Politecnico di Milano
Faculty of Architecture and Society
Master of Science in Architecture

Title:

Design with climate – A case study in Shanghai, China

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I am, of course, the only person responsible for any accidental omissions and all the inevitable mistakes.

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Abstract

The “House” was the fundamental mark of the beginning of human civilization. After that there had never before been a situation in which a single species so dominated the planet's biota and affected so many of its ecological processes. This period now certainly is the pay back time for the humanity because of the climate change and the global warming. As an architect I believe "Housing" can have an important role of to stop the climate change firstly in terms of the human third skin (to adapt for the different climatic conditions) and secondly in terms of sustainability (saving energy, using renewable energy, advanced material, construction types, rules of building process and a zero carbon house). Hence the three main ideas this thesis pursues are *the impact of climate on architecture*, *the design approach* and *the building performance*. It involves the exploration of an architecture that is sensitive to the climatic particularities of its site and is able to create not only the passively comfortable environment but also minimize the heating/cooling energy demand for its inhabitants. Of particular interest has been the study of traditional courtyard house in China, its climatic adaptation to the living comfort and how to apply its strategy and its bioclimatic advantages into high-rise residential building.

The focus of this thesis has been the design of the residential buildings in a new urban area contents housing, hotel, commercial, mixed-use and facilities. The site is located at Hongkou District, a high dense residential area in Shanghai. In this project Courtyard-Duplex typology is designed as a result of the research of traditional courtyard house and others proposals for medium-rise building.

Introduction

This thesis is just a little voice within many voices are calling for changes in the way we build. For change to be widely accepted there have to be convincing evidences of climate change process, especially in China-the world most rapid economic development has lifted millions out of poverty but has come at a huge environmental cost. The First Chapter of this thesis seeks to set out those evidences of the climate change in Shanghai from 1873 to 2005, showing that the temperature in Shanghai is become more and more extreme. In this chapter, with the help of Climate Consultant 5.0 represents not only a detailed accurate understanding of the local climate of Shanghai, but rather to organize and represent the information in easy-to-understand new ways that reveals the subtle attributes of climate and its impact on built form.

The Second Chapter mentions the benefit of simulation tool in design process. In this thesis, the author uses Autodesk Ecotect Analysis 2010 as the most comprehensive and innovative analysis tool. What really helps architect and designer by using Autodesk Ecotect Analysis 2010 is its support for very early stage conceptual design as well as final design validation. Designers can start generating vital performance-related design information before the building form has even been developed. It can start with a detailed climatic analysis to calculate the potential effectiveness of various passive design techniques or to optimise the use of available solar and wind resources.

In the Third Chapter, a new design for 10 hectares residential and mixed-use area in Shanghai project using bioclimatic approach with the help of simulation tools, demonstrates the best Master Plan must come along with considering thoughtfully impacts of the site's context, the local climate and the need of city. The design is illustrated by some environmental simulations run by Ecotecct software such as shadow range and total sunlight hours.

By doing a research of Chinese traditional courtyard house and making several new proposals for medium-rise typology in Chapter 4 and Chapter 5 especially the Courtyard-Duplex typology on Chapter 6, the author initially desires to identify the relationship between three aspects: *the impact of climate on architecture*, *the design approach* and *the building performance*, after all to provide one most appropriate design solution. Chapter 7 illustrates the value of environmental simulation in the design approach of Courtyard-Duplex system by means of shadow and daylight simulations. The result can work out as a strategy for terrace garden, bases on light condition of different houseplants.

The idea is to *minimize the heating/cooling energy demand of building envelope* by an appropriate passive solar building design as well as using super insulating material and low emissivity window. Hence Chapter 8 talks about material and insulation which is applied on Courtyard-Duplex typology in terms of saving energy. In the end Chapter 9 mentions the building performance of Courtyard-Duplex typology examined by Autodesk Ecotect Analysis 2010.

Chapter1: Climate of Shanghai

Scientists have been at odds over who would suffer most from the consequences of global warming. A report by the Intergovernmental Panel on Climate Change (IPCC) analyzing the impact of greenhouse gas emissions states that the most vulnerable people in Asia will be the rural poor who rely on river delta for their livelihoods [1]. Britain-based International Institute of Environment and Development (IIED), meanwhile, says Shanghai and other coastal cities in Asia are at risk. Their figures suggest that sea levels at Shanghai and Tianjin, another coastal city in northern China, could rise by 60 centimetres by 2050 [2]. As an architects, answer the question how to prevent sea storms and lower the risk of flooding is not simply like build a water gate or erect sea walls, hoping that such embankments can fend off the advancing tides [3], but rather we must have a wide view by understand profoundly the climate condition of Shanghai and its records of climate change then the most appropriate proposal may revealed, not only for Shanghai but to a certain extent for our planet.

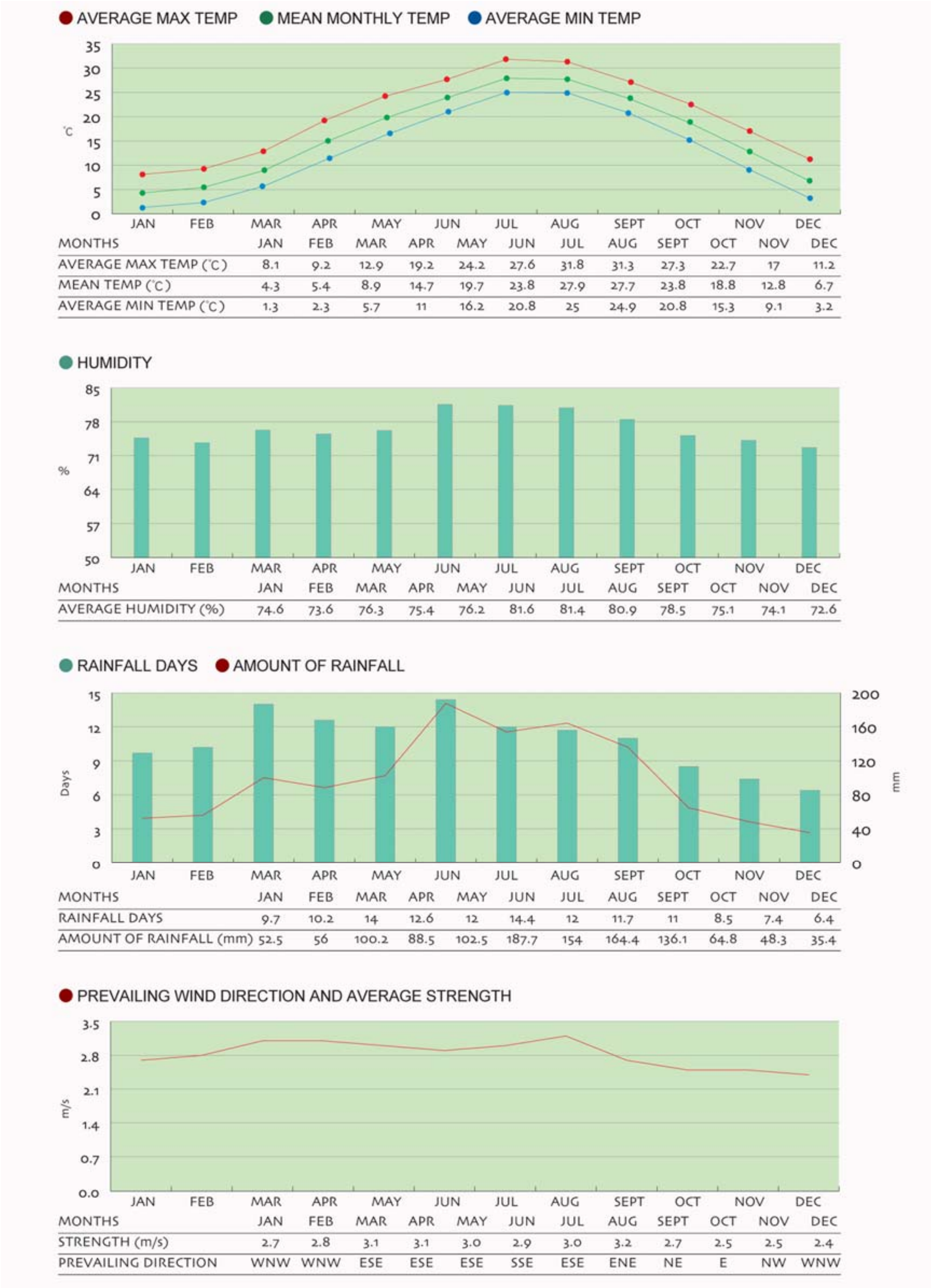
1.1. Climate condition of Shanghai

Shanghai lies at a latitude of 31°4'N, on the Yangtze River delta on China's east coast and is approximately equidistant between Beijing and Hong Kong. Being a coastal city, the weather of the region is immensely affected by the Yangtze River Delta. Shanghai has *humid subtropical monsoon climate* featuring four distinct seasons, generous sunshine and abundant rainfalls, the annual average temperature is 17.6°C. Shanghai experiences extreme climatic conditions, on one hand it has extremely hot and humid summers and on the other hand freezing winters, with temperatures dropping to 0°C.

Compared to summers and winters, spring and autumn are shorter in duration. The summer season lasts from May to September, with July and August being the hottest and most humid months of the year with maximum monthly average temperatures of 31.5°C and the average humidity is 81.5%. Winter in Shanghai is extremely chilly and cold sets in October and lasts till mid March. December, January and February happen to be the coldest months of the year with minimum monthly average temperatures of 1.8°C. The city does not receive much snowfall but owing to cold northerly winds from Siberia, Shanghai can receive one or two days of snowfall per year.

Shanghai receives abundant rainfall and the average annual precipitation is 1,302 mm. The "Plum Flower Rain" season (frequent light rain) is from mid-June to early July with an average daily rainfall of 259 mm. During July and September, strong storms with torrential rain become frequent.

Prevailing winds come from north north-west in winter bringing cold dry air form Siberia and the Mongolian plain and from south-east in summer bringing warm, humid air from the coastal regions.



MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
AVERAGE MAX TEMP (˚C)	8.1	9.2	12.9	19.2	24.2	27.6	31.8	31.3	27.3	22.7	17	11.2
MEAN TEMP (˚C)	4.3	5.4	8.9	14.7	19.7	23.8	27.9	27.7	23.8	18.8	12.8	6.7
AVERAGE MIN TEMP (˚C)	1.3	2.3	5.7	11	16.2	20.8	25	24.9	20.8	15.3	9.1	3.2

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
AVERAGE HUMIDITY (%)	74.6	73.6	76.3	75.4	76.2	81.6	81.4	80.9	78.5	75.1	74.1	72.6

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
RAINFALL DAYS	9.7	10.2	14	12.6	12	14.4	12	11.7	11	8.5	7.4	6.4
AMOUNT OF RAINFALL (mm)	52.5	56	100.2	88.5	102.5	187.7	154	164.4	136.1	64.8	48.3	35.4

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
STRENGTH (m/s)	2.7	2.8	3.1	3.1	3.0	2.9	3.0	3.2	2.7	2.5	2.5	2.4
PREVAILING DIRECTION	WNW	WNW	ESE	ESE	ESE	SSE	ESE	ENE	NE	E	NW	WNW

Figure 1: Climatic data of Shanghai (Average temperature, Humidity, Rainfall, Prevailing wind)

Source: Wikipedia

Climate consultant 5

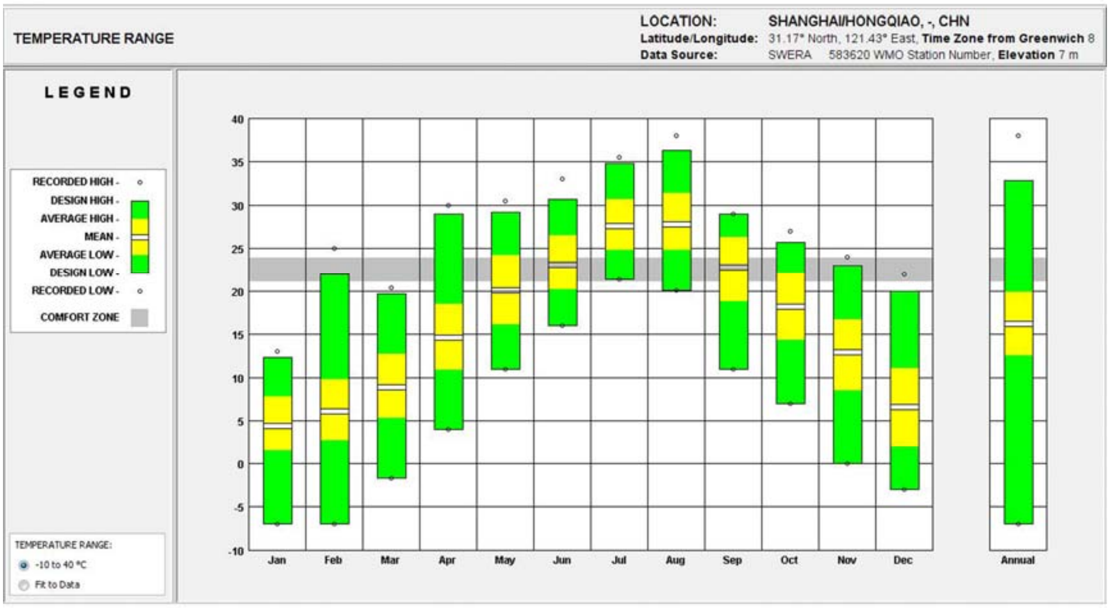


Figure 2: Temperature range

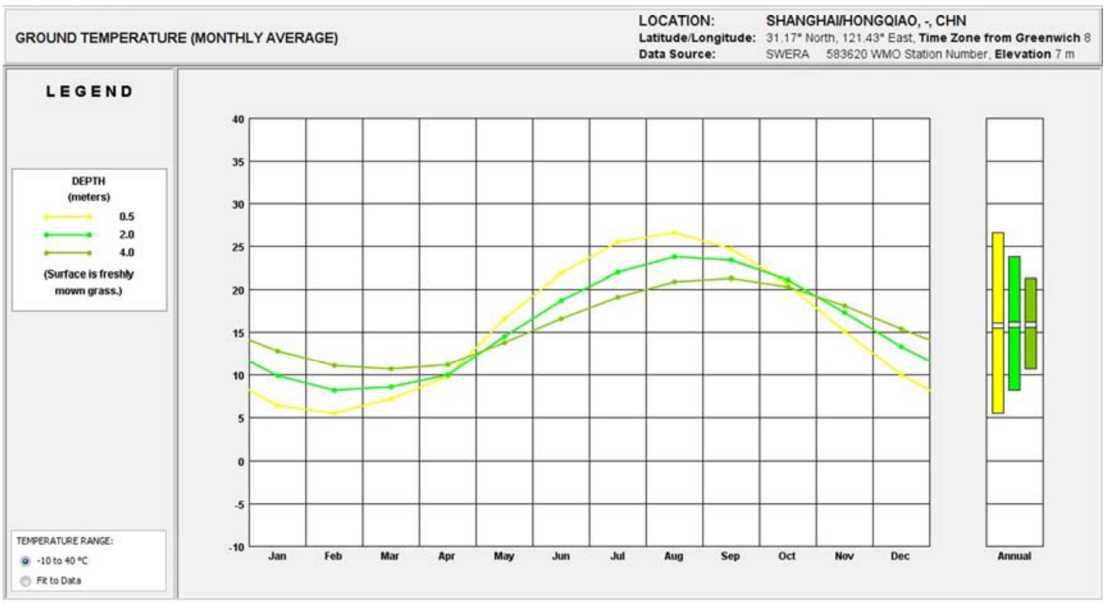


Figure 3: Ground temperature (monthly average)

Source: Climate Consultant 5

The temperature range in Shanghai is from -6 to 36°C and the comfort zone is from 21 to 24°C. From September to March, the temperature range is almost out of the comfort zone (fig. 2). The Ground temperature range is from 6 to 27°C. The lowest ground temperature is in February at 0.5 meters depth while the highest value is in

August. At level 4 meters depth, the temperature fluctuation is less, ranging from 11 to 21°C. Geothermal system can be applied for heating in winter and cooling in summer (fig. 3).

