioned room has a radiant floor, connected to the HW and CHW circuits, and the air extraction and intake fans, connected to the air handling unit.

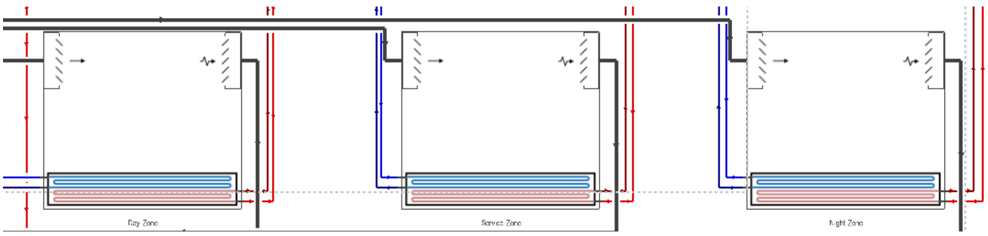


Fig. 6.27 ▶
The three different thermal zones inside the DesignBuilder model.

• DHW Loop_Domestic Hot Water loop connected to the Solar Loop of thermal solar panels

The part of the DHW Loop system takes care of covering the home's hot water needs and works according to the schedules set for the request of hot water by the tenants. The system is connected to the heat pump and to the circuit of the thermal solar panels that are the part of the system that helps to cover the need for water heating. The system automatically creates the water storage inside the software during the calculations, based on the demand for water, in order to store the hot water produced. The terminal of the system is the Water Outlet, in which the rooms served by the water loop are selected, which here are the two bathrooms and the kitchen.

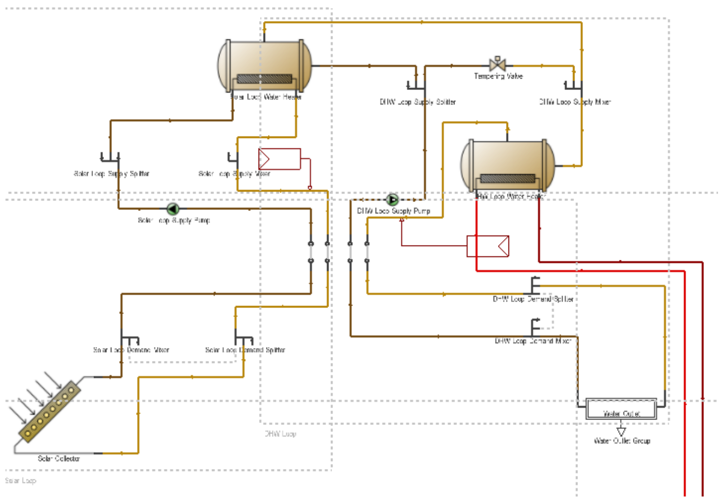


Fig. 6.28 ▶
The Solar Thermal panel and DHW circuits inside the DesignBuilder model.

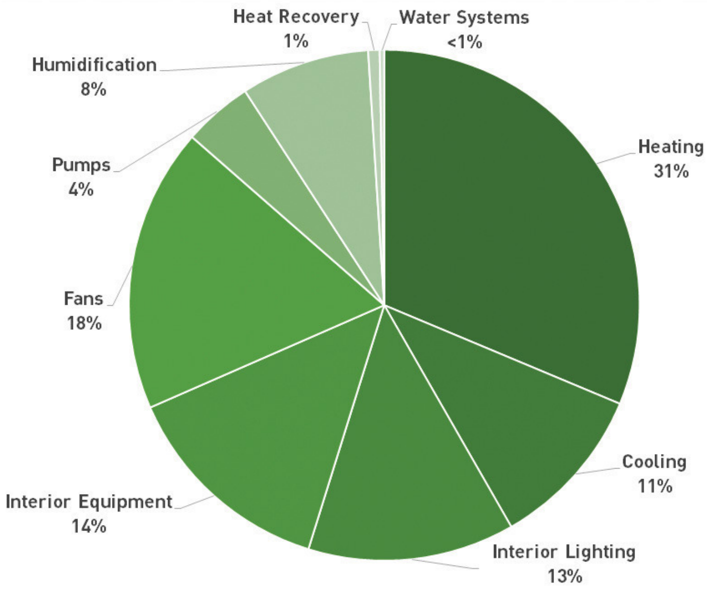
6.8 Energy analysis with hybrid compact system

At this point in the analysis work, which led to the achievement of satisfactory results, the data relating to general loads are shown; in fact, during the project process ample space was dedicated to passive strategies, which, comparing different solutions, were the basis for the choices made for active systems. In this section therefore the quality of the solutions using the data returned in terms of kWh, i.e. of energy consumed, are evaluated.
Unlike what was explained in the passive strategies, here are not shown graphs referring to indoor temperatures and relative internal humidity, since the systems work based on setpoints and schedules set in the modelling phase: working in this way, they only need to "work" relying on them, so they cannot be evaluated as correct or incorrect design choices. They do not constitute a fundamental criterion for the evaluation, differently from actual consumption values, which instead allow to evaluate the quality of the project. In this sense, the most important information for energy analysis is the m^2 energy consumption and the difference between heating and cooling loads.

Fig. 6.29 ▶
Annual loads of the private house

As explained in section 6.3, by accessing the "Simulation" tab of DesignBuilder it was possible to carry out the energy analysis in a dynamic regime, chosen in order to obtain hourly values using specific time intervals, such as specific days, weeks or months, for the private house.
This analysis refers to the use of the hybrid compact system, which as mentioned involves the use of a geothermal heat pump combined with the radiant floor for heating and cooling and the Controlled Mechanical Ventilation for air control; at the same time there are photovoltaic and solar thermal systems (and the heat pump itself) for the amount of renewable energy produced on site.
Regarding lighting and equipment consumption, more than on the environmental conditions, they are based on the actual consumption of tenants: being the one explained here a consumption forecast and therefore not an analysis of an existing building, these types of consumptions refer to the created schedules, that were detailed in section 5.6.
Regarding the renewable sources, a photovoltaic system of 4.55 kW, consisting of 14 panels and a solar thermal system, consisting in two solar thermal panels were installed; at the same time the geothermal heat pump, that uses the energy of the ground for its thermal exchanges, it is considered as renewable source.

First of all it is necessary to report the values related to the total building consumption derived from the analysis on an annual scale, so as to understand the actual loads of the building, both for heating and cooling, but also for the ventilation system and lighting and electrical equipment.
The analysis showed the achievement of an excellent level in terms of building performance, with the achievement of values in line with those of the nZEB buildings.

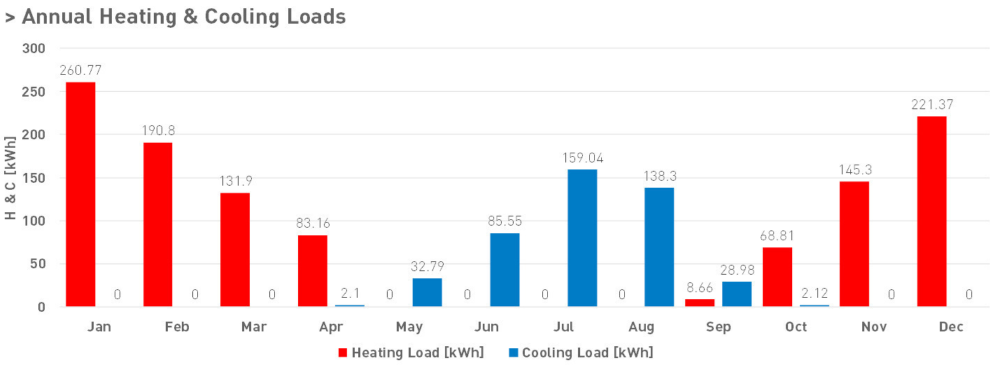


	kWh
Heating	1100.77
Cooling	448.88
Lighting	458.59
Interior Equipment	493.44
Fans	724.1
Pumps	173.03
Humidification	278.9
Heat Recovery	27.5
Water Systems	10.96
Total End Uses	3716.17

The values obtained show a "Total Site Energy" (or Total End Uses) of 3716.17 kWh; this is the value without the contribution of photovoltaic panels. Inside the Total Site Energy the main energy consumptions values for all the building are contained, and are referred to: Cooling, i.e. the cooling load for the summer period, Heating, i.e. the load for heating in the winter period, Fans, i.e. the energy consumption of the ventilation system, Pumps, the energy consumption of the geothermal heat pump, Humidification, the energy consumption to control the relative humidity rate in the building, Heat Recovery, the energy consumption of the Heat Recovery Ventilator; and to the energy consumption related to the habits of the tenants (set with schedules), that are Lighting, the energy consumption for artificial light, Interior Equipment and Water Systems, i.e. the energy consumption for the domestic hot water deducting the energy produced by the solar thermal panels.
The Total Site Energy value means an "Energy per total building area" of 18.52 kWh/m^{2}year i.e. EPI = 18.52 kWh/m^{2}year; with the amount of energy produced by the photovoltaic panels, it is reached a "Net Site Energy" of 2636.32 kWh, which means an "Energy per total building area" of 13.18 kWh/m^{2}year.
The aforementioned values refer to the entire surface of the building, thus also counting the non-air-conditioned rooms and the countertops in the service zone for a total surface of 200.07 m^2. It is therefore necessary to outline the actual consumption related to the "Energy per conditioned building area", thus not taking into account the technical room, the deposit and the countertops of the service zone, with a total surface of 146.73 m^2: the values obtained show a EPI = 25.25 kWh/m^{2}year[12]; with the amount of energy produced by the photovoltaic panels, it is reached a EPI = 17.97 kWh/m^{2}year.

	kWh/m^{2}year
EPI Net building area	25.25
EPI with PV contribution	17.97

6.12 EPI, Energy Performance Index, is a parameter that expresses the total demand of primary energy for winter and summer air conditioning, domestic hot water production, ventilation, equipment and lighting referred to the useful surface area.



◀ Fig. 6.30
Heating and Cooling loads along the year derived from the annual simulation.

At the same time it's necessary to outline the monthly loads for heating cooling and humidification; in this way it was possible to analyse their trend and see if they were compatible with the design intentions.
From the graphs it can be inferred an good functioning of the system, with an alternation of heating and cooling loads, without abnormal turning on of the components. Starting from the total value of heating load, that is 1100.77 kWh, it can be seen that the heating peak is reached during the month of January, that is the coldest month, with a value of 260.77 kWh, while the lowest peak is registered in September, with 8.66 kWh, where it can be seen the presence of both cooling and heating loads, since September has relatively warm days and cold nights. Heating loads are not registered from May to August.
The total cooling load is 448.88 kWh and the peak is reached during the month of July, that is the hottest one, with 159.04 kWh, while the lowest values are registered in April, with 2.1 kWh and October, with 2.12 kWh. No cooling loads are present from November to March.

It is also possible to provide the heating and cooling consumption values weighed on the m^2 of the building, so as to check the weight difference of the respective loads, dividing the first two by the latter. Knowing the m^2 of the all house, counting the unconditioned spaces, that are 200.7, and the annual loads of cooling, 448.88 kWh, and heating, 1100.77 kWh, 2.24 kWh/m^{2}year for the Cooling Load and 5.48 kWh/m^{2}year for the Heating Load are obtained.
Analysing instead the consumption per m^2 of the conditioned surface, which for the house is 146.73 m^2, the following values are obtained:

	kWh/m^{2}year
Cooling Load conditioned building area	3.33
Heating Load conditioned building area	7.50

In both cases the obtained data are good, being quite low, especially regarding the heating loads, that despite the building is located in a cold semi arid zone, with a prevalence of cold climate, they are in line with those of the nZEB buildings.