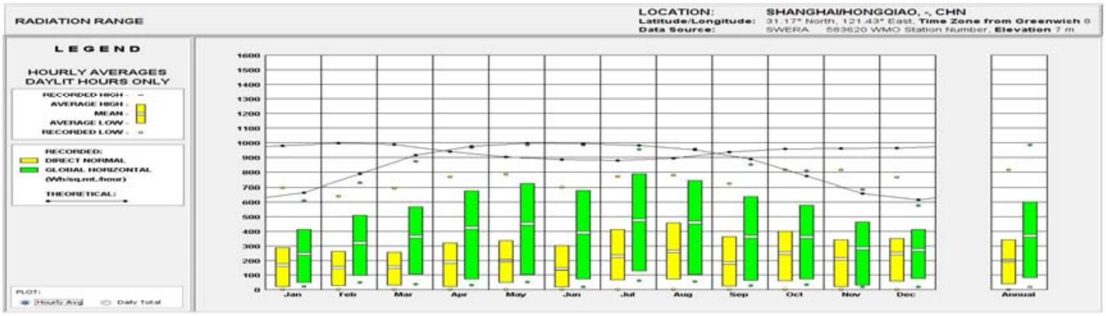


Figure 4: Radiation range

Source: Climate Consultant 5

The hourly average of direct normal radiation is from 0 to 474Wh/sq.mt with the recorded highest value in October and November, above 800Wh/sq.mt. For the global horizontal radiation, its range is from 0 to almost 800Wh/sq.mt, the recorded highest value in May and Jun with 1000Wh/sq.mt (fig. 4).

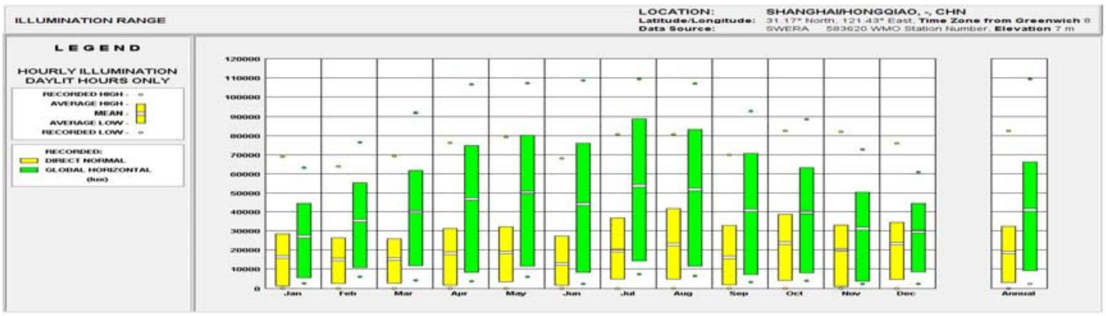


Figure 5: Illumination range

Source: Climate Consultant 5

The hourly average of direct normal illumination is from 0 to 40,000lux with the recorded highest value in October and November, above 80,000lux. For the global horizontal illumination, its range is from 0 to almost 90,000lux, the recorded highest value in May and Jun with 110,000lux (fig. 5).

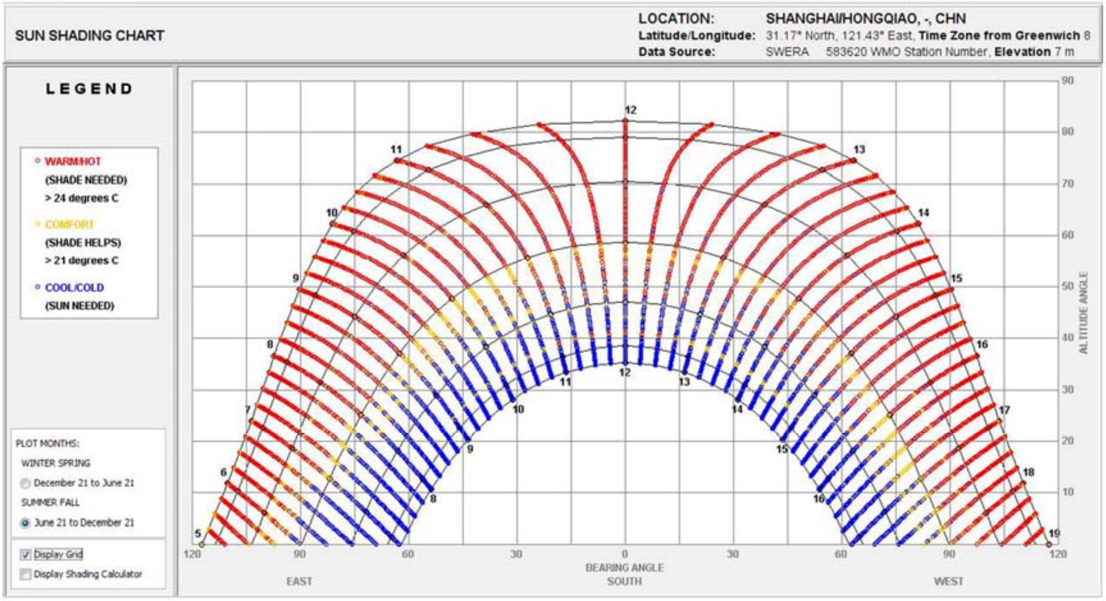


Figure 6: Sun shading chart *Source: Climate Consultant 5*

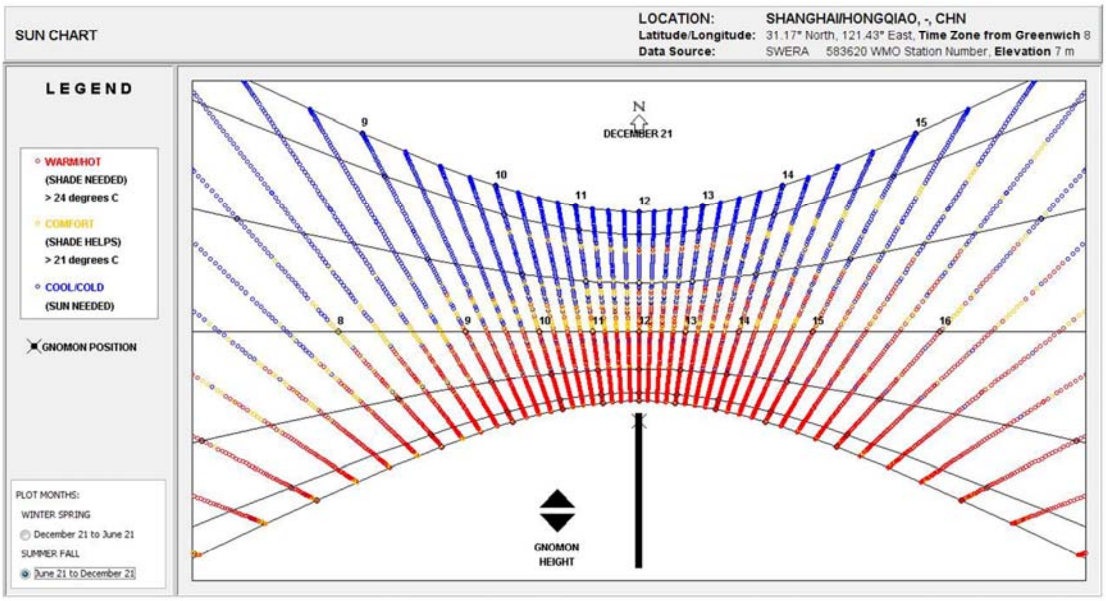


Figure 7: Sun chart

Source: Climate Consultant 5

According to the Sun shading chart and Sun chart, the time period when shade needed is from March to September, from 8:00 to 16:30. The temperature where shade needed is larger than 24°C and in comfort zone is 21 to 24°C where shade may help (fig. 6, 7).

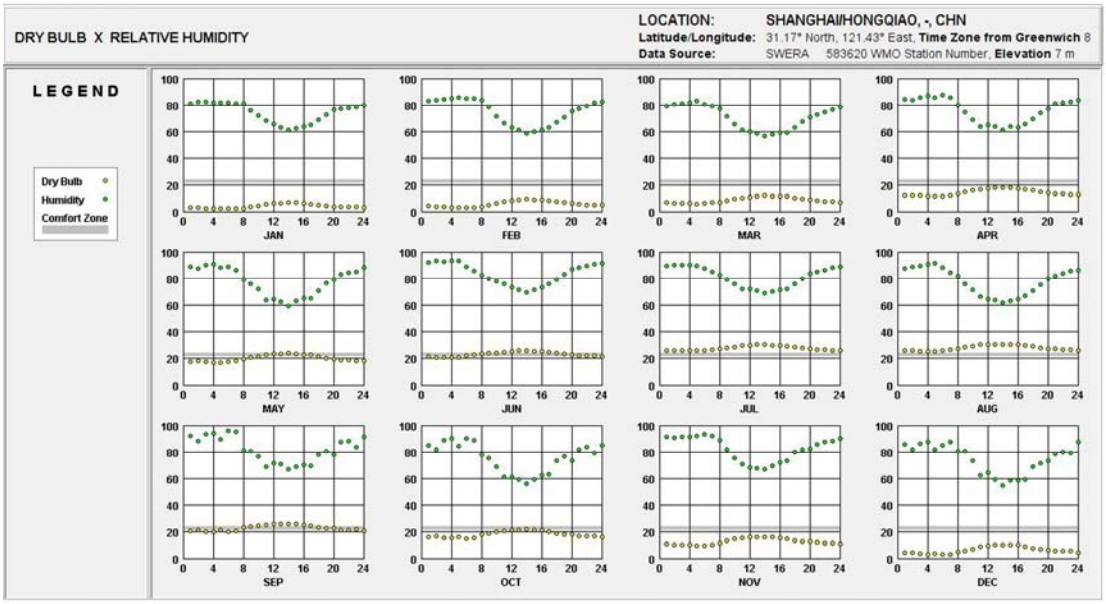


Figure 8: Dry bulb and Relative humidity

Source: Climate Consultant 5

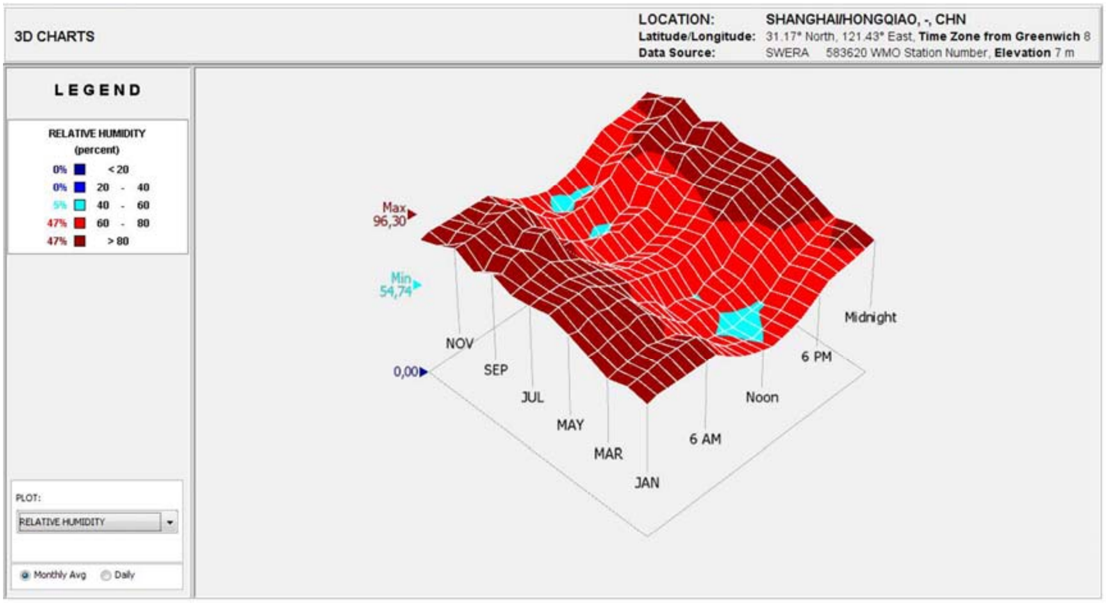


Figure 9: 3D chart of Relative humidity *Source: Climate Consultant 5*

The Relative humidity of Shanghai is very high, in almost half of year is higher than 80% and from 60 to 80% in another half of year. Because of Shanghai's location-a coastal city and its humid subtropical monsoon climate therefore it is extremely hot and humid in summer but chilly and cold in winter. Natural ventilation and dehumidification is very important in summer and must be well thought-out in design process (fig. 8).

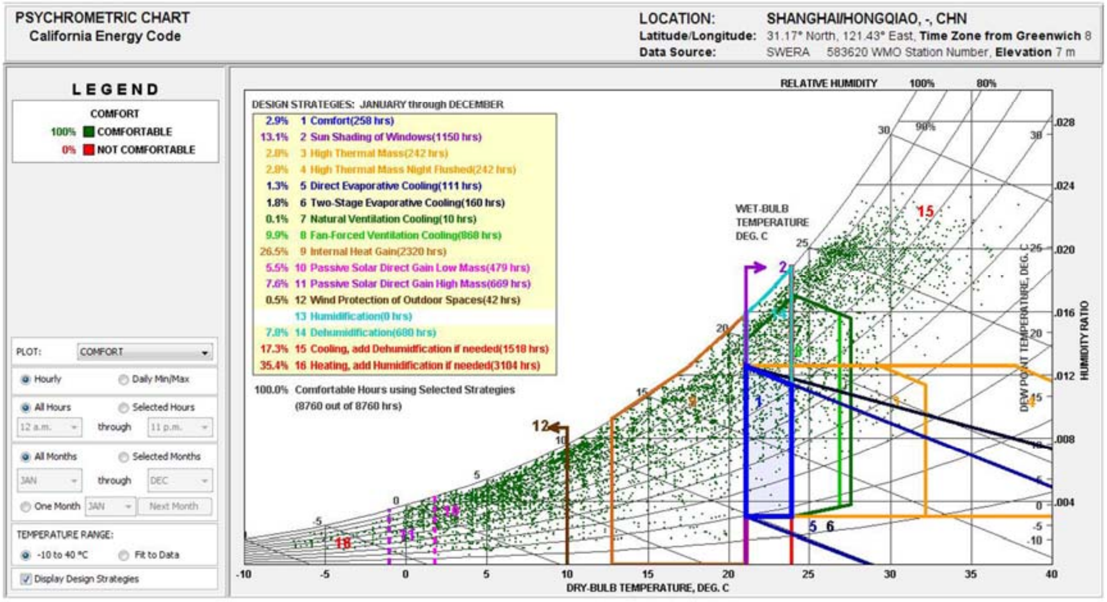


Figure 10: Psychrometric chart *Source: Climate Consultant 5*

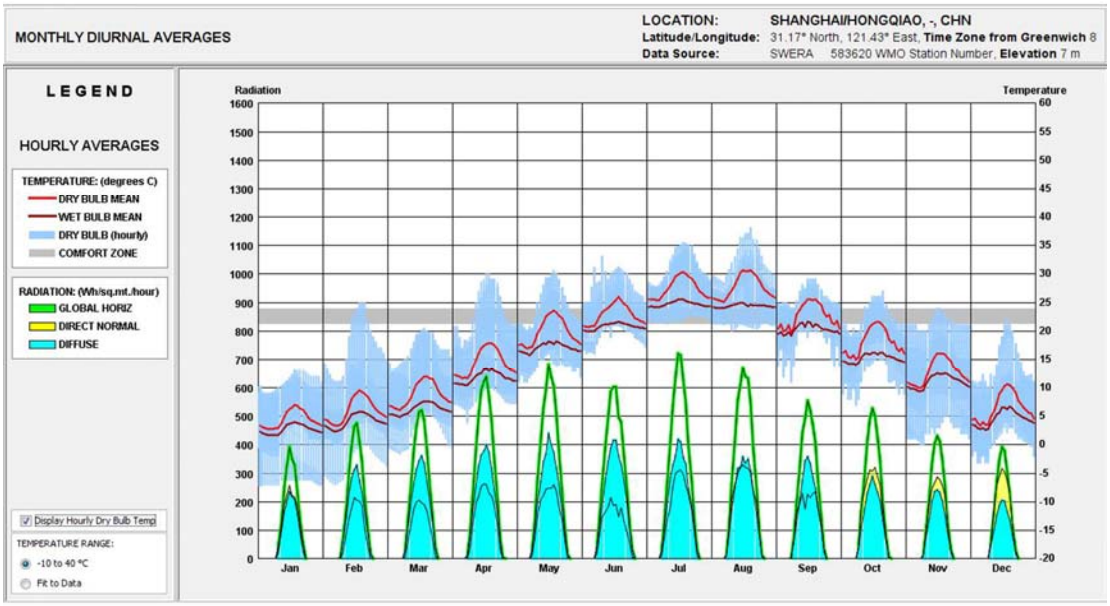


Figure 11: Monthly diurnal averages

Source: Climate Consultant 5

Climate consultant 5 can propose a design strategy which has 16 tasks to achieve 100% comfortable hours. These tasks include such as: Sun shading of window (13.1%); Internal heat gain (26.5%); Cooling, add Dehumidification if needed (17.3%) and Heating, add Dehumidification if needed (35.4%). In Shanghai, there are 8760 hours as 100% of total comfortable hours (fig. 10).

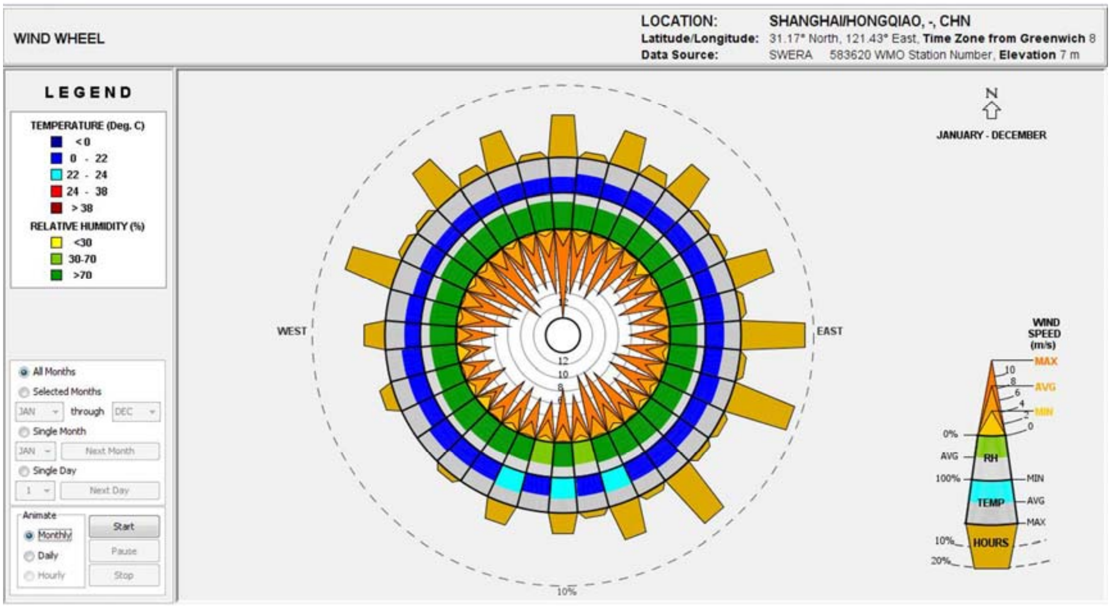


Figure 12: Wind wheel *Source: Climate Consultant 5*

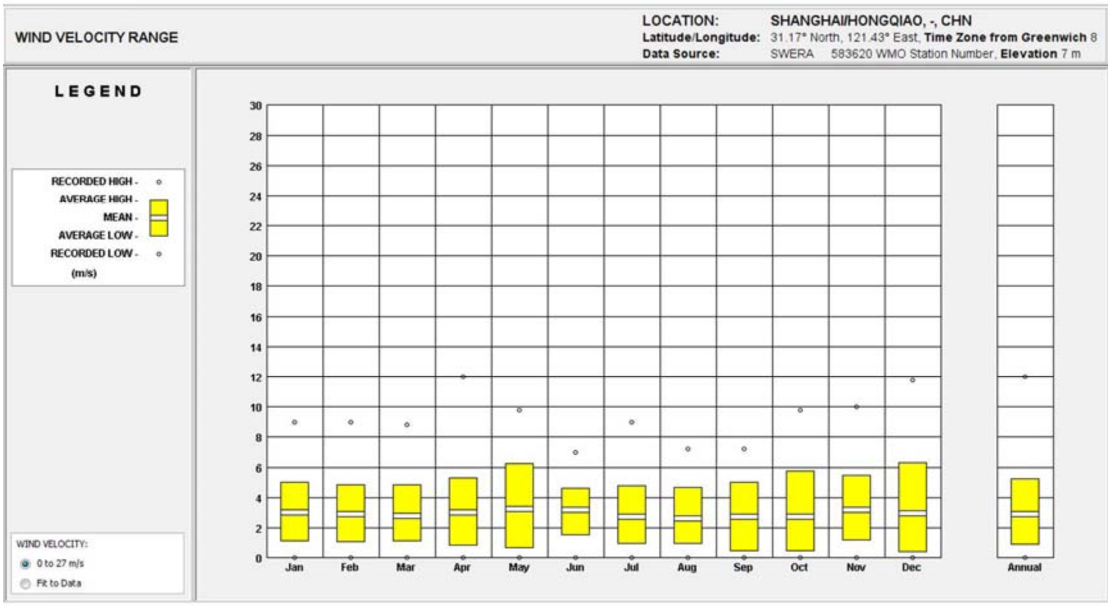


Figure 13: Wind velocity range

Source: Climate Consultant 5

The winter wind comes from north-west bringing cold dry air from Siberia and the Mongolian plain, the maximum speed is 12m/s recorded in December. In summer the wind comes from south-east bringing warm, humid air from the coastal regions, the maximum speed is 12m/s in April (fig. 13).

The list below is the Design Guidelines proposed by Climate Consultant 5, applies especially to Shanghai's particular climate, starting with the most important first.

1. Heat gain from equipment, lights, and occupants will greatly reduce heating needs so keep home tight, well insulated *(use ventilation in summer)*.
2. *Keep the building small (right-sized)* because excessive floor area wastes heating and cooling energy.
3. *Lower the indoor comfort temperature at night* to reduce heating energy consumption (lower thermostat heating setback) (see comfort low criteria).
4. *Window overhangs* (designed for this latitude) or *operable sunshades* (extend in summer, retract in winter) can reduce or eliminate air conditioning.
5. On hot days *ceiling fans* or *indoor air motion* can make it seem cooler by at least 5 degrees F (2.8C) thus less air conditioning is needed.
6. *Extra insulation (super insulation)* might prove cost effective, and will increase occupant comfort by keeping indoor temperatures more uniform.
7. *Glazing* should minimize conductive loss and gain *(minimize U-factor)* because undesired radiation gain or loss has less impact in this climate.
8. A whole-house fan or natural ventilation can *store nighttime 'cool' in high mass interior surfaces,* thus reducing or eliminating air conditioning.
9. Sunny wind-protected outdoor spaces can extend living areas in cool weather.
10. Locate garages or storage areas on the side of the building facing the coldest wind to help insulate.
11. Tiles or slate (even on low mass wood floors) or a stone-faced fireplace can help *store winter daytime solar gain and summer nighttime 'cool'.*
12. High Efficiency furnace (at least Energy Star) should prove cost effective.
13. Trees (neither conifer nor deciduous) should not be planted in front of passive solar windows, but rather beyond 45 degrees from each corner.
14. In this climate air conditioning will always be required, but can be greatly reduced if building design *minimizes overheating.*

15. *Raising the indoor comfort temperature* limit will reduce air conditioning energy consumption (raise thermostat cooling setpoint).
16. *Good natural ventilation* can reduce or *eliminate air conditioning in warm weather,* if windows are well shaded and oriented to prevailing breezes.
17. A radiant barrier (shiny foil) will help reduce radiated heat gain through the roof in hot climates.
18. Organize floor plan so winter sun penetrates into daytime use spaces with specific functions that coincide with solar orientation.
19. *Carefully seal building to minimize infiltration* and eliminate drafts, especially in windy sites (house wrap, weather stripping, tight windows).
20. *High mass interior surfaces* like stone, brick, tile, or slate, feel naturally cool on hot days and can reduce day-to-night temperature swings.

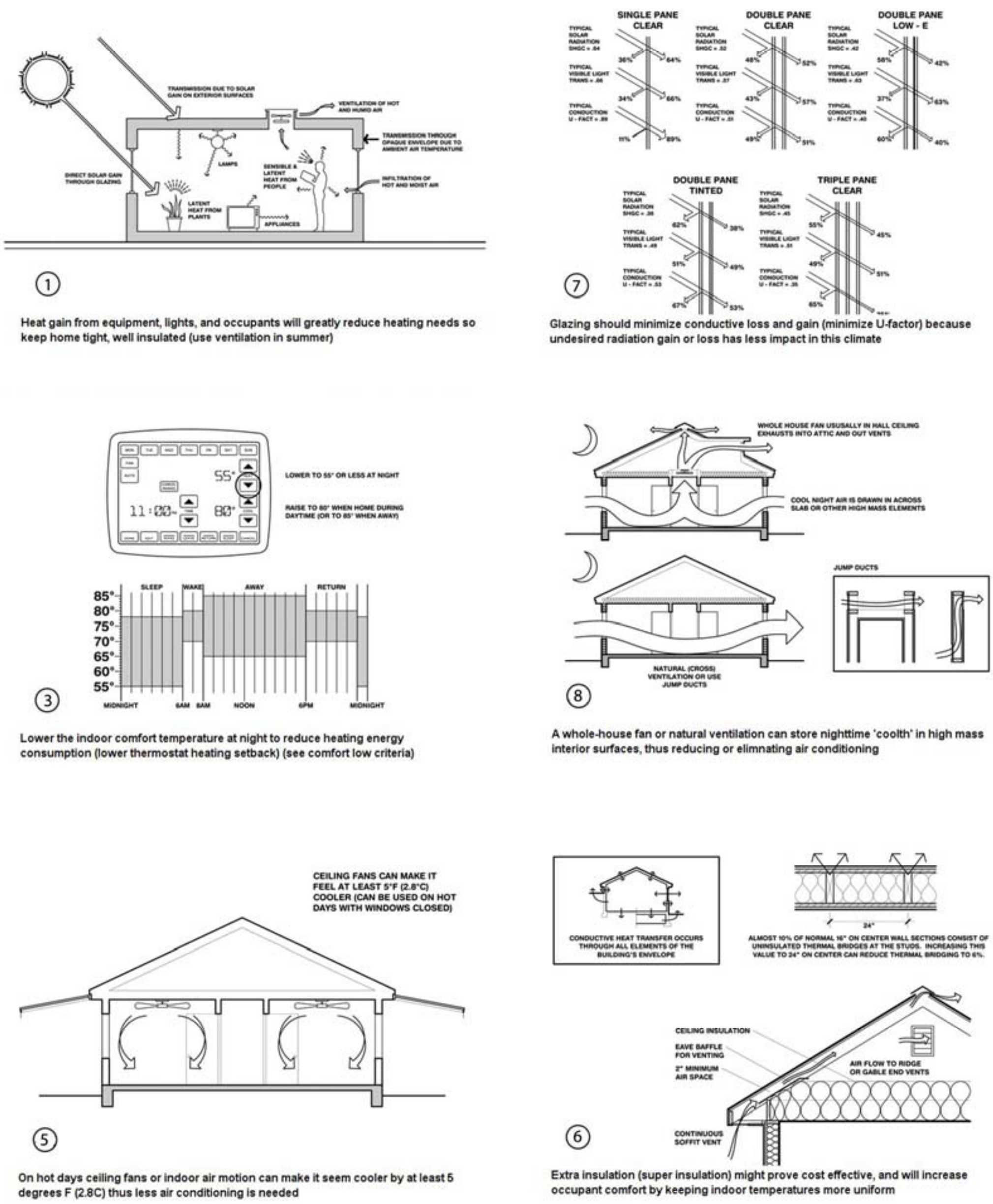


Figure 14: How the Design Guideline shapes building design

Source: Climate Consultant 5

1.2. Climate Change from 1873 to 2005

Based on the Shanghai's meteorological data, land use date from TM images and social statistical data, the evidences of Shanghai temperature change with the elements of mean annual temperature, mean annual maximum and minimum temperature, and extreme high and low temperature from 1873 to 2005 were detected in the paper "*Urbanization and Climate Change in Shanghai and the Yangtze Delta Area*" by Shi Jun, Shanghai Climate Center, 2006. The results indicated the increase of mean annual temperature, mean annual maximum and minimum temperature. Mean annual temperature in the city is greater than before, and the increase rate in winter was greater than that in spring and autumn. In Shanghai most hot days, least cold days and the highest mean temperature all appeared in the first 5 years in this century [4]. This paper properly provides us the understanding and attribution of climate change in Shanghai.

Mean annual temperature: It is no doubt that Shanghai is warming. Before 1930s, average mean annual temperature is around 15.5°C, until early 1950s it went up to 16°C. From 1980s it increased rapidly, in 2005 the mean annual temperature is almost 17.5 °C and still going higher (fig. 15).

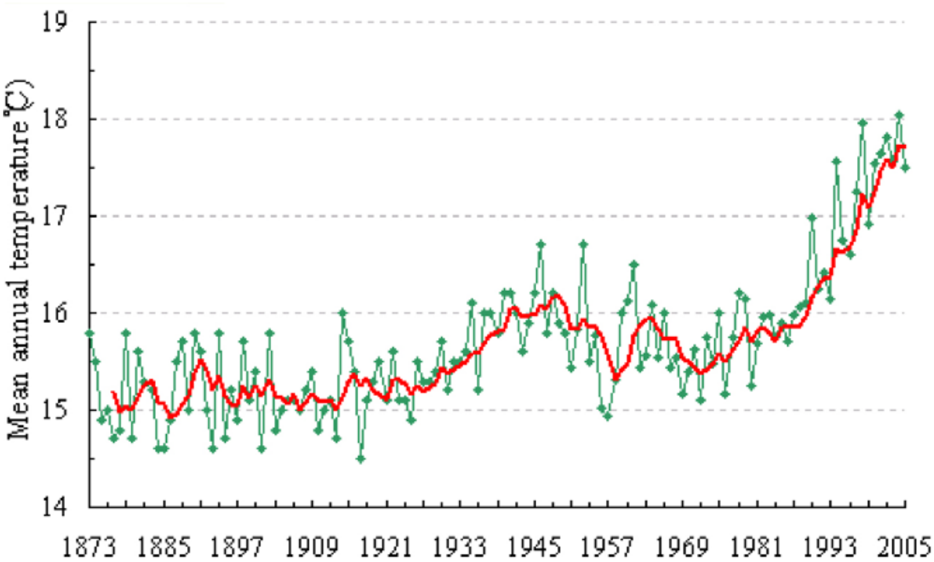


Figure 15: Mean annual temperature in Shanghai from 1873 to 2005

Source: Urbanization and Climate Change in Shanghai and the Yangtze Delta Area, Shi Jun

Variability of mean annual temperature: It was obviously higher than the former in near 30 years, indicated an increasing fluctuation of temperature. Over almost 100 years the average variability of mean annual temperature was maintained as 2.6%. The fluctuation is two times wider in just recent 30 years (fig. 16).

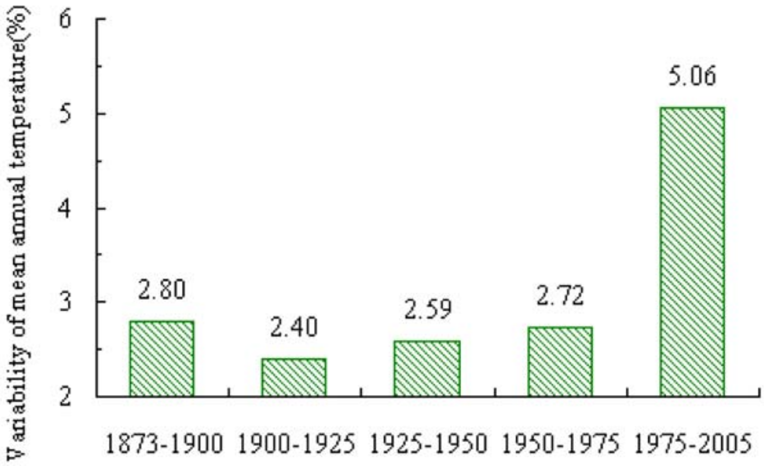


Figure 16: Variability of mean annual temperature in Shanghai from 1973 to 2005

Source: Urbanization and Climate Change in Shanghai and the Yangtze Delta Area, Shi Jun

Annual extreme low temperature: In 50 years from the early 1930s to 1980s, annual extreme low temperature increased slowly, the range is from -8 to -6°C. After that it increased rapidly, up to -4.5°C in 2005 (fig. 17).