For the humidification and de-humidification loads, it can be noted that low monthly values are registered during the hottest months and constant operation throughout almost the rest of the year; the peak is reached during

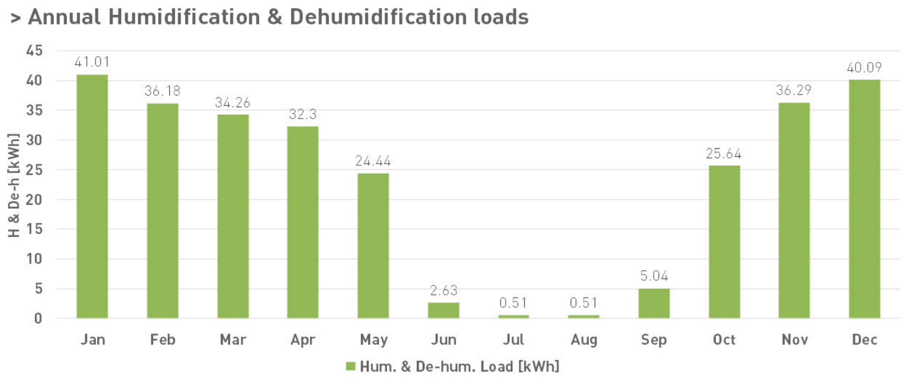
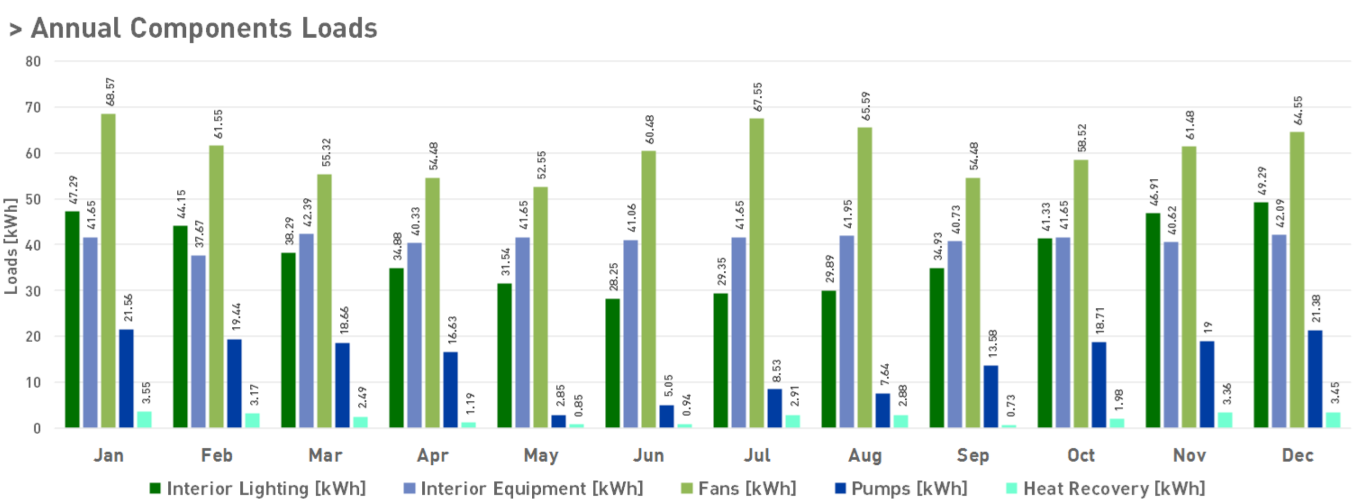


Fig. 6.31 ▶
Humidification and de-humidification loads along the year derived from the annual simulation.

January, with an energy consumption of 41.01 kWh, but it can be noted that from November to April values over 30 kWh are recorded.
The lowest data are instead recorded during the hottest months, from June to September, with July and August that have the lowest loads, respectively 0.51 and 0.5 kWh.
Clearly it can be said that colder is the local climate, more humidification is required: this is directly connected with the natural ventilation rate and the air-tightness of the building. The natural ventilation in fact, helps to keep the interior spaces within acceptable relative humidity rates but it is logically expected to be "active" only during the months from May to September, when the external temperatures allow it; it is not available from October to April when outdoor temperatures become prohibitive and do not allow the building to be ventilated naturally. To this, it is added the high air tightness of the building, which allows to have few leaks in order to prevent heat losses: for this reasons the mechanical ventilation system, keeping under control the indoor air quality, has these consumptions.

On the other hand,the energy consumptions complementary to that relating to cooling, heating and the relative humidity control were also analysed on an annual scale, in order to assess the weight of each for each month of the year. The data refers to: interior lighting, interior equipment (i.e. computer, television, etc.), fans (i.e. mechanical ventilation), pumps (related to the geothermal heat pump), heat recovery.
Concerning the interior lighting, consumptions are directly linked to the set schedules, and for the most used environments, on the target illuminance of 250 lux as mentioned in section 5.6.5. They therefore vary according to the natural light present in the different periods of the year: in the coldest months when solar radiation is present for less hours a day, it is necessary to use more artificial light; the reverse happens in the warmer months when there is a higher presence of natural light. At the same time, a lighting system was used which involves the use of high energy efficiency light bulbs as envisaged for the construction of new nZEB buildings, with a power density of 5 W/m^2.
It can be seen that the greatest consumption occurs from November to February, with the highest peak in December with 47.29 kWh; the lowest consumption instead occurs from June to July, with the lowest peak in July with 28.25 kWh.
For the interior equipment, which refers to all internal electrical equipment



▲ Fig. 6.32
Components loads along the year derived from the annual simulation.

except energy systems and artificial light, its consumption is based on the data set for each schedule and zone, as mentioned in section 5.6. Thus consumption tends to be constant throughout the year, with values around 41 kWh; the small variations in consumption, being connected to the building occupancy schedules, depend on how many weekend and weekdays there are in a month; in fact in the schedules they are differentiated as quantity of occupation hours; February, having less days has the lowest consumption, 37.67 kWh.

Regarding the fans, which refer to the energy consumption of the ventilation system, they present values that varies during the year: the operating peaks in fact occur during the hottest months, from June to August, and in the coldest months, from December to February. This is because the system comes into operation more often when a greater heating and cooling load is required to maintain comfort conditions during occupied hours. The peak consumption therefore occurs in the months of January, with 68.57 kWh, and July with 67.55 kWh.

Talking about the pump consumption, which refers to the geothermal heat pump, it can be seen that its profile is similar to that of the fans; this because it works with the same principle, i.e. more the external conditions are far from comfort temperatures higher is the consumption of the system. In this case, unlike the ventilation system, the values of the hottest and coldest months are different: this because during the winter, despite the passive strategies that allow to maintain the comfort conditions in day-zone and service-zones with low energy consumption, the radiant floor requires a greater heating load in order to maintain the comfort conditions in rooms that are not very sunny as in the night zone. During the summer, on the other hand, thanks to the contribution of ventilation and passive strategies, as the adequate shading of the building, minor kWh are needed to cool the interior spaces.

The highest consumption is recorded in July, with 8.53 kWh, and January with 21.56 kWh.

At last, regarding the heat recovery system energy consumption, being located in the controlled mechanical ventilation with the objective of recovering part of the energy used in the air intake and extraction processes, it is active when the ventilation system is also active. ; in this way its consumption over the course of the year is proportionate to those of the fans, having also the same profile: the highest peak in the cold season is reached in January with 3.55 kWh while in the hot season in July with 2.91 kWh.

It was therefore decided to analyse the data obtained for specific rooms of the house considered more critical, and not for the entire building, as in this way it was easier to understand its performance and understand if there were some criticalities. Two specific rooms have been chosen, having the same surface, A = 23 m^2, allowing in this way to make an adequate comparison:

• the living room,which is the one that has the best conditions in terms of exposure, being exposed to the south, but presenting the worst summer conditions, resulting in higher cooling loads.

• the parents bedroom, which is the one that has the worst exposure, being exposed to the north and therefore in winter requires greater heating loads.

Regarding the Living Room, it can be seen how the passive strategies have allowed to have a low amount of heating, with even November in which there is no heating load; on the contrary, in summer, due to the high external temperatures, quite high values can be reached in July and August, respectively 31.72 kWh and 32.39 kWh.

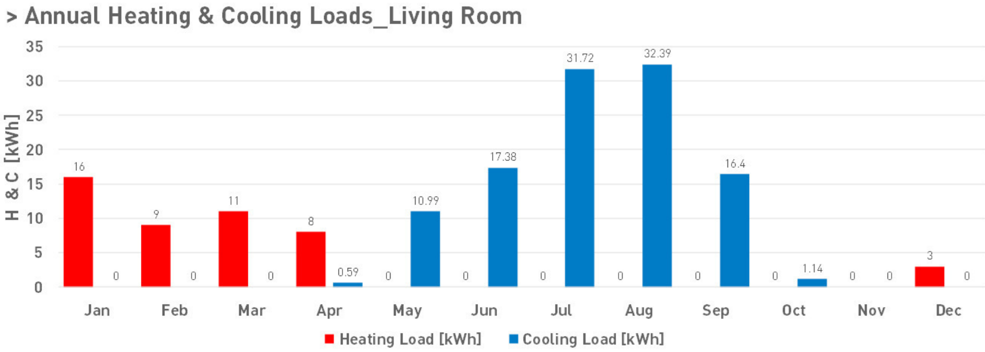


Fig. 6.33 ▶
Heating and Cooling loads along the year derived from the annual simulation for the Living Room.

For the Parents Bedroom, on the other hand, it can be noted the reversal of consumptions compared to the living room: the cooling loads decrease by at least 40%, with peaks of 80% in May; the heating loads instead increase, due to the low solar contributions of the cold season, doubling in the months from January to April, and increasing exponentially in the months from October to December. The peak is registered in January, with 25.7 kWh.

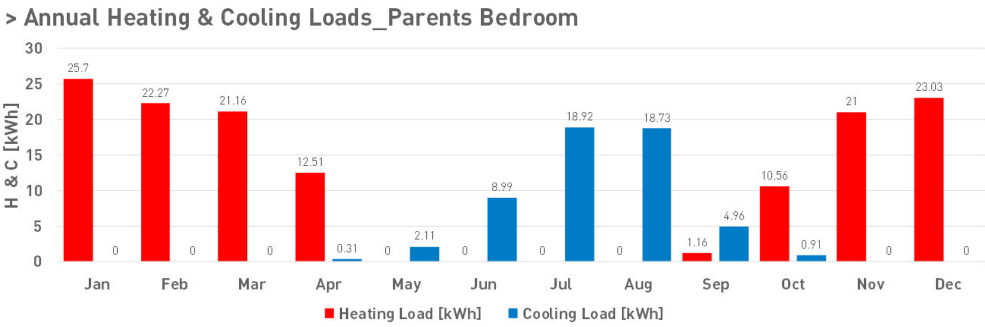
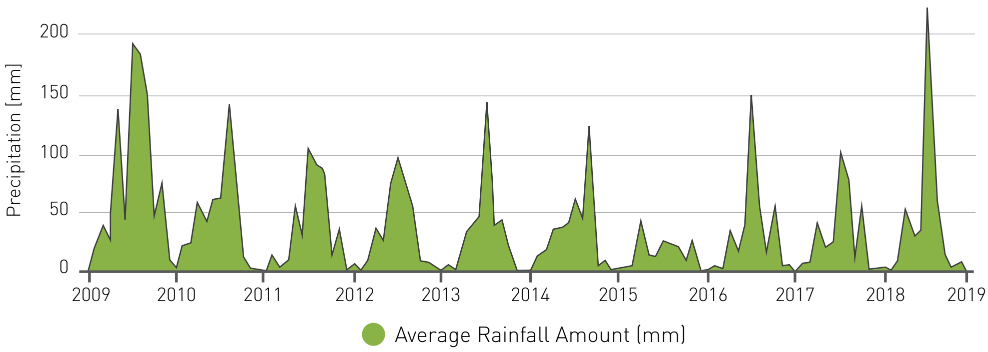


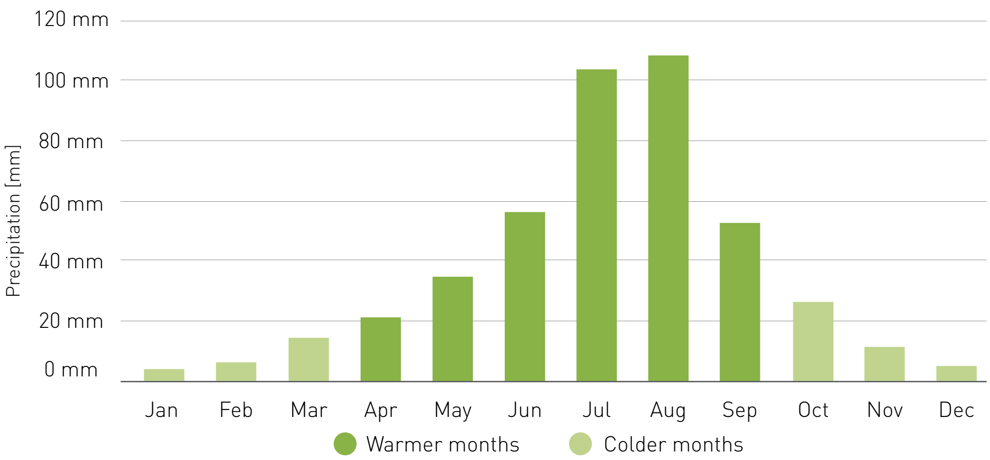
Fig. 6.34 ▶
Heating and Cooling loads along the year derived from the annual simulation for the Parents Bedroom.