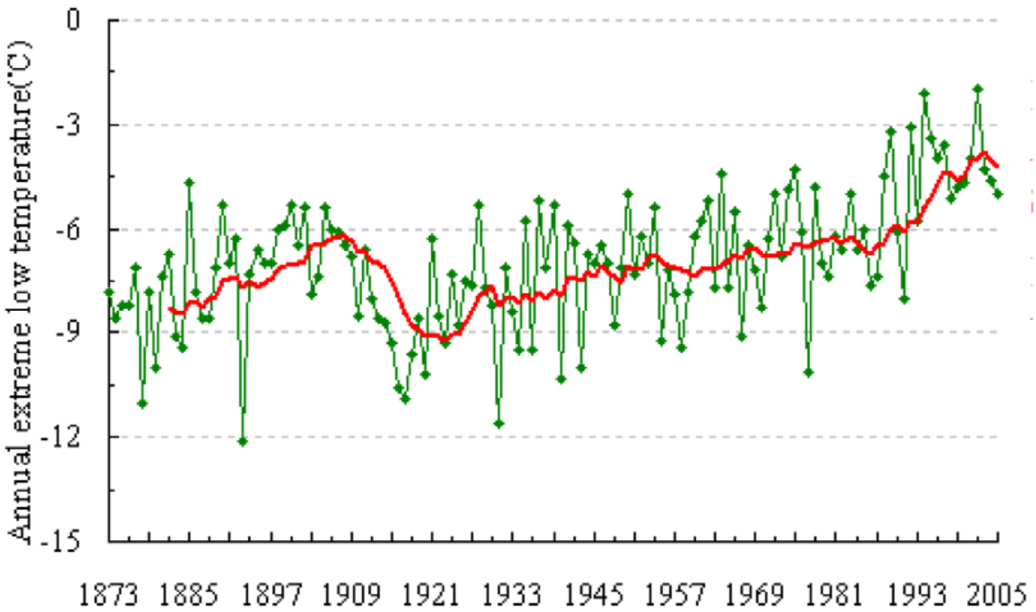


Figure 17: Annual extreme low temperature in Shanghai from 1873 to 2005

Source: Urbanization and Climate Change in Shanghai and the Yangtze Delta Area, Shi Jun

Variability of annual extreme low temperature: In the recent 30 years the variability of annual extreme low temperature was the highest over 130 years (fig. 18).

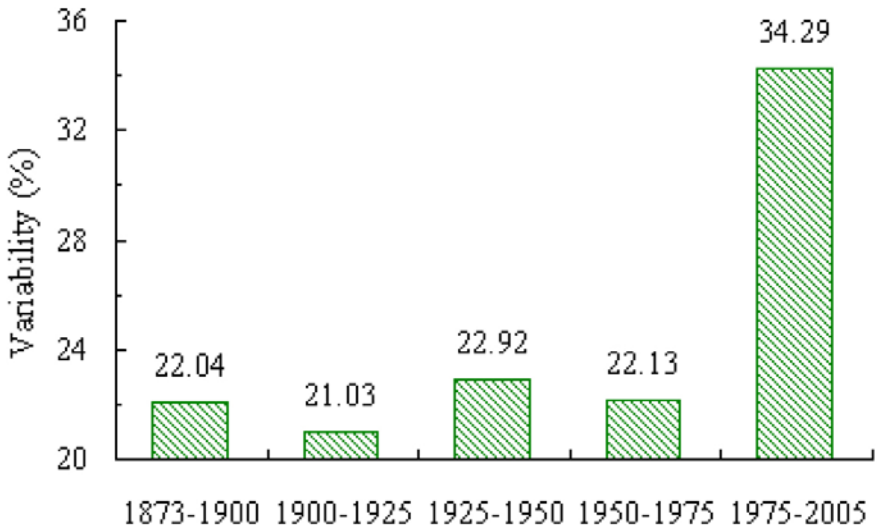


Figure 18: Variability of annual extreme low temperature in Shanghai from 1873 to 2005

Source: Urbanization and Climate Change in Shanghai and the Yangtze Delta Area, Shi Jun

Annual extreme high temperature: Annual extreme high temperature increased rapidly after the early 1980s until 2005, from 36 to 38°C (fig. 19).

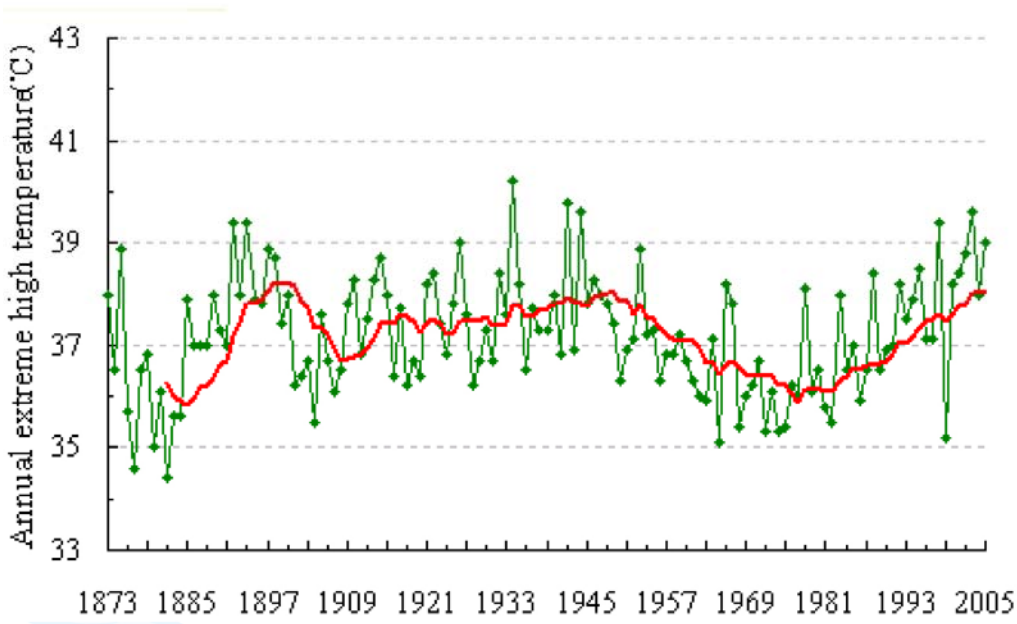


Figure 19: Annual extreme high temperature in Shanghai from 1873 to 2005
Source: Urbanization and Climate Change in Shanghai and the Yangtze Delta Area, Shi Jun

Annual maximum daily range of air temperature: Annual maximum daily range of air temperature increased before the 1950s, after then, it decreased from 19.5 to 16.5 °C (fig. 20).

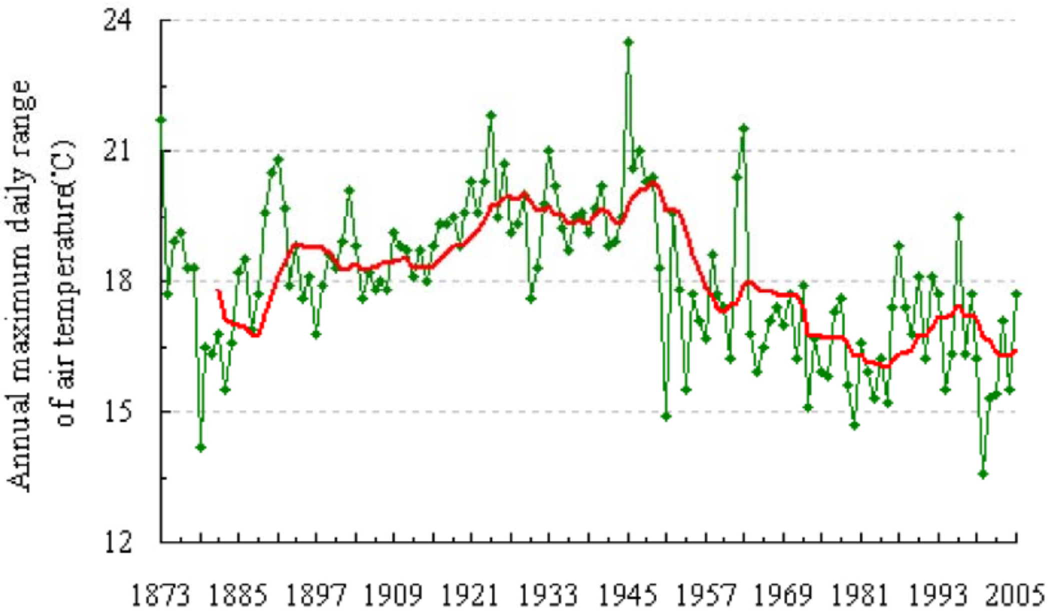


Figure 20: Annual maximum daily range of air temperature in Shanghai from 1873 to 2005
Source: Urbanization and Climate Change in Shanghai and the Yangtze Delta Area, Shi Jun

Climate change is happening and its impacts on our lives are going to be far worse than generally expected. "The only way we can hope to survive the following century in tact is if we not only begin to radically reduce CO2 emissions from our buildings and stop building climatically disastrous building types but also build only the buildings that can survive in the changed climates of the future" [5].

Chapter 2: Design with simulation tools

Over the past two decades the building simulation discipline has matured into a field that offers unique expertise, methods and tools for building performance evaluation. It draws its underlying theories from diverse disciplines, mainly from physics, mathematics, material science, biophysics, human behavioral, environmental and computational sciences. The theoretical challenges are bountiful when one recognizes that the physical state of a building is the result of the complex interaction of a very large set of physical components. The integration of these interactions in one behavioral simulation poses major modeling and computational challenges. "Its ability to deal with the resulting complexity of scale and diversity of component interactions has gained building simulation a uniquely recognized role in the prediction, assessment and verification of building performance" [6].

In this thesis, the author uses Autodesk Ecotect Analysis 2010 which is the most comprehensive and innovative environmental analysis tool for architecture. Ecotect is used to simulate impact of local climate on building such as natural light, shadow and solar radiation as well as building performance such as material, insulation, thermal comfort and heating/cooling loads. Autodesk Ecotect Analysis software is a concept-to-detail sustainable design analysis solution with architect-designed desktop tools that measure the impact of environmental factors on a building's performance and web-based technology for whole building analysis. Ecotect Analysis makes it easier for building designers to conduct simulations and visualize results. Because analysis can be conducted on a building model as soon as the thermal zones are defined, the designer can make fact-based, more sustainable design decisions during the schematic stage when designs are easier and less expensive to change. Ultimately, these capabilities result in better building performance, faster time to market, and lower project costs, as well as lower total cost of ownership over time. Unlike complicated engineering analysis tools, Autodesk Ecotect Analysis was developed specifically for architects and designers to provide powerful feedback that's easier to interact with, interpret, and communicate [7].

In Chapter 3, Ecotect is used to analyze the impact of environment on the design of master plan such as Shadow range analysis of housing, housing with mixed-use facilities. The simulation helps to define accurate location of building and its dimension in terms of natural light requirement in winter. Another analysis done by Ecotect is Total sunlight hours on ground level. The simulation works as a strategy to classify appropriate ground areas for different activities base on their sunlight hours, like sport activity or children playground should be placed where there is more sunlight in winter and spaces for sitting or relaxing require shading in summer. It is also useful to determine fitting area for planting and for green space. It is not suitable for tree and garden in where there are zero sunlight hours both in summer and winter.

Ecotect is used for daylight simulation of Courtyard-Duplex typology in Chapter 7 such as Shadow range. The results present total amount of sunlight areas and shadow areas on one day. It is useful for the designer to modify the position and size of windows as well as shading device. Furthermore, it can help as an interior design approach, to determine areas for different activities that need shadow or sunlight such as: relaxing, studying, working, reading, cooking and sleeping. Daylight is an important consideration when designing energy efficient buildings, a well designed daylight system can reduce the required lighting energy. Ecotect provides daylight simulation which can examine daylight level by current Design Sky value. By that the architect can calculate and then modify the design in order to achieve the most natural light comfort in all rooms. Furthermore, the daylight simulation can be a strategy to design terrace garden in Courtyard-Duplex system, in the way to match different light levels and sunlight areas to appropriate housplants. We can determine the planting area by simply overlapping the areas of daylight levels and the areas of sunlight levels, each area will have appropriate plants due to their light condition.

There is a possibility for the architect to design shading device simply and without any difficulty by Ecotect Solar Tool. With its interactive user interface, the Solar Tool helps to accurately size and position window overhangs, shading devices and louvers with ease. It provides a 3D model of window that can be interactively manipulated by changing the number of horizontal, vertical or detached shading surfaces. At the same time, it displays the resultant annual shading pattern on a Sun-Path Diagram, showing when in the year the window will be exposed to the Sun or in shade.

Using Ecotect Material Library the architect can choose the most appropriate energy saving material for the building by understand its properties. U-values, specific admittance, solar absorption, shading coefficients, alternating solar gains, emissivity, density and thermal conductivity are all determined in Ecotect Material Library for each material. Chapter 8 illustrates how to achieve super insulating building component such as wall, floor, roof and window by using Ecotect Material Library.

Ecotect offers a wide range of thermal performance analysis features. The idea is to minimize the heating/cooling energy demand of building envelope by an appropriate passive solar building design as well as using super insulating material and low emissivity window. Therefore in the last Chapter, Ecotect is used to simulate building performance by calculating annual temperature distribution, heat gains/losses and heating/cooling loads of all thermal zones in Courtyard-Duplex typology.

Chapter 3: A case study in Shanghai-Hongkou project

The Project is a collaboration between Politecnico di Milano in Italy and the Tongji University in Shanghai. The project is in an old neighborhood, which has experienced a dramatic increase in population, while at the same time its resources and services remained the same. Hongkou District is home to many residents of Shanghai who are leaving in old and heavily dense zone, with very basic urban facilities. Hence the aim of the project is to create not simply a new high dense urban area for a huge number of people, but rather to give them a high quality of living condition and an advantage environmental design of building and landscape. The project profoundly considers three factors: the impact of climate on architecture, the environmental design approach and the building performance.

3.1. The site

3.1.1. Location

Figure 21: Location of Shanghai in China

Source: Internet

Figure 22: Shanghai border

Source: Internet

Shanghai is a coastal city on east-central China, one of the world's largest seaports and a major industrial and commercial centre of China. The city is located on the coast of the East China Sea between the mouth of the Yangtze River (Chang Jiang) to the north and the bay of Hangzhou to the south. The municipality's area includes the city itself, surrounding suburbs, and an agricultural hinterland; is China's most populous urban area (fig. 23).

SHANGHAI MUNICIPALITY

Longitude: 121°29' E

Latitude: 31°4'N

Area: 6,340.5 sq km

Location: Southern wing of the Yangtze River Delta

Population: 19,210,000

Density: 2,729.9/km2

Figure 23: Shanghai municipality.

Source: Made by the author

Shanghai was one of the first Chinese ports to be opened to Western trade, and it long dominated the nation's commerce. The city has also undergone extensive physical changes with the establishment of industrial suburbs and housing complexes, the improvement of public works, and the provision of parks and other recreational facilities. Shanghai has attempted to eradicate the economic and psychological legacies of its exploited past through physical and social transformation to support its major role in the modernization of China.

HONGKOU DISTRICT

Land area: 23.48 km2

Population: 860,700

The Hongkou district lies to the north and east of the Suzhou River (fig. 24). It was originally developed by American and Japanese concessionaires and in 1863 was combined with the British conc--ession to the south to create the Internat--ional Settlement. It is an important industrial area, with shipyards and factories spread out along the bank of the Huangpu in the eastern section of the district. Located where land and water meet, with its convenient traffic and superior geography position, Hongkou district is a central urban area with integrate functions of commerce, shopping, and urban residence.

Figure 24: Hongkou District

Source: Made by the author

PROJECT SITE

Lot1: 3.06 ha

Lot2: 4.25 ha

Lot3: 3.03 ha

Total area: 10.36 ha

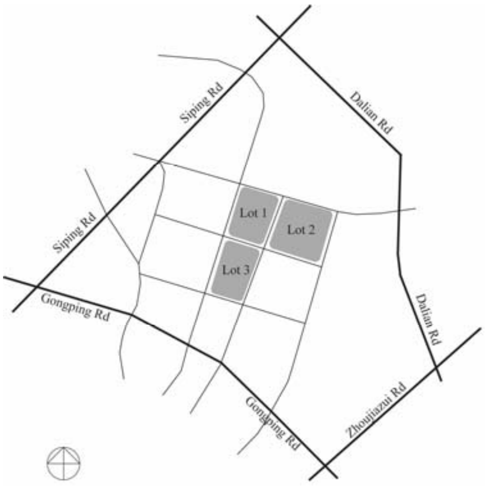


Figure 25: Location of project site

Source: Made by the author

3.1.2. Context

There are two main facilities that next to the site, one on the north is Heping Park (Peace Park) and one on the east is the Sport Centre. They provide a green space for fresh air, relaxation as well as sport activities for habitant in the entire area. The current housing situation on the site is poor. Most of them are low-rise, dense with unqualified daylight and thermal condition. All of them will be demolished for the new project includes residential, commercial and mix use facility (fig. 26).