6.9 Water harvesting

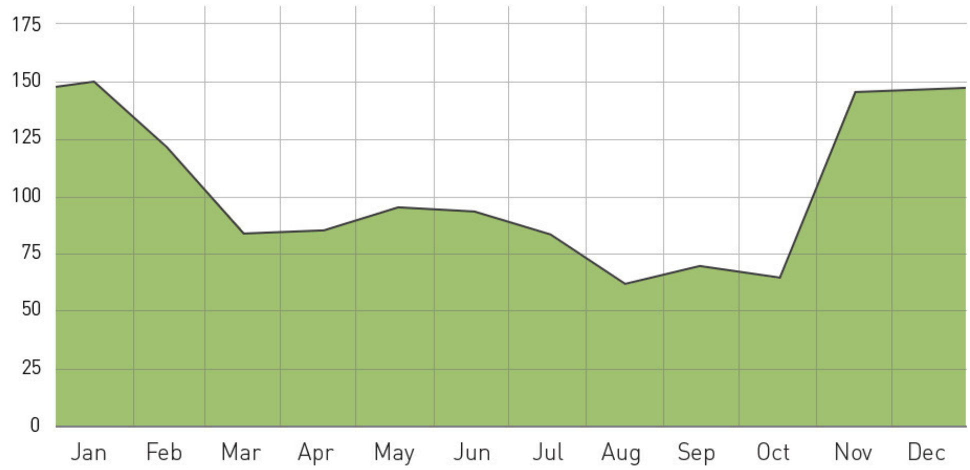


◀ Fig. 6.35
Pingyao's average wind speed.
Source: Climate consultant+Author's elaboration

From the beginning, within the project it was suggested to insert a rainwater collection system, an element that however required some analysis that could confirm or reject this choice.
First of all it was necessary to analyse, thanks to the climate analysis detailed at the beginning of the chapter, the amount of precipitation that affects the area, which is a fundamental element for calculating the actual amount of water that could be collected. In the same way it was important to know the precipitation trend over the last few years to understand if it was constant or if there had been a decrease or an increase in the overall amount.
As can be seen from the graph, which shows the average precipitation of the city of Pingyao in the last ten years, from 2009 to 2019, except for the year 2015, in which there was a strong shortage of precipitation, with peaks not exceeding 40 mm in the wettest months, the trend remained fairly constant: this does not mean that the values were the same, but that there has been a continuous turnover between hot and cold seasons with rain peaks always equal to or greater than 100 mm in the hottest months and little rainfall in the cold months. In fact, where values tend to zero, these are the colder months (October-March) while as they increase the closer it gets to August, which is the wettest month.
In general, the average amount of annual precipitation in Pingyao area is about 435.0 mm, which is an important data to know in order to calculate the possible amount of water that can be harvest.
From the graph above it is possible to deduce the air quality of the city of



◀ Fig. 6.36
Average precipitation in Pingyao.
Author's elaboration



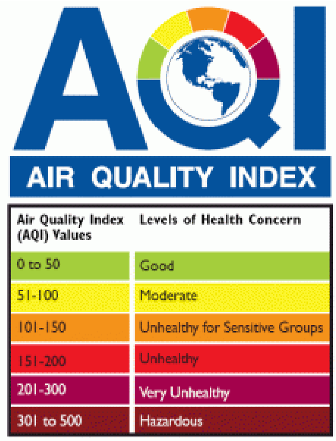
AQI Peak	151	120	85	86	96	94	84	62	70	65	147	147

where

Good: 0 - 50	Moderate: 51-100	Unhealthy for sensitive groups: 101-150
Unhealthy: 151-200	Very unhealthy: 201-300	Hazardous: 301-500

Fig. 6.37 ▶
Air Quality Index Peak of Pingyao along the year .
Author's elaboration

Pingyao, over a year, obtained thanks to control units installed in the town used to detect the presence of pollutants.
The graph is based on the typical division of AQI, acronym of Air Quality Index, which is an index used by government agencies to monitor the level of air pollution, associating it to the effects it could have on population health. In this sense, the AQI refers in particular to the effects that can be experienced following an exposure for periods of time from a few hours to a few days. Generally the threshold to be taken as a reference is 100, which corresponds to the national air quality standard for the pollutant set by EPA[13], Environmental Protection Agency, in order to protect public health.
Regarding the project area, the positive factor is that the highest pollution rates recorded in Pingyao, while remaining within acceptable parameters for human health and water collection, are recorded during the coldest months, which are also the least rainy; not to mention that HouJi is located about 5 kilometers from the city, so pollution rates are probably lower.
In fact the rainy season in this area goes from May to September, with the hottest months, July and August, which are also the wettest: August reaches an average of 100-120 mm of rain. The cold months are, as mentioned, the driest, reaching almost 0 mm during January, which is also the coldest month. Therefore a water harvesting project can be carried out, since rain would be affected to a small extent by air pollution, and indeed, with the use of simple filters, it can be used to irrigate the gardens of courts and green roofs. The objective therefore is to collect as much rain water as possible during the rainy months, from April to September, and store it in special underground tanks in the courts, so that it can be used for irrigation as long as possible over the year, without taking it from the public circuit.



Air Quality Index (AQI) Values	Levels of Health Concern
0 to 50	Good
51-100	Moderate
101-150	Unhealthy for Sensitive Groups
151-200	Unhealthy
201-300	Very Unhealthy
301 to 500	Hazardous

▲ Fig. 6.38
Official table of Air Quality Index values related to health concern.

For the calculation of the quantity of meteoric water that can be collected

6.13 The Environmental Protection Agency, EPA, is an agency of the government of the United States of America, in charge of environmental and human health protection, pursued through the application of the laws approved by the congress of the United States of America.

in at the project site, it was taken as a reference the UNI/TS 11445:2012[14] standard, which refers to plants for the collection and use of rainwater for various domestic uses from human consumption. In this sense, the goal of this part of the project is to use the water collected solely for the irrigation of the vegetable compartment of roof and internal courtyards, since in this case the water doesn't need special treatments to be purified at the microbial level, unlike that for human consumption.
In fact it is useless as well as not economically and environmentally convenient, to use potable water for uses for which it is not necessary, and it is possible, instead, to use water with lower quality. In fact, rainwater being sweet and chloride-free, it is particularly suitable for irrigation.

It was therefore planned to build a collection plant for each of the three buildings, so as to make them independent of each other.
Therefore, the sizing of the storage system requires knowledge of the following aspects:

• the rainfall trend
• the dimensions and characteristics of the collection surfaces
• the characteristics of current and future water demands

The collection volume, according to the UNI/TS 11445: 2012 standard, can be sized using two calculation methods: a simplified and an analytical one. In the following analysis, the simplified procedure was adopted, which is limited to the following application conditions:

• the demand for rainwater for domestic use, different from human consumption, must be characterized by almost uniform consumption during the year
• the prevailing typology of the collection surfaces must be the coverage
• the storage system must be closed and / or covered, so as to avoid significant losses of water through evaporation

First of all, following the indications of the legislation, it is necessary to choose the inflow coefficients φ, which represent the ratio between the total volume flowed in the closing section of the collecting surface, and the total volume of rainfall fallen on the same surface (flowed volume). This makes it possible to determine the meteoric influx in relation to precipitation.

Type of coverage	Inflow coefficient φ
Waterproof pitched roof (>3%)	0.8
Waterproof flat roof	0.7
Permeable roof (Green roof)	0.5
Waterproof ground pavement	0.7

◀ Tab. 6.1.1
Inflow coefficient values for different types of collecting surfaces.
UNI/TS 11445:2012

6.14 UNI/TS 11445:2012 Systems for the collection and use of rainwater for uses other than human consumption - Design, installation and maintenance

The following values have been chosen:

- Permeable green roof 0.5, relating the surface of the green roof
- Waterproof ground pavement 0.7, relating the exterior floor of the building

Therefore it was necessary to calculate the annual meteoric inflow Q, which again according to the UNI/TS 11445 standard, is calculated as:

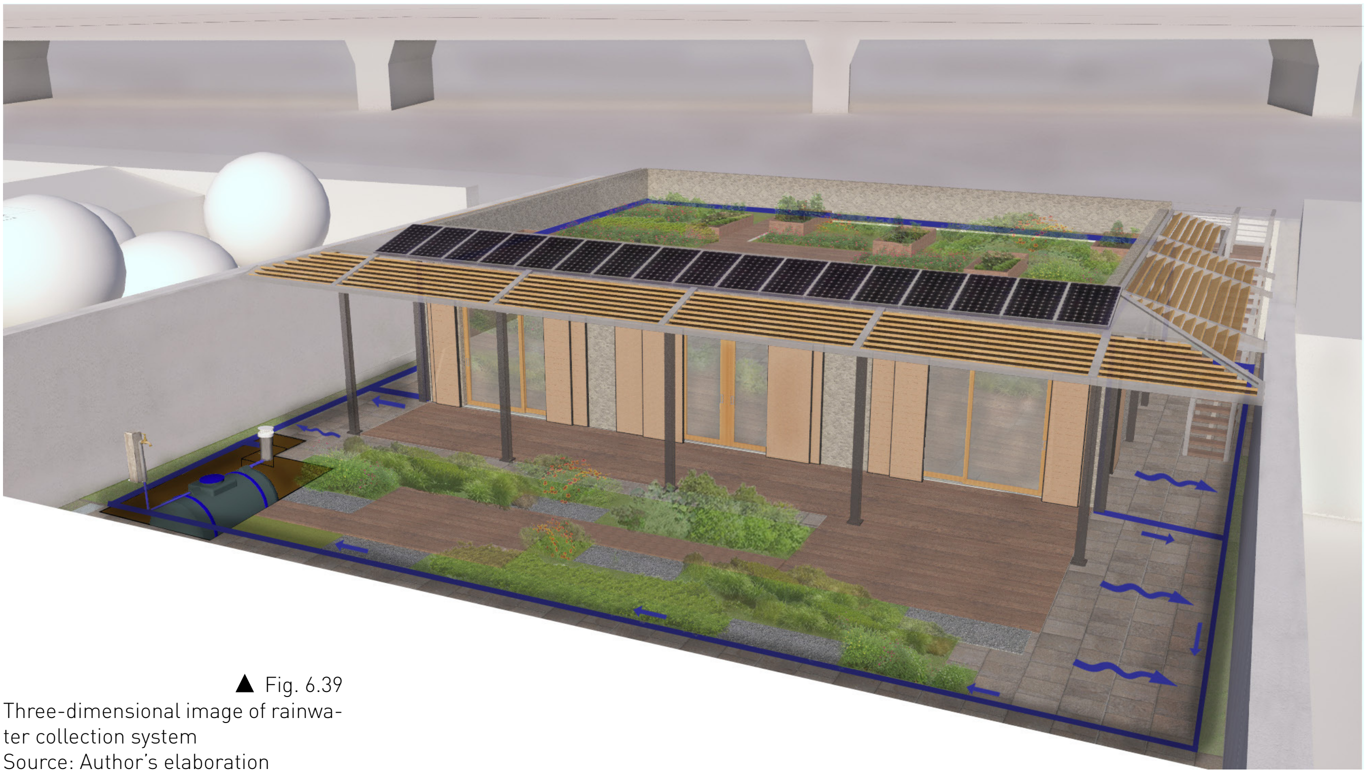
$Q = \varphi \times P \times A$ [L]

where:
Q annual meteoric inflow [L]
φ inflow coefficient [$\leqslant 1.00$]
P annual rainfall [mm or L /m^2]
A horizontal projection of the collection surface [m^2]