Figure 26: The bird view of project site (Heping Park on the north and Sport Center on the east)

Source: Made by the author

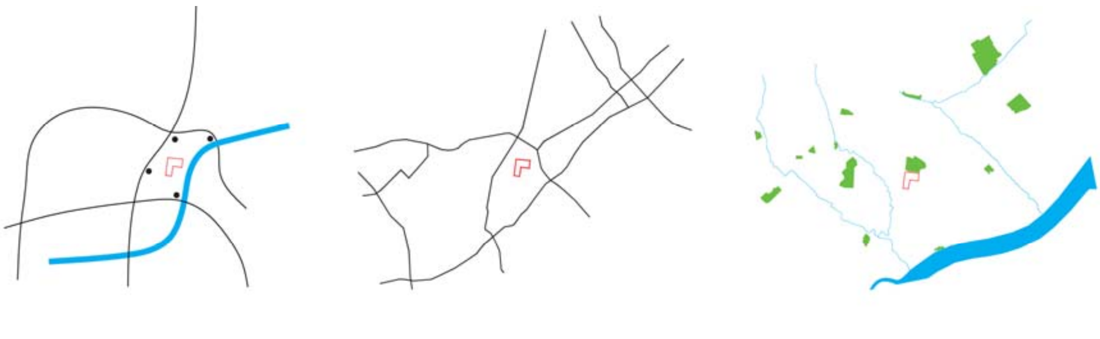


Figure 27: Subway, roads and green area network *Source: Made by the author*

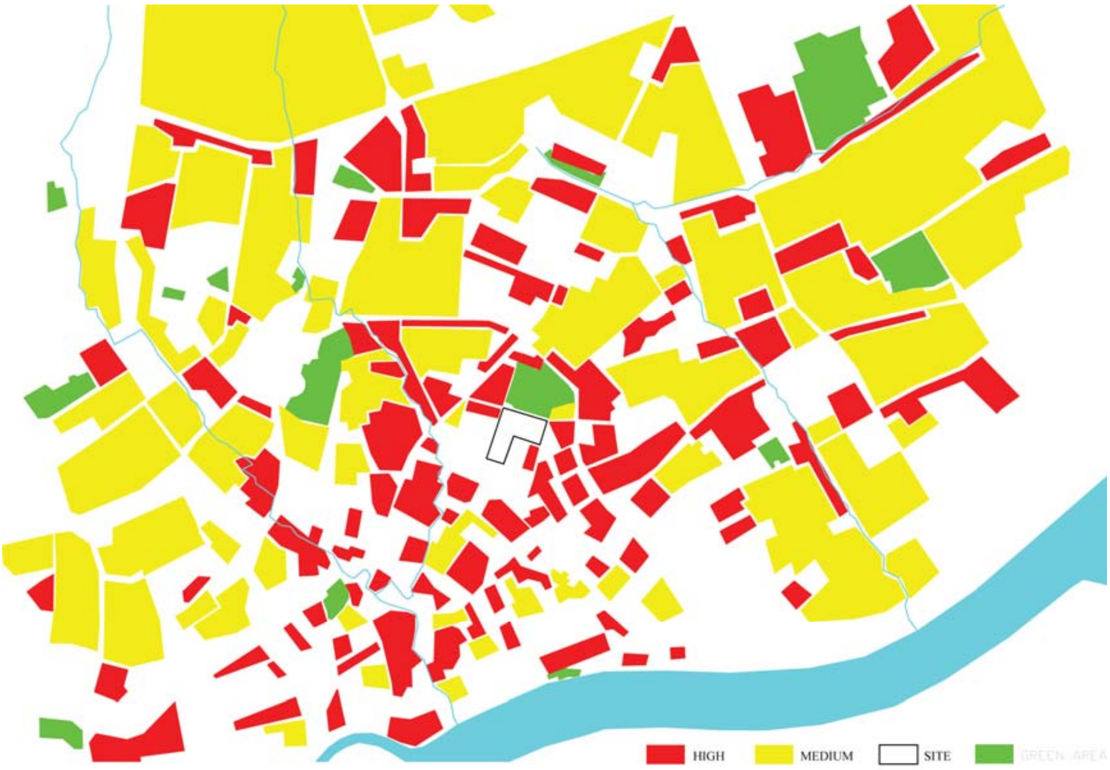


Figure 28: Shanghai Density analysis

Source: Made by the author

The figure above shows us the density of buildings in Shanghai. The red colour presents high-rise buildings; the yellow is for medium-rise buildings; the green colour is for green areas. The project site is located in high-rise building area and well connected with the Heping Park in the North hence it can be a Green corridor-a linkage between Heping Park and the south area (fig. 28).

3.2. Strategy for master plan

The strategy for master plan is made due to the site's context and the needs of project. The master plan is reveal by making a good strategy, takes in account all the aspects of the environment, the social community, the inhabitant and the city. The first step is defining the main goals; the second step is designing with bioclimatic approach. The proposal is simulated by environmental tools to obtain best result.

3.2.1. Main goals

Because of an extreme necessity of housing in Shanghai, the project must achieve a high density:

Project area:	103.640 sqm
Gross Floor Area (GFA):	310.920 sqm
Floor Area Ratio (FAR):	3
Housing area:	102.375 sqm
Mixed-use and facilities area:	178.545 sqm
Hotel area:	30.000 sqm

Large green space on the site (the central green space between buildings is no less than 400m2 and 1/3 of it is out of the shadow) and green roof (for commercial, mixed-use and facilities areas).

Nature day lighting and nature ventilation for all residential buildings must be qualified.

The buildings must obtain not only passively comfortable environment but also a most energy efficient for its inhabitants.

3.2.2. Bioclimatic approach

Bioclimatic approach is a climatically interactive building design approach, which integrates the scope to use the location and the regulatory systems inherent in architecture, through the choice of orientation, form, fabric and use of natural resources of energy to achieve indoor comfort conditions. This is often succeeded at no extra construction or maintenance cost [8].

The first proposal (Orientation and shape of the building)

All the residential buildings must be facing to the south. Elongated building shape maximizes heat gains sides in winter and minimizes heat gains in summer. In winter the South side receives three times more solar radiation than the East and West.

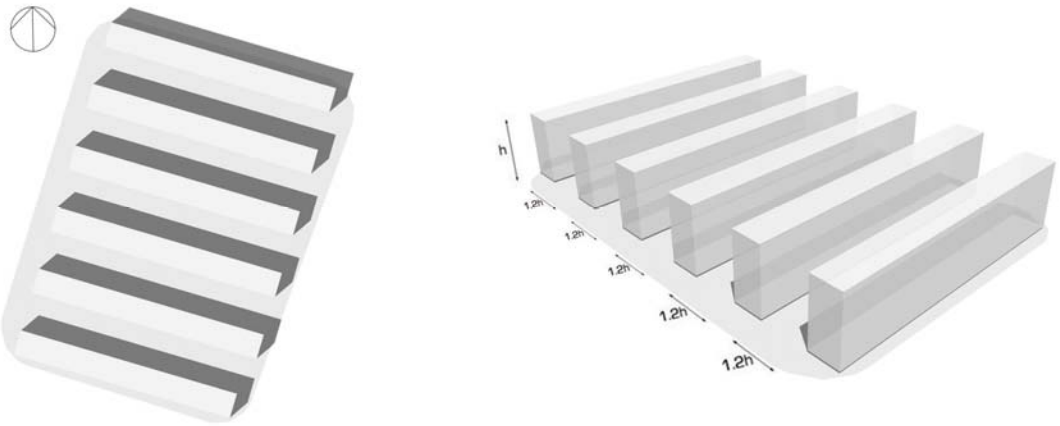


Figure 29: High-density/ North-South orientation

Source: Made by the author

The first proposal is having a row houses oriented to the south, keep the distance in between is 1.2 time of the building's height (fig. 29). This case can achieve a very high density; however the distance is too close hence it is not the best solution for natural light and visibility.

The second proposal (Daylight; Summer breeze;, Height and Distance of buildings)

The second proposal takes in account the orientation, the summer breezes, the height and distance between buildings. The summer breezes can be guide through the site by alternately orients the buildings. In this layout, the height of buildings now is 25 m and the distance between them increases to 60 m, 2.4 times of the height (fig. 31). The natural light and shadow simulation by Ecotect will demonstrate that it is the most appropriate proposal for medium-rise residential buildings.

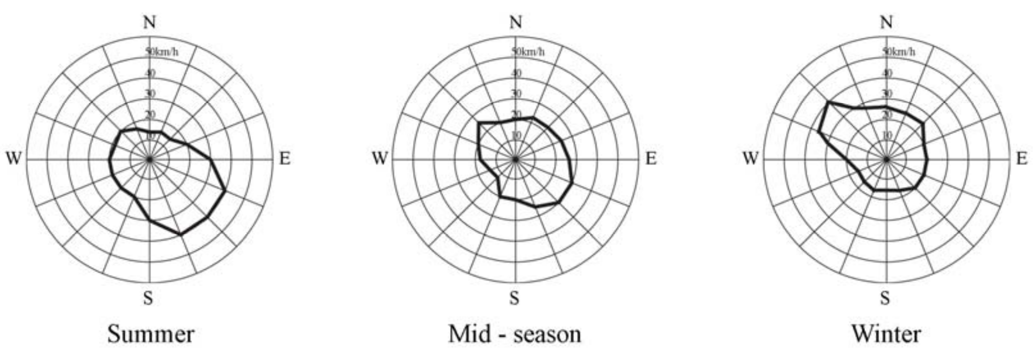


Figure 30: Wind roses in Shanghai *Source: Internet*

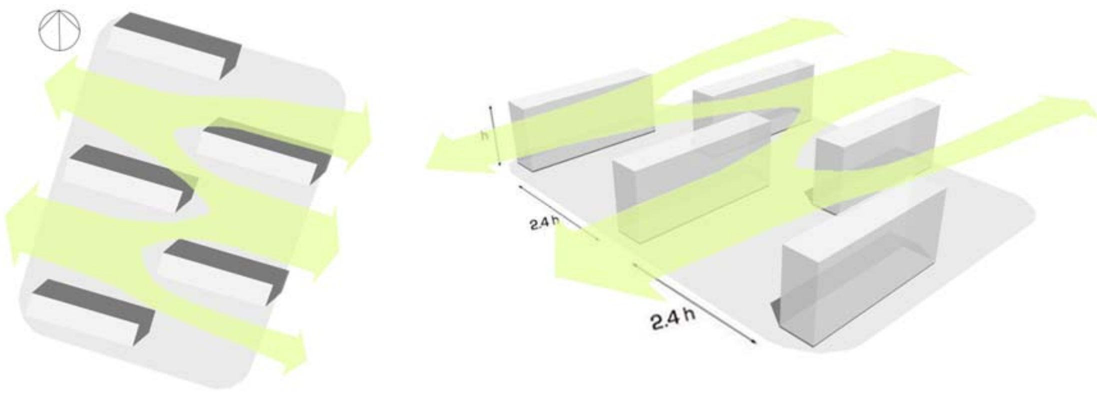


Figure 31: Accurate distance and height of buildings for daylight, summer breezes and green space

Source: Made by the author

The third proposal (Combination of residential building and mixed-use facilities)

The idea is to lift up the mixed-use facility 15m above the ground hence allows the cross ventilation underneath and the possibility to have a wide-free landscape on ground. The mixed-use facilities will be connected as a single body and located in the middle of the lot so that it can visually link all the buildings together, as a backbone of one single body (fig. 32).

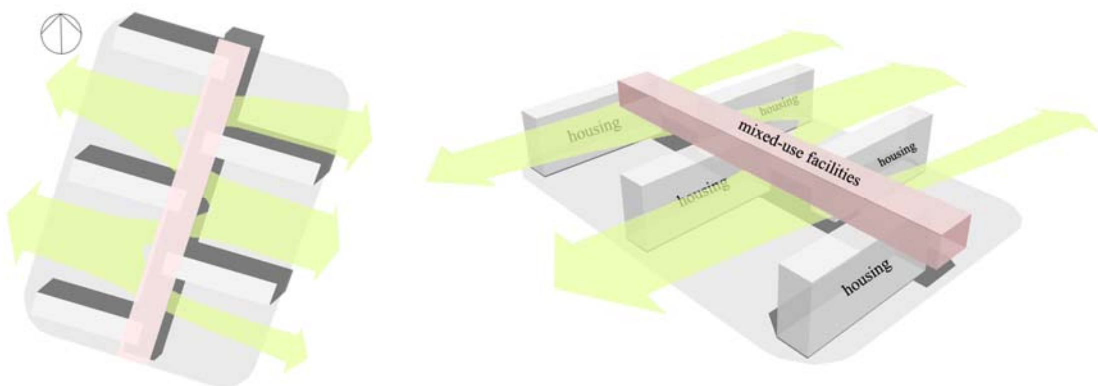


Figure 32: Mixed-use facilities backbone forms the central axis, lifting up to free the ground and the wind flow.

Source: Made by the author

The space inside the mixed-use area is organized an Urban Street where people can walk from the south direct to the Heping Park on the north. On the out side there is a system of open landscape with green spaces, exhibitions, outdoor theatre, playgrounds for children, sport activities, water surfaces and pedestrians.

The final layout

The different functionalities of mixed-use area can be design base on both the inside connection and the landscape outside. Inside connection is like an Urban Commercial Street with shops, stores, offices, school, restaurants, café, bar and other facilities; it is a vertical connection starts from the south and finishes at Heping Park on the north (fig. 33). The landscape outside is also a guideline to locate the inner space (fig. 36). The restaurants, café, bar should be located where people can have a great view to the outside without obstructions. On the other hand, working spaces such as office, school and store can locate where the obstruction is unavoidable (fig. 36). Different spaces can be formed as different blocks and well connected by street, ramp, staircase and elevator (fig. 37). Green roof will be placed on the top of each commercial and mix-use blocks, the total green roof area is 1.08 ha equals to 9.6% of total ground area (fig. 35). They can reduce heating, cooling, filter pollutants, carbon dioxin and heavy metals out of rain water. Green roof can serve as absorbing rainwater, providing insulation and even creating a habitat for wildlife or help to lower the air temperature on the site. Renewable energy can be applied on residential building in terms of solar energy (active solar techniques-by the use of photovoltaic panels and solar thermal collectors to harness the energy; passive solar techniques-include orienting a building to the Sun, selecting materials with thermal mass and light dispersing properties, and designing spaces that naturally circulate air) and geothermal energy (geothermal heat pump) for heating in winter and cooling in summer.

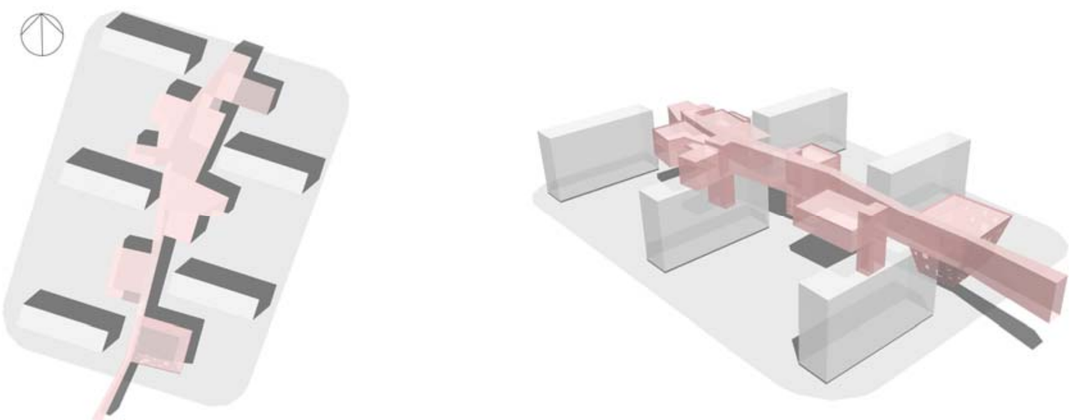


Figure 33: Achieve the final output *Source: Made by the author*

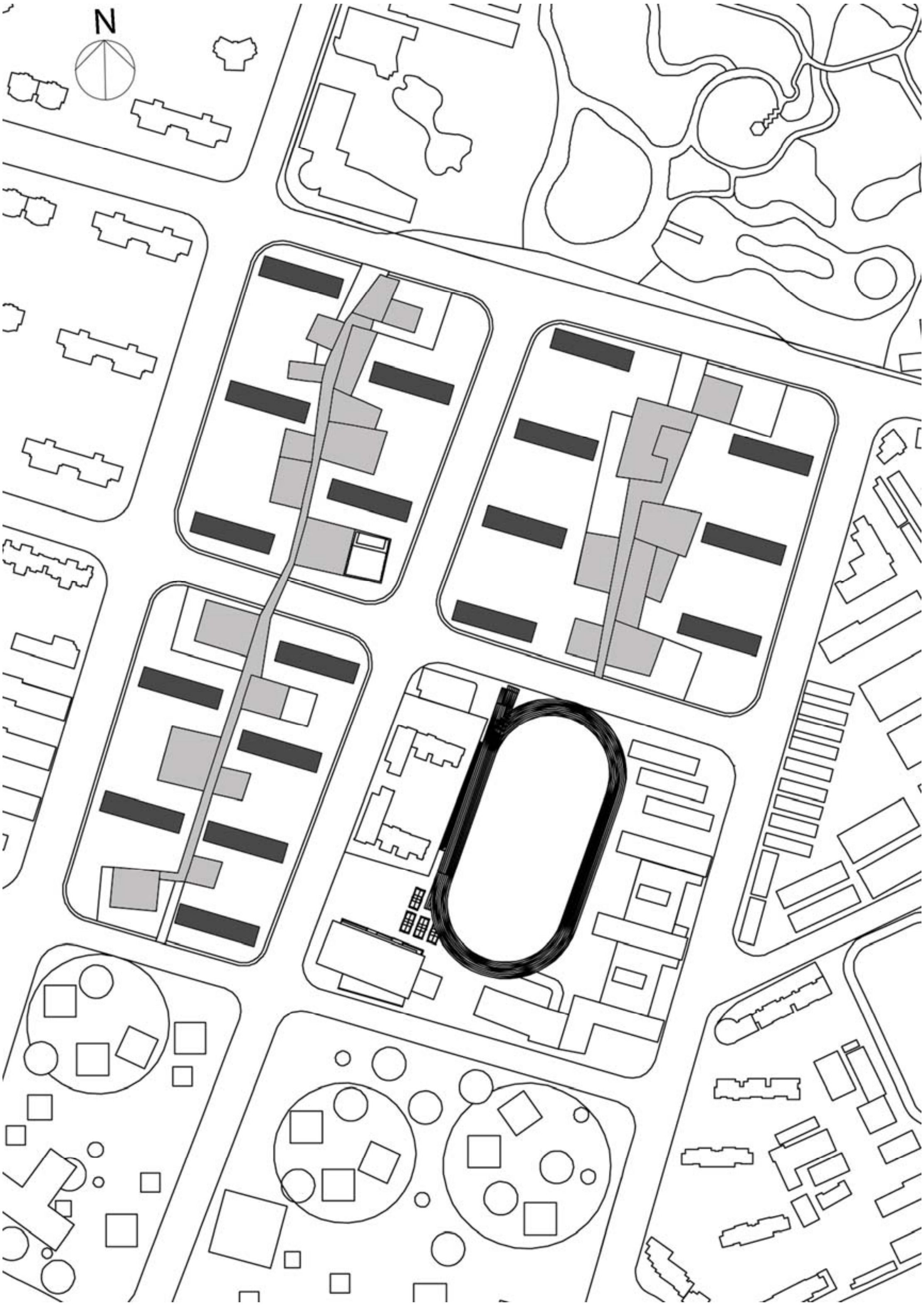
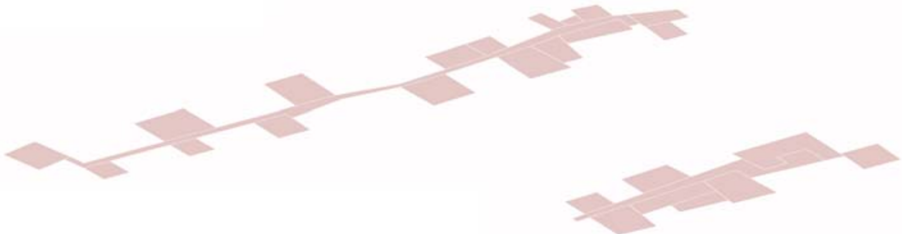


Figure 34: Master plan diagram

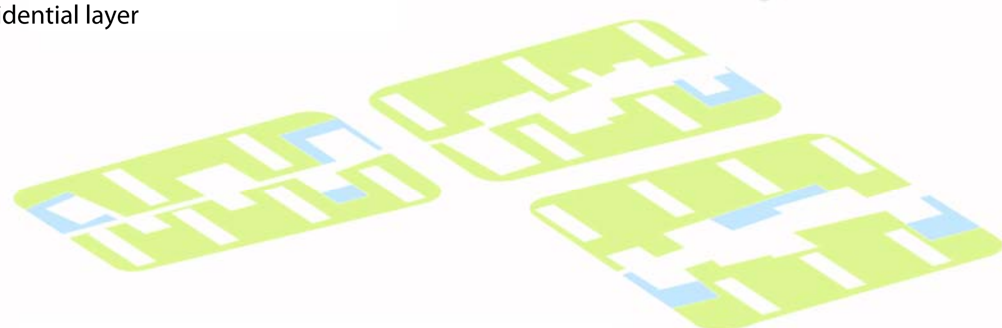
Source: Made by the author

Green roof layer

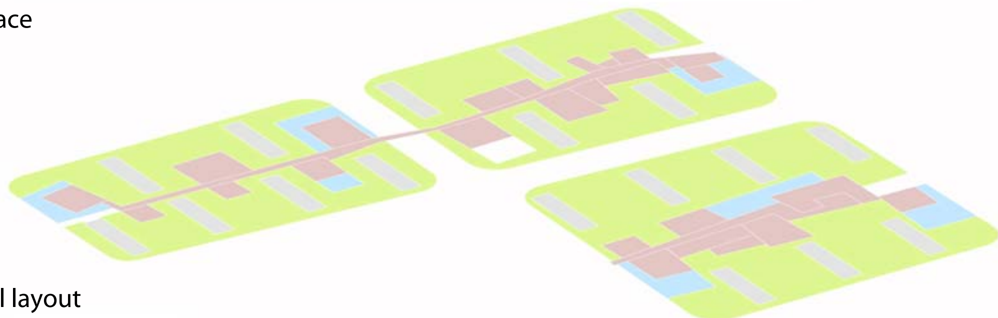


Commercial, mixed-use and facilities layer

Residential layer



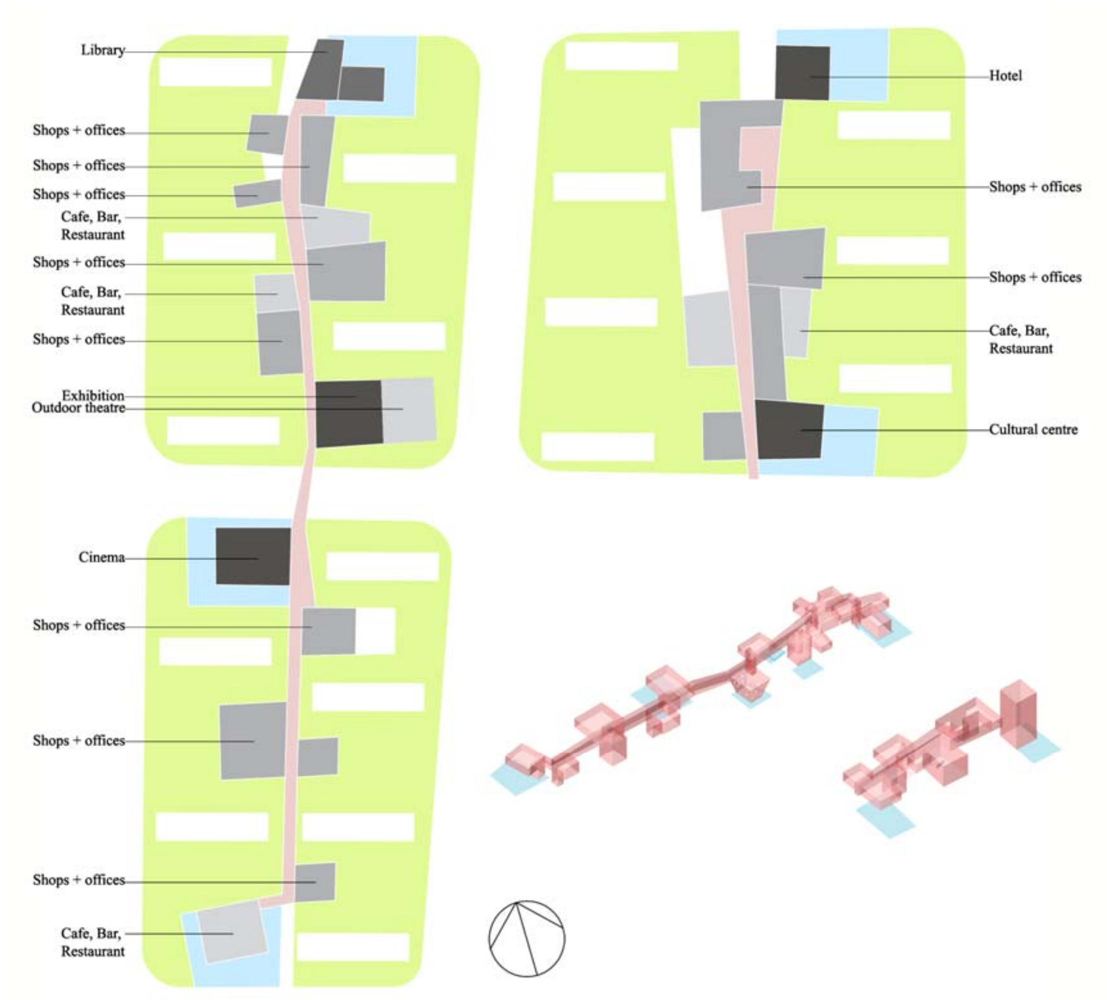
Ground layer for gardens, exhibitions, outdoor theatre, playgrounds, sport activities and water surface



Final layout

Figure 35: Different functional layers of Master plan

Source: Made by the author



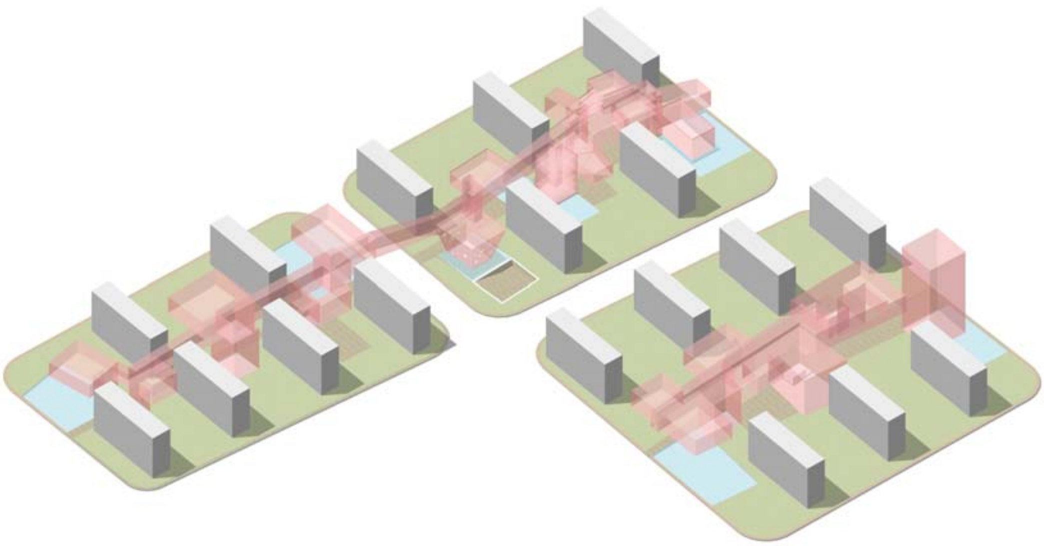


Figure 36: Commercial, mixed-use and facilities

Source: Made by the author

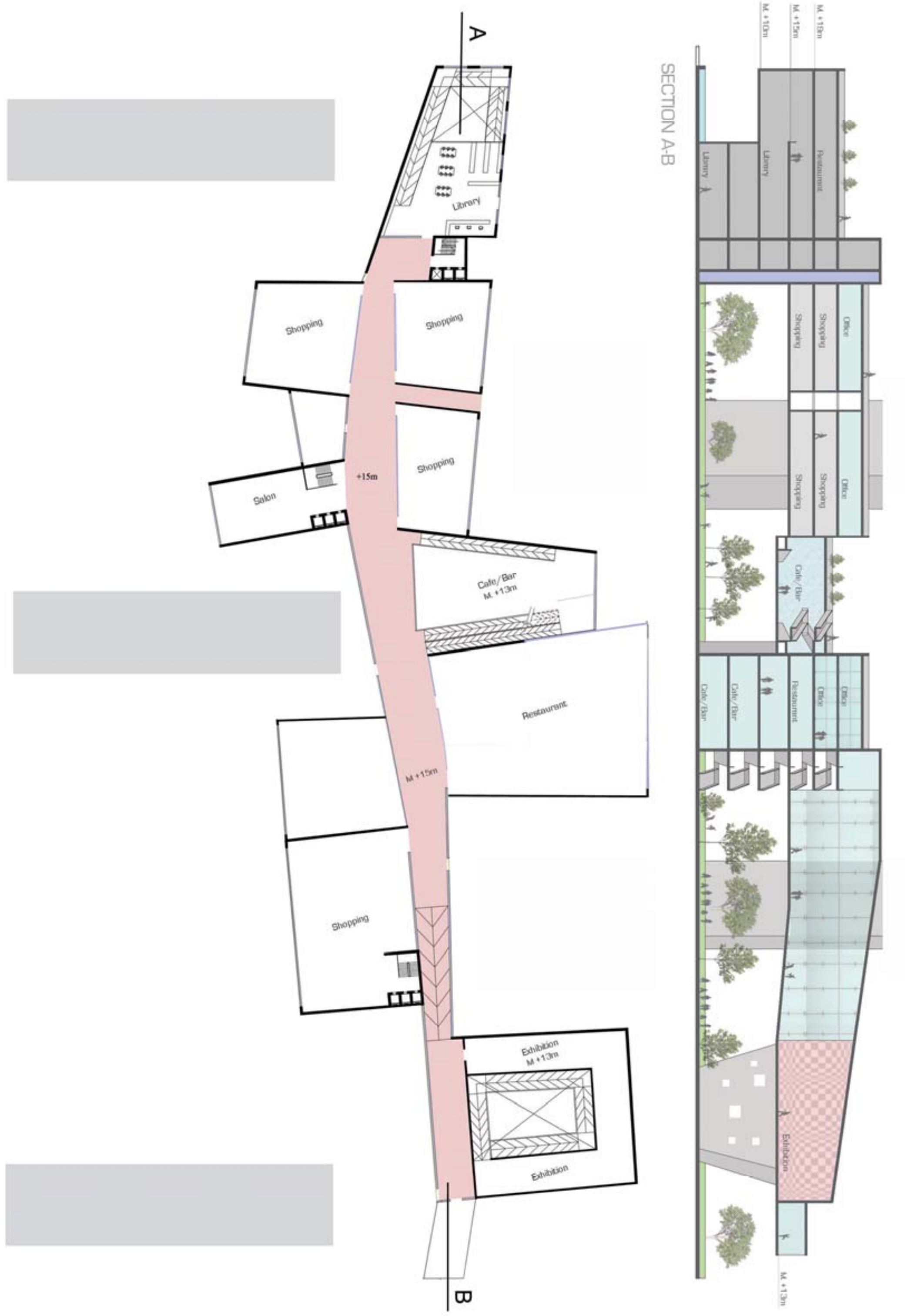


Figure 37: Plan of commercial street level (+15m) in Lot 1

Source: Made by the author

Environmental simulation

While designing master plan, Ecotect can test the environmental impact to the design by simulating visual model. The test result shows that the final layout is accurate in terms of the distance and the height of building. In this case all the south facades have sun light and almost half of the ground area has 5 hours for sun light on 21st, December (fig. 38, 39).