Analysing the private house, knowing the inflow coefficient, 0.5 for green roof and 0.7 for pavement, the annual rainfall, which is 435 mm and the collection surface, that is 153 m^2 for the green roof and 140 m^2 for the pavement, Q was calculated:

$Q = [(0.5 \times 153) + (0.7 \times 140)] \times 435 = 75907$ L

Then from UNI/TS 11445:2012, it is possible to derive the future water demand for domestic use other than human consumption, in this case for irrigation, R. According to the regulation, for the irrigation of 1 m^2 of green area 300 L/



▲ Fig. 6.39
Three-dimensional image of rainwater collection system
Source: Author's elaboration

m^2 per year are required; therefore, for the analysed building, it is estimated a consumption equal to:

$R = m^2 \times 300$ [L]

$R = 189 \times 300 = 56700$ L

Therefore, according to UNI/TS 11445:2012, the useful volume of the storage system of the future tank was calculated, taking into account the minimum value between Q and R, multiplying it by a percentage factor:

V_u = [minimum value between Q and R] x F_p [L]

F_p is a dimensionless factor, equal to the ratio between the maximum annual period of consecutive days with no precipitation, in this case 29, and the days of the year:

$F_p = 25/365 = 0.068$

$V_u = 56700 \times 0.068 = 3856$ L

Lastly, the legislation states that in order to obtain the optimum volume of the storage system, which maximizes the performance of the collection and use of rainwater, the useful volume must be corrected by a safety coefficient, which allows to obtain a good system efficiency even in the presence of significant changes in local pluviometry (dry periods) and water use methods:

$V_o = V_u \times C_s$

C_s is the safety coefficient (dimensionless) equal to 1,50

$V_o = 3856 \times 1.5 = 5784$ L

6.10 Photovoltaic and solar thermal systems

Within the project, the installation of photovoltaic and solar panels was planned in order to cover part of the electricity consumption and energy demand for the production of domestic hot water.
Initially their installation was planned to be on the flat surface of the roof thanks to a combined system of panels and green roof; this at first was convincing, since when the two components are combined together, that can enhance their functions and effectiveness by cooling and shading effects: the evapotranspiration of green roof plants enables a higher efficiency of the panels since they work with a lower temperature, and at the same time, the panels shade the plants from excessive sun exposure and evaporation thus improving their growth.
However, the installation of panels on the roof brought with it some practical problems. In fact, positioning the panels on the roof in a correct manner to avoid shadowing between each row would have meant covering a large part of the roof, and this, given the fairly limited dimensions of about 150 m^2, was not convenient for the green roof realization. In this sense, as mentioned at the beginning of the section, while helping the vegetation by shading, the panels would not have allowed the construction of a green roof as it had been thought since the beginning of the project: a space that could be used to cultivate medium-sized plants in combination with spaces for the tenants.
A hybrid panel-green roof solution was convenient if an extensive green roof had been built, which involves the use of plant species that have limited development and low cultural needs.
Consequently it was decided to position the panels where the greatest convenience between ease of installation and performance was found, namely on the south-exposed part of the external shading system.
In this way, in addition to use a clearly unused space, the panels, other than help to block the sunrays during the months with the greatest solar radiation, have an excellent sun exposure, as the building faces south, with a rotation of 11 degrees compared to the N-S axis.

• Solar thermal

In order to size the solar thermal system, firstly the square meters of the building were not taken into account, but rather the number of tenants occupying it and their foreseeable consumption of water.
Analysing the private house, in residential buildings the heat requirement for hot water production remains constant during the year, and usually the daily per capita consumption of hot water at 45 ° C is estimated around these values:
- Low comfort 30 l/(person/day)
- Medium comfort 50 l/(person/day)
- High Comfort 80 l/(person/day)

Therefore a family of four people, as it was designed for the private house,

needs, in order to have an average comfort, about 50 liters for each person, that is 200 l/day of hot water.
At the same time the hot water produced by a solar collector of 2 m^2 is on average equal to 80 -130 liters/day, therefore for a first sizing of the system for the purpose of supplying only sanitary water, it can be considered a collector surface of 1 m^2 per person.
Therefore, to cover the domestic hot water requirement of a family of four people, it was necessary to install a system of at least 4 m^2, which is equivalent to installing two solar panels, since their average size is one meter in width and two meters in height.
Regarding the regulatory reference, D.G.R. n. 46-11968 of 4/08/2009[15] modified by D.G.R. 29-3386 of 05/30/2016 was taken as a reference, since, even though it is a local Italian law and not a Chinese one, it prefigured well a new construction intervention. It provides for new buildings to be equipped with a solar thermal system designed to meet 60% of the annual primary energy requirement for the production of domestic hot water.
With the help of the software, it was possible to obtain that 2 thermal solar panels were needed to satisfy 60% of the sanitary hot water needs. The panels used have an area of 2.31 m^2 each, a heat dispersion coefficient k1 of 4,421 W/(m^2K) and a heat dispersion coefficient k2 of 0,020 W/(m^2K^2).
They, as mentioned, were installed on the external shielding system which has an inclination of 15 ° and are rotated 11 ° with respect to the North-South axis.

• Photovoltaic system

The photovoltaic system has as its primary objective that of reducing as much as possible the building electricity needs.
Given the size of the south-facing side of the external shading system and the presence of at least two thermal solar panels, as detailed in previous paragraph, the space available for the photovoltaic installation was definite; in this sense, the available net coverage side is 16 meters long.
Assuming that the chosen photovoltaic panels have a width of 1 meter and at the same time a minimum space of a few centimeters is needed between one and the other, and that the solar thermal panels are expected to be two and also have a width of 1 meter, a maximum of 14 photovoltaic panels can be installed.
As a regulatory reference, the Italian legislation was initially considered, which according to the law gives a minimum amount to install, obtainable from the Legislative Decree 28-2011[16] updated by the Legislative Decree 244-

6.15 Deliberation of the Regional Council 4 August 2009, n. 46-11968 Update of the regional plan for the rehabilitation and protection of air quality - Excerpt of the plan for environmental heating and air conditioning and implementing provisions on the energy performance of buildings pursuant to Article 21, paragraph 1, letters a) b) and q) of the regional law of 28 May 2007, n. 13 "Provisions on energy performance in buildings".