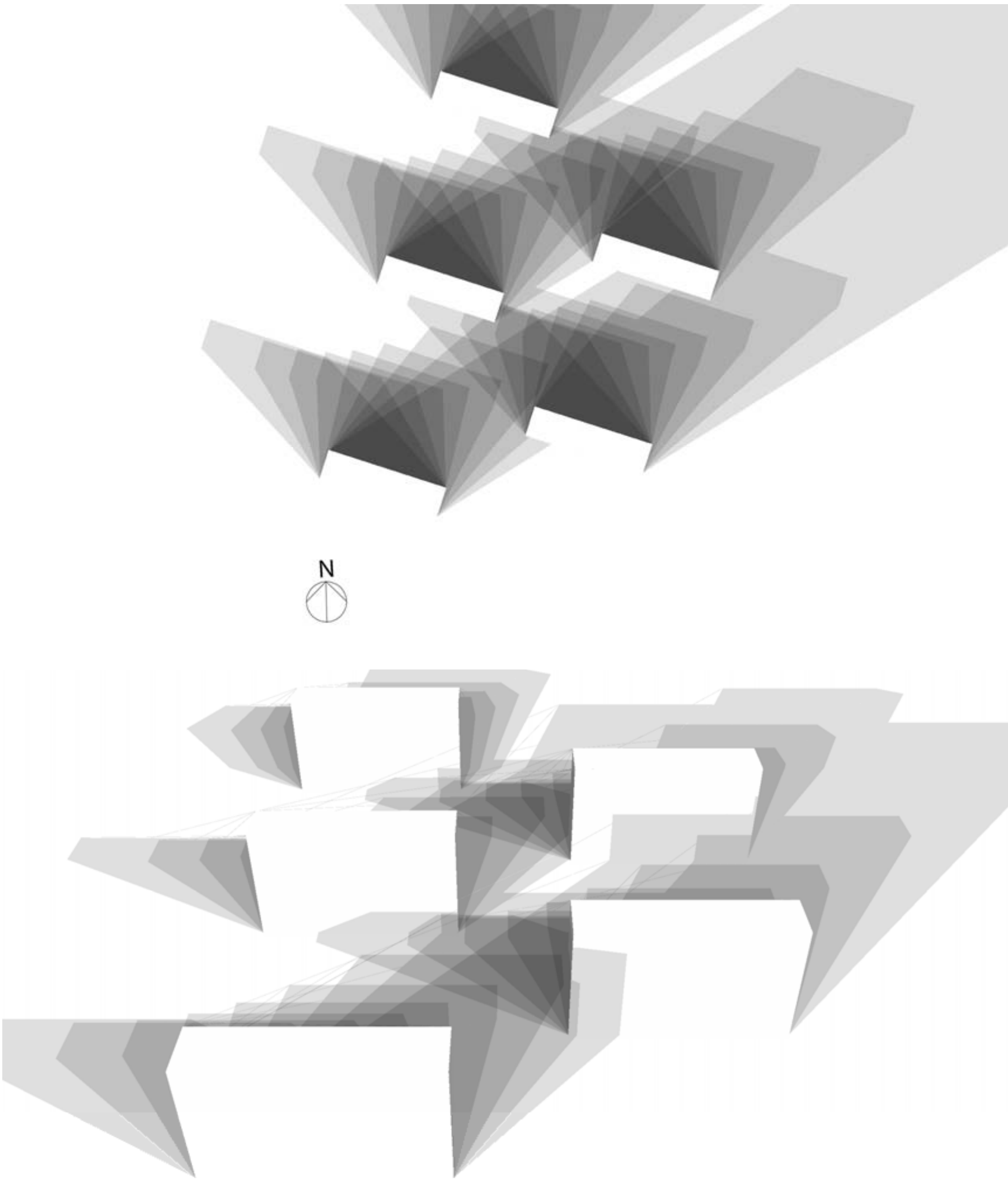


Figure 38: Shadow range of housing in Lot 1 (From 9:00 to 17:00, 21st, December)

Source: Simulated by Ecotect

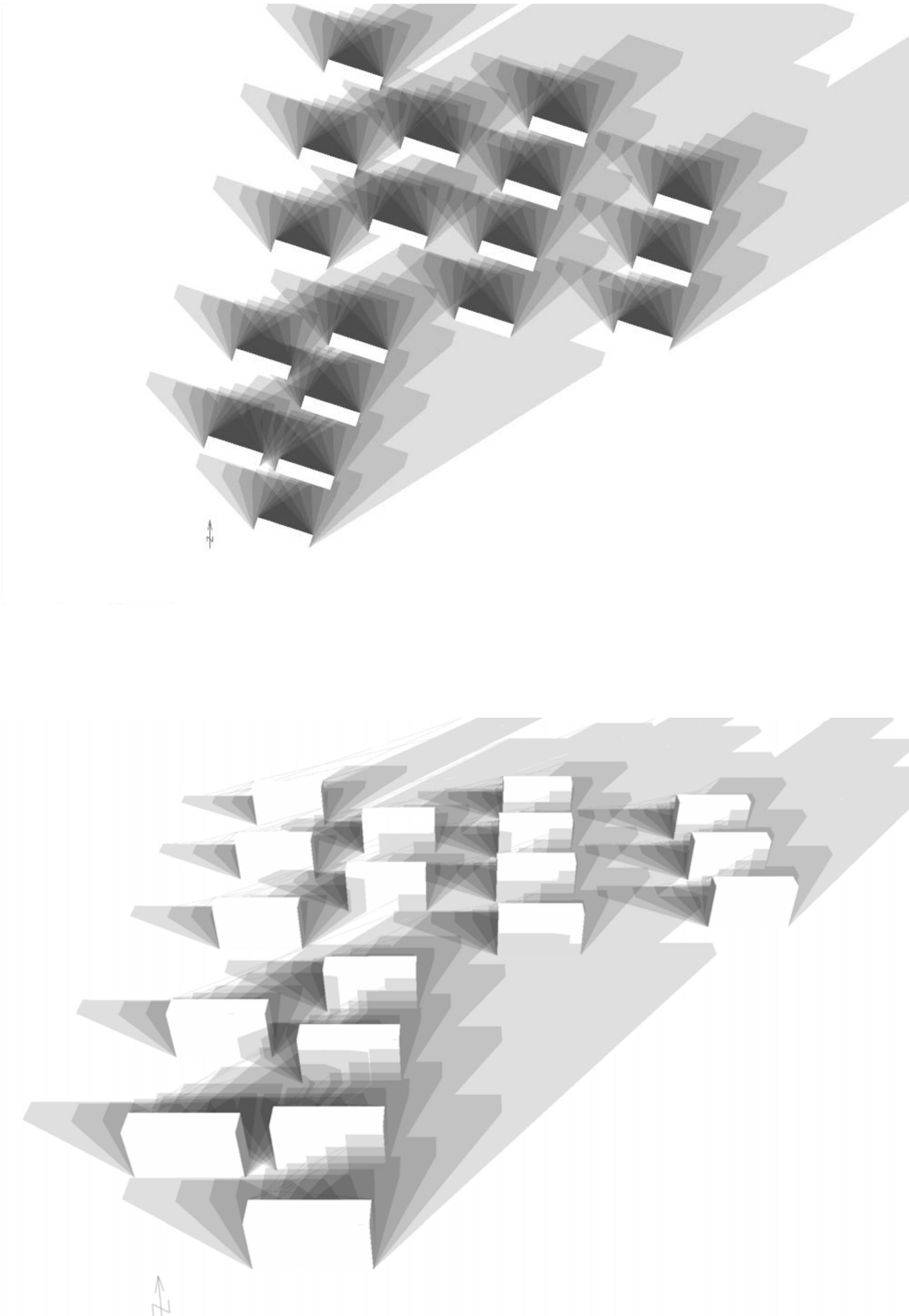


Figure 39: Shadow range of housing in three Lots (From 9:00 to 17:00, 21st, December)

Source: Simulated by Ecotect

After simulate with both housing and mixed-use facilities the result shows that 60% area of south facades have sun light in all daytime and 50 % has sun light for at least 4 hours on 21st, December. Comparing with the Chinese standard at least 2 hours for sun light in winter, our result is better (fig. 40, 41).

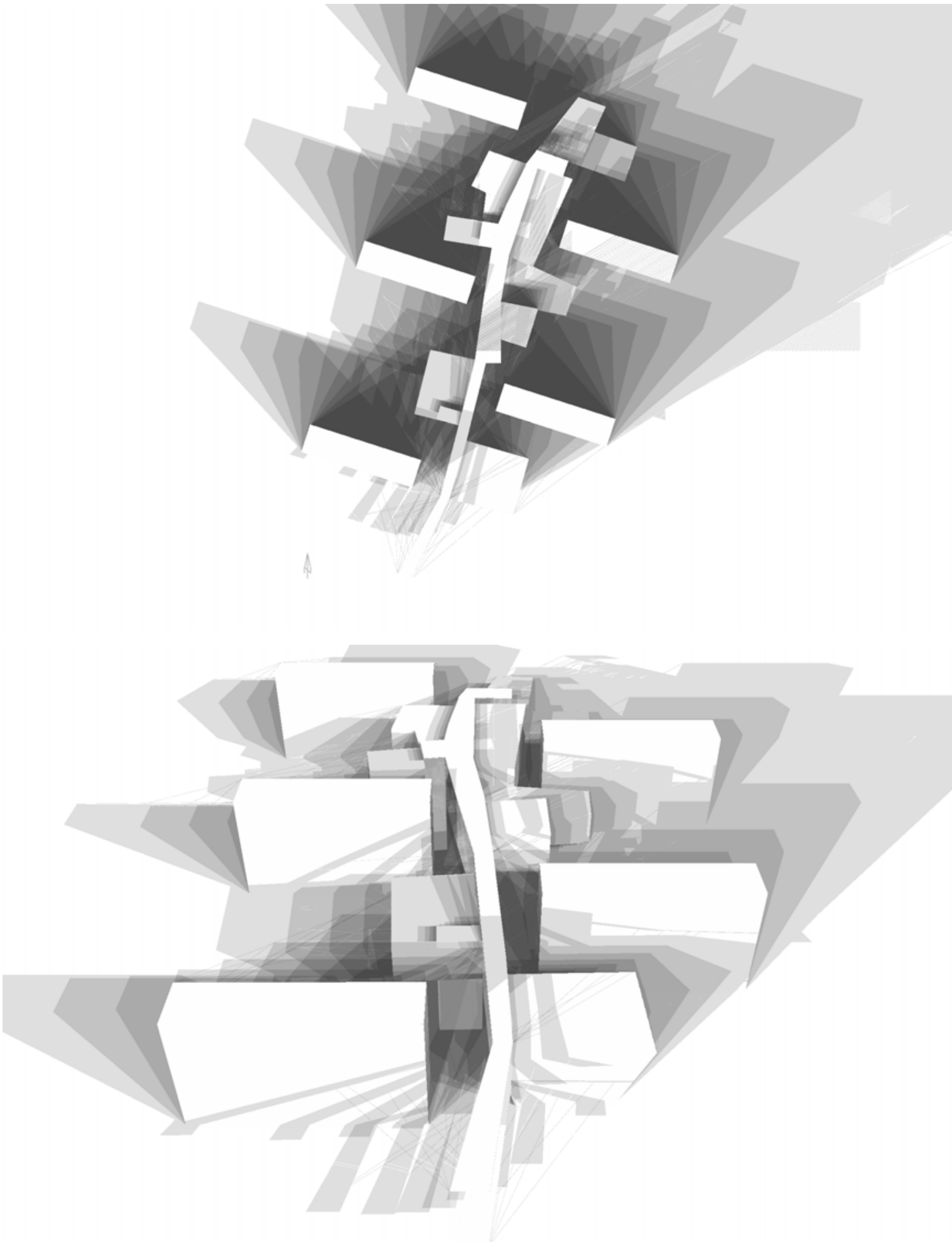


Figure 40: Shadow range in Lot1 (From 9:00 to 17:00, 21st, December)

Source: Simulated by Ecotect

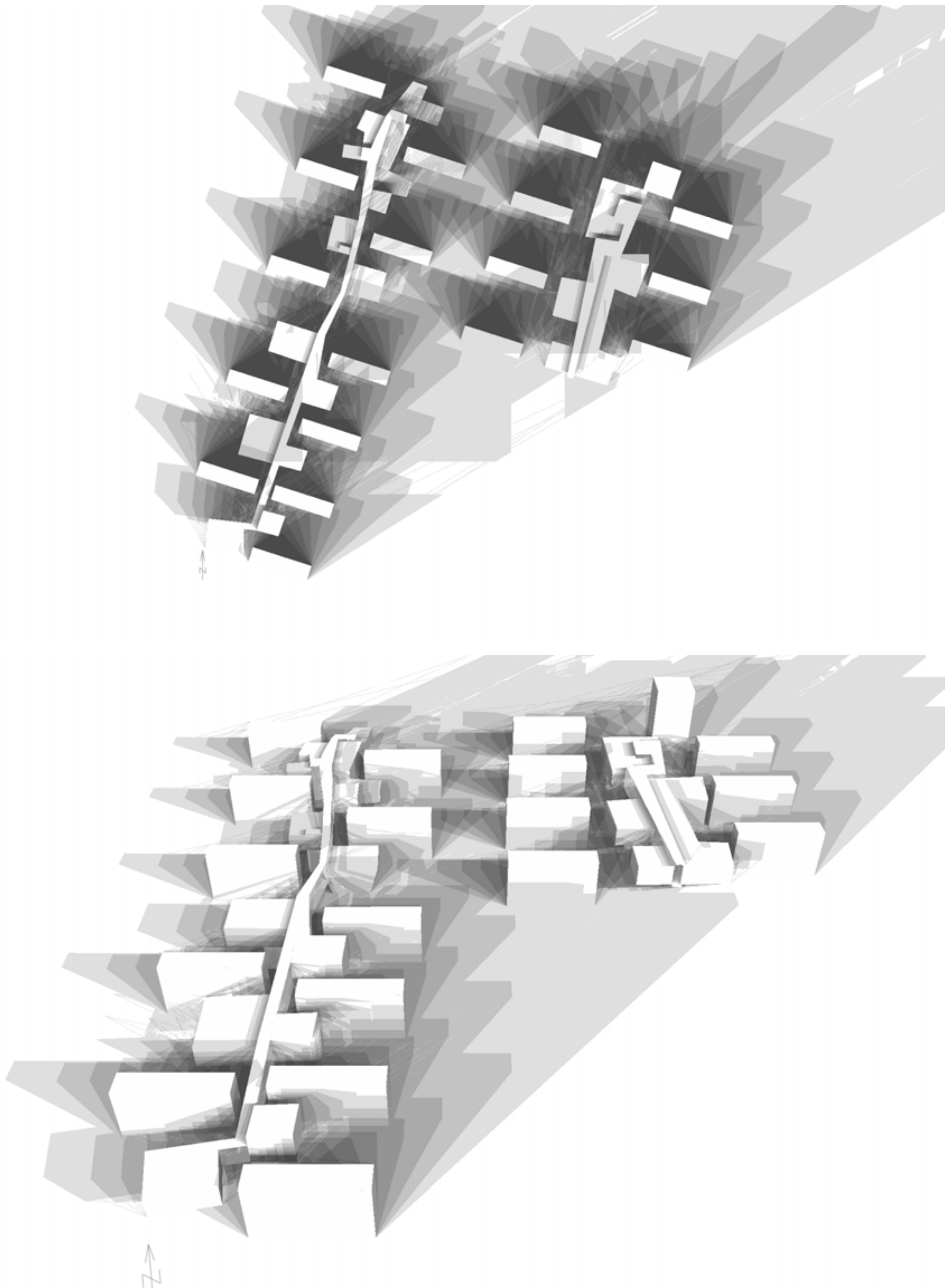


Figure 41: Shadow range of housing and mixed-use in three Lots (From 9:00 to 17:00, 21st, December)

Source: Simulated by Ecotect

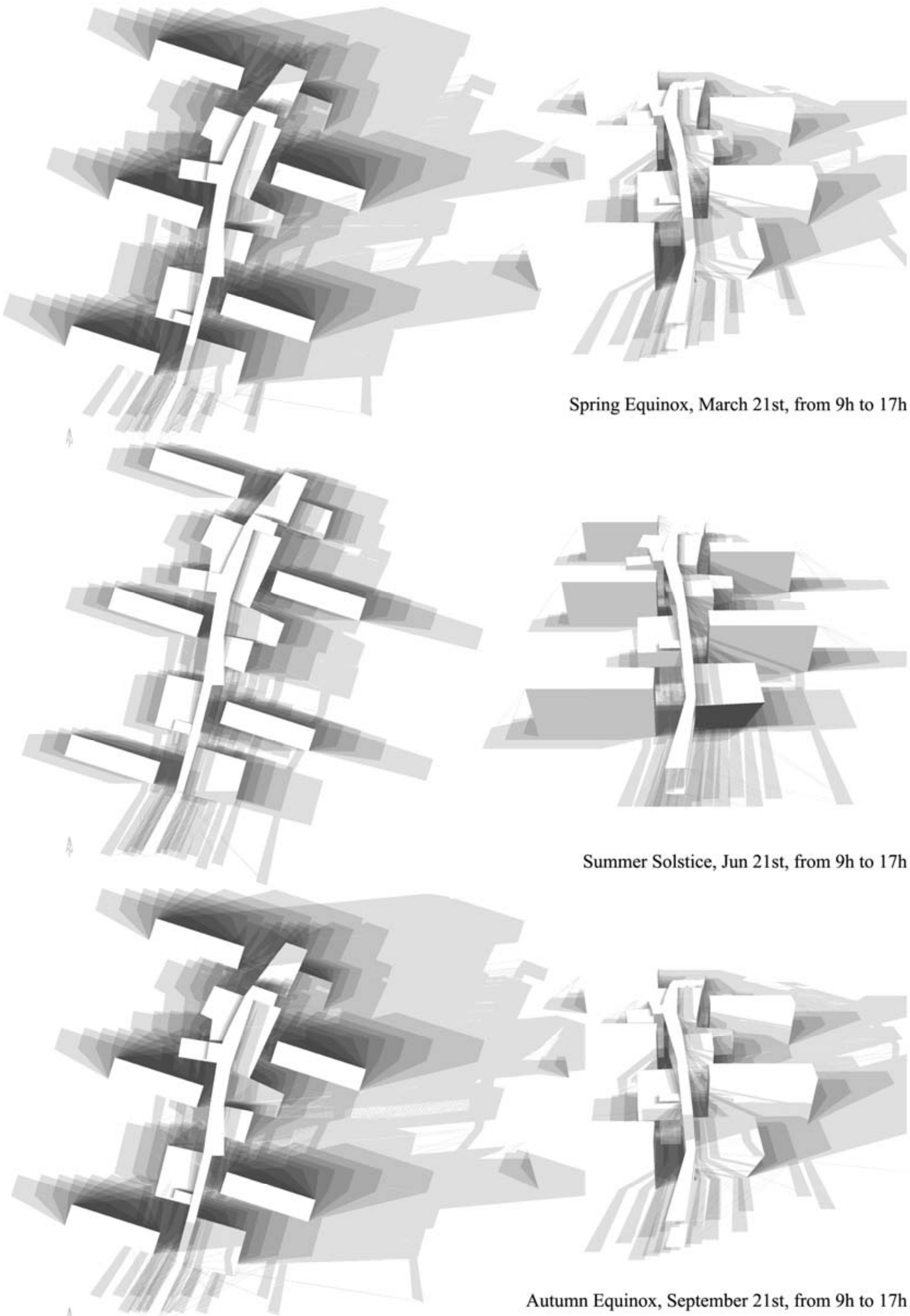


Figure 42: Shadow range in Lot 1 (From 9:00 to 17:00) *Source: Simulated by Ecotect*

Ecotect authorizes the architect to do the lighting simulation for many purposes; one useful output is the Total Sunlight Hours. The test will show how many sunlight hours in total that a surface can get in one day. Hence the architect can manage and reorganize the design in the way different spaces get their appropriate sunlight hours. In this design, the first graph presents the total sunlight hours on ground level on 21st, Jun (fig. 43). In summer, there are some areas which have zero sunlight hours means that these areas provide shadow. Consequently they can be used for activities which need shading like sitting or relaxing. These areas are not appropriate for planting garden and green space. Contrariwise, areas where have more than 10 hours of sunlight are applicable. Other location of public spaces like children's playground, sport activities, exhibition and outdoor theatre also can follow this approach.