6.16 Legislative Decree 3 March 2011, n. 28 Implementation of Directive 2009/28 / EC on the promotion of the use of energy from renewable sources, amending and subsequently repealing the directives 2001/77 / CE and 2003/30 / CE.

2016. In Paragraph 3 it specifies the minimum electrical power to be installed for plants powered by renewable sources, using the formula:

$P = (1/K) \times S$ [kWp]

where:
P= peak power to be installed [kWp]
K= coefficient equal to 50 m^2/kW
S= surface of the building [m^2]

$P = (1/50) \times 155 = 3.1$ kWp

Thanks to this formula it was possible to obtain the minimum peak power to install equal to 3.1 kWp.
The panels used are composed of mono-crystalline cells, having a power of 325 Wp each, and an area of 1.63 m^2 (1,046 m x 1,559 m).
The minimum peak power was therefore reached through the installation of 9 panels; given the availability of space it was decided to install 5 more, for a total of 14. The result was a total peak power of 4.55 kWp with a yield of 20%, with an inverter efficiency of 90%. The panels, as mentioned, were installed on the external shading system which has an inclination of 15° and is rotated of 11 degrees compared to the N-S axis.

During the energy simulations made using the DesignBuilder software, it was possible to obtain a quite accurate result, since it allows to realize annual simulations that take into account the exact environmental conditions and external factors that can influence the yield of the panels, such as the presence of vegetation etc., as well as the physical position of the panels in the designed building.
With DesignBuilder an annual amount of produced energy equal to 1078.89 kWh was obtained. Starting from the value of the total building electricity consumption, that was 3716.17 kWh, it allowed to cover about 28% of the total electricity consumption of the building. This value represents the amount of electrical energy produced by subtracting the losses due to the power conversion and the system losses that can occur on site.

CONCLUSIONS

China's rapid economic growth and the massive urbanization brought by that, resulted in different consequences for rural areas and villages, which have taken on a secondary role in economic and social scenario, while the distribution of wealth and resources became definitely unbalanced. Despite this situation has improved the living conditions of a large part of the population, at the same time it is contributing to the loss of the millenary Chinese identity identified by social, cultural and architectural traditions of the villages, due to internal migration and lack of maintaining of the heritage; and this phenomenon does not seem to stop, with cities that continue to attract more and more people, tending to centralize most of the Chinese economy on them, while the villages could not keep up with the economic progress: by 2035 the estimates predict that 71% of the Chinese population will live in urban areas, while only in 1980 this percentage stood at 19%.
It is therefore necessary, as emerged at the end of the project carried out in this thesis, how it is of fundamental to increase the interest for the conservation and protection of Chinese villages and rural areas, above all by increasing investments and projects that go in this direction: in the near future it will be necessary to create the conditions for which the population is not obliged to transfer in order to improve its economic and social conditions, but that it can do it at the local level; only through concrete actions the population awareness of the value of the existing heritage can be increased.
In this sense Hou Ji is an example, being placed in a border position, between the modernity and the past, being close between recently built high-speed highway and railway, and being in a border area with the future expansion of Pingyao, according to the 2013-2030 Masterplan.
Therefore projects for the redevelopment, reconstruction and modernization of villages, without losing contact with culture and traditional architecture that must be preserved as much as possible, must be combined with projects for new buildings, such as those designed in this thesis, which for their design take inspiration from traditional architecture by combining the use of passive strategies with high-performance energy systems that use as little as possible fossil fuels, or energy from power plants that use them, and use energy from renewable sources, whether produced locally or not.
Only in this way will it be possible to adequately integrate new buildings characterized by living standards in line with the times in rural contexts; another very important fact is that the pilot building is designed to meet the parameters of low energy consumption buildings, reducing polluting emissions, thus placing itself in direct contrast with the type of building developed to date on the Chinese territory, with low quality buildings that have contributed to significantly increase consumption and pollution.

In conclusion of the design process, it can be affirmed how a very positive result was obtained, using design strategies that took into account all the considerations before mentioned and all the analysis carried out, from

the local culture to the local climate to the use of modern technologies. With the developed project it was highlighted how putting into practice an integrated design, from all points of view, correctly combining historical, urban and climatic analysis with passive and active strategies, suited on the local climate, and performing construction, respecting at the same time the traditional architecture, it is possible to obtain very low energy consumptions in line with those of the nZEB buildings,compared to a cost not much higher than that of a modern home in line with the reference energy parameters.
However, it emerged that it was necessary to use a design that under some points of view, detached itself from tradition, since by now the Chinese population generally sets its housing standards in line with Western ones, so a design too tied to existing buildings would get an opposite effect from the expected one.

The use of passive strategies has made it possible to considerably reduce the energy loads of the building: the orientation of the buildings based on wind and solar radiation has made it possible to maximize external inputs; the use of large south-facing windows has considerably reduced the heating load thanks to the high solar gains, which in many winter days allowed the active systems to be used for a short time; the use of designed external shading system has made it possible to halve the solar gains in the summer, considerably reducing the cooling loads; the use of massive assemblies with good levels of inertia for walls, floor and roof has allowed to have low heat losses, therefore lower consumption to heat.
The division into well-defined zones based on their use, i.e. the day-zone, service-zone and night-zone, allowed to assign different setpoints according to the rooms, for example the day-zone has a heating setpoint of 20 °C while the bedrooms of 18 °C: thus it was possible to obtain reduced energy consumption by maximizing the efficiency of the system.
The active energy system, i.e. the hybrid system, showed how by combining the use of all the components in an integrated system it is possible to achieve higher levels of efficiency, compared to an initial expense now not much higher than conventional systems; but the amortization that occurs in the following years makes it possible to greatly reduce the pay back time.
The use of the green roof, with the green courts, has made it possible to halve the heat losses compared to the use of a traditional roof during the winter period and to lower the overall external summer temperatures, integrating another fundamental element for the preservation of the rural identity, that is the use of green areas and agriculture in buildings: this may represent the right compromise between local tradition and openness to new design strategies that are currently uncommon, as the self-sustainance.
From the energy analysis it emerged how the pilot building has an Energy Performance Index EPI = 25.25 kWh / m^2year, which allows to reach a standard in line with that of nZEB buildings.

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