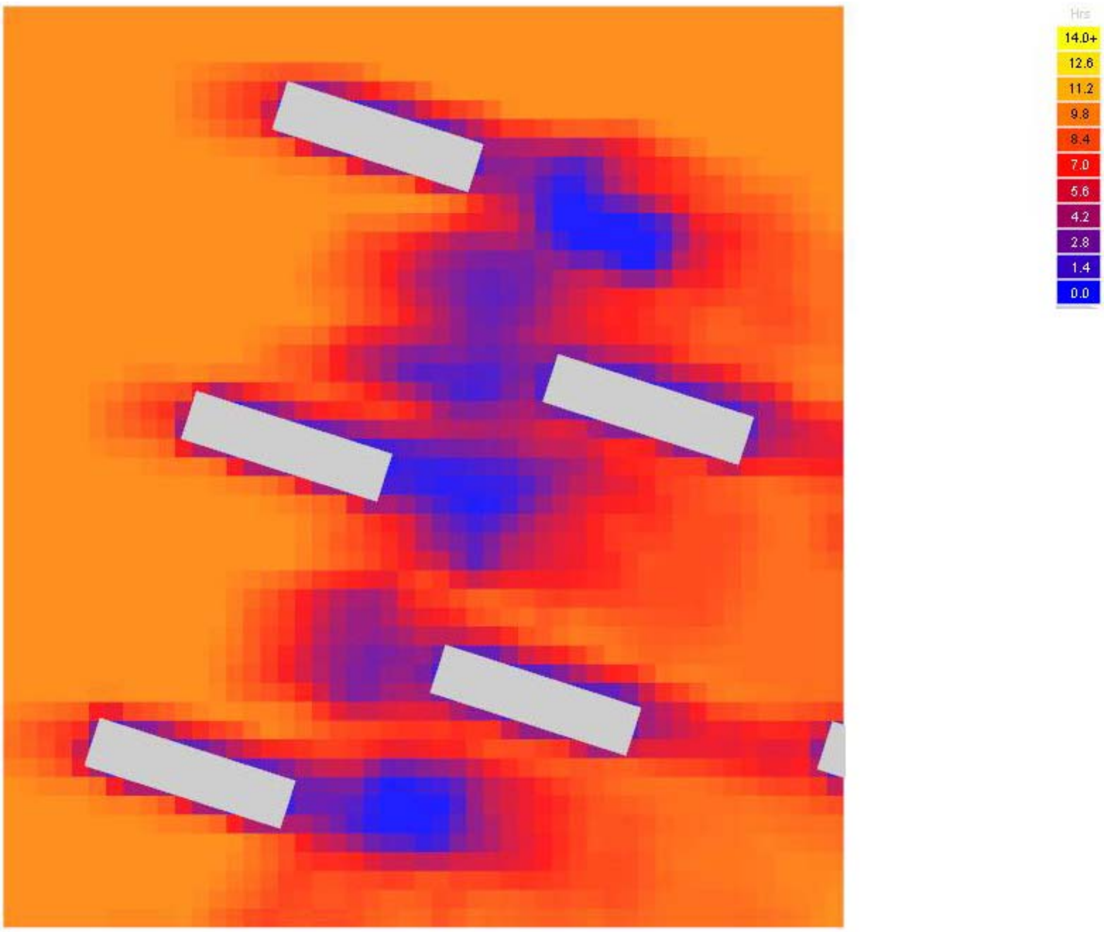


Figure 43: Total sunlight hours on 21st, Jun (ground level, Lot 1)

Source: Simulated by Ecotect

In winter more sunlight is needed, however because of the low altitude angle of the sun, there is a large shadow area on the ground. The second graph shows that on 21st December, half of the ground area gets more than 4 sunlight hours and another half gets less than 2 hours (fig. 44). Base on this result, spaces for sport activities and children playground must be placed where there is more sunlight. In the areas that have no sunlight both in summer and winter, planting is inapplicable.

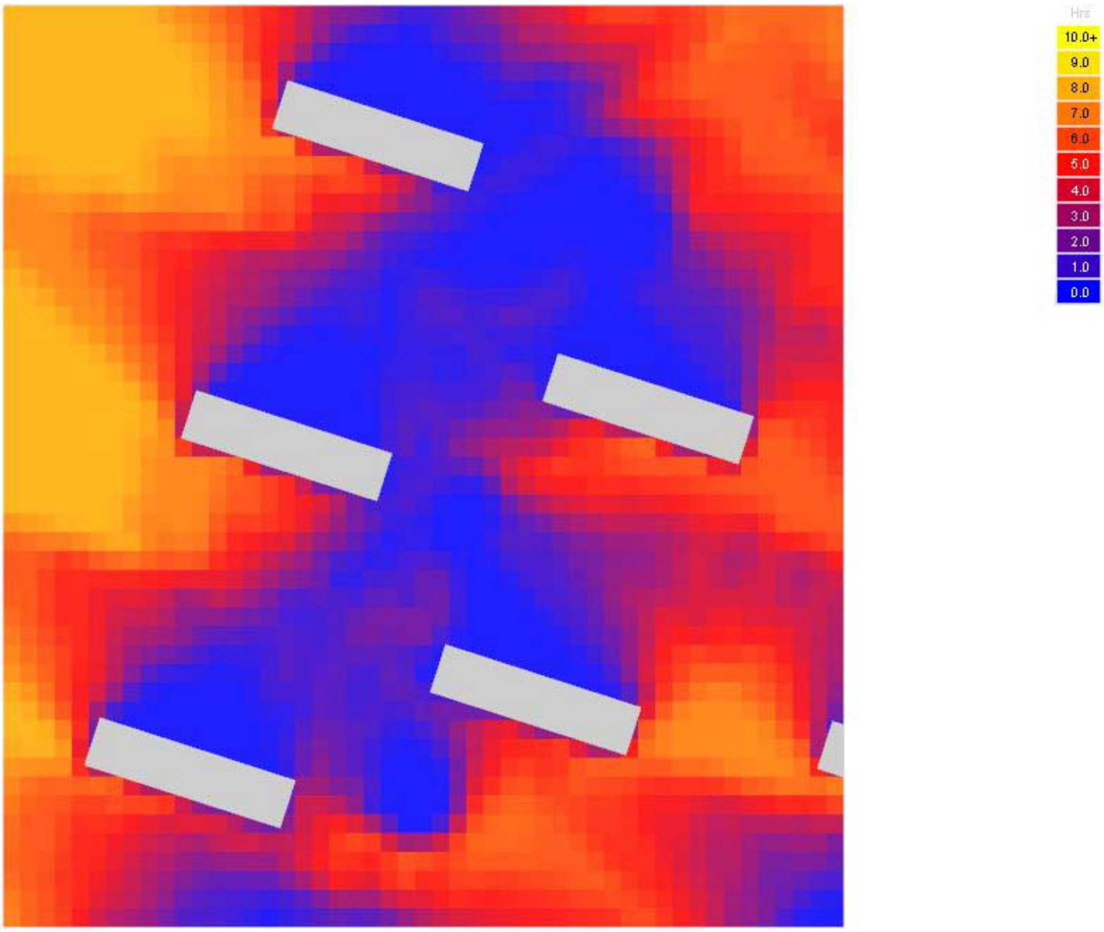


Figure 44: Total sunlight hours on 21st, December (ground level, Lot 1)

Source: Simulated by Ecotect

The above design concept for master plan is basic consideration of bioclimatic design approach. However, detailed bioclimatic analysis, optimization of the regulatory building systems in order to achieve its fine tuning and become successful climatic moderator, evaluation of the building performance, necessitate detailed and at the same time robust, dynamic and interactive design approach [9].

Chapter 4: Traditional courtyard house and its bioclimatic advantage

Contemporary architecture is frequently seen as the example of an internationalism, which eradicates local traditions and transforms the globe into a faceless urban sprawl [10]. It is often forgotten and even ignored that architectural traditions are rich in content, given that they have found the right harmony between the necessities of living, the environment, material resources and ideas on the use of space [11]. With the growth of population in cities brought by the modern urbanization, the horizontal development based on the typology of courtyard house, however, is not able to accommodate the growing population density of the modern cities. In addition, there appears a conflict between the conventional housing which is lack of modern facilities and the contemporary living style which is greatly dependent on equipment. Modern high-rise buildings, on the contrary, provide well-equipped housing for more residents, but lose some of the traditional spatial, social, and cultural values. To combine the precious traditional values and the modern architectural technology will be beneficial for contemporary architectural design [12]. Using these criteria, contemporary architecture could take a direction where cultural continuity and adaptability take pride place but also provide guidelines for climate-adapted and sustainable architecture. Contemporary design is depending increasingly on mechanically controlled environments in order to maintain comfort, hence increasing energy consumption [13].

This chapter focuses on the Chinese traditional courtyard house by analysing which design characteristics of the traditional house could be adopted in medium-rise building in order to further improve occupants' comfort and minimise energy consumption while considering issues of lifestyle requirements of contemporary living and culture issues which may also influence the housing design and its performance.

4.1. The form

The traditional Chinese courtyard house (Siheyuan) is a historical dwelling typology that was commonly found throughout China, most famously in Beijing. The form of the vernacular courtyard house has evolved over more than thousand years and produced building patterns best suited to local cultural and climatic conditions. Still today, many courtyard houses from the Ming and Qing Dynasties are preserved. The courtyard house presents some valuable spatial features which are hard to achieve in other housing types. Enclosure and opening in one is the fundamental principle of this old form of housing. The courtyard as an enclosed garden is open to the occupants of the house but completely closed against the outside world [14]. Starting from this principle, plenty of functional advantages such as sufficient social interaction, a clear spatial division between public and privacy, and a close connection of human and the nature all exist in the Chinese traditional courtyard house.

The literally translated name "quadrangles" means a courtyard surrounded by four buildings, indicating the basic layout of the courtyard house. The overall composition is in a symmetrical plan with an obvious axis, implying the hierarchical organization of the buildings [15]; the buildings are open to the central courtyard, while solid walls with limited fenestration are facing outside; narrow corridors provide a covered circulation within the complex. The presence of such components as the main hall, the decorated gate, the screen wall, the platform, and the wing chambers further shaped the configuration of the courtyard house. The layout of a courtyard house is in a very simple and rigid order. The four buildings of a courtyard house are normally positioned along the north-south and east-west axes (fig. 45). The building positioned to the north and facing the south is considered the main building. The buildings adjoining the main house and facing east and west are the side buildings. The northern, eastern and western buildings are sometimes connected by beautifully decorated pathways. These corridors provide shading, and serve as a transitional space between interior and exterior. The building facing north is known as the opposite building. The entrance gate, usually painted vermilion and with copper door knockers on it, is usually at the south-eastern corner. There is normally a screen wall inside the gate to protect the owner's privacy from the street (fig. 46). All of the rooms around the courtyard have large windows or doors facing onto the yard and small windows high up on the back wall facing out onto the street. Some houses do not even have back windows. Behind the northern main house, there would often be a separate backside building, the only place where two-story buildings are allowed to be constructed for the traditional courtyard house.

The courtyard is totally closed towards the outside and the whole complex is accessed through a single gate. The courtyard in the centre of the house is a natural, comfortable, peaceful and private open-air living room where the family members get contact with each other (fig. 48). With plants, rocks, and flowers, the courtyard is also a garden. Each courtyard was inhabited by a single large family. The main building with the rooms for the parents and the main hall - which was the main living space are always south orientated. The subsidiary buildings formerly containing the rooms for children and servants are located at the eastern and western side of the courtyard. All courtyard houses and the yard were entirely closed towards north (fig. 49). The houses have no basement, a stone floor, 30 - 50 cm thick walls out of grey brick, and a pitched wooden roof structure that is covered with a thick layer of clay and grey tiles.

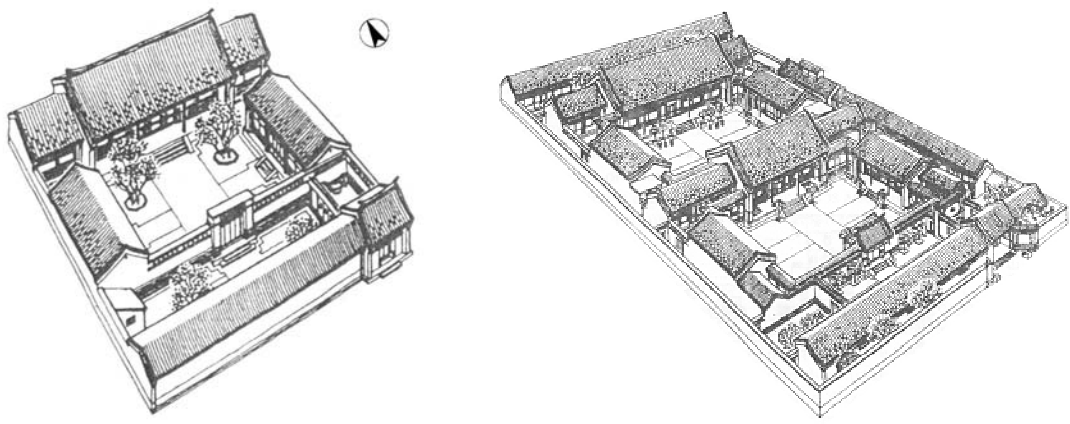


Figure 45: Traditional courtyard houses *Source: Beijing Siheyuan, by Ma, Bingjian, 2004*

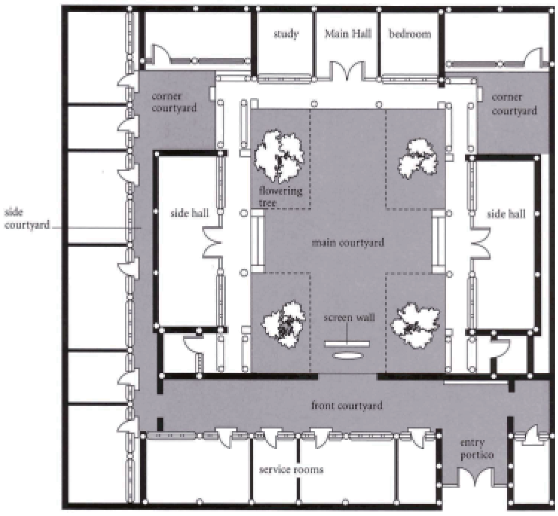


Figure 46: The Floor Plan of Mei Lanfang's (a celebrated actor) Residence in Beijing

Source: Chinese Houses, by Ronald Knapp, 2005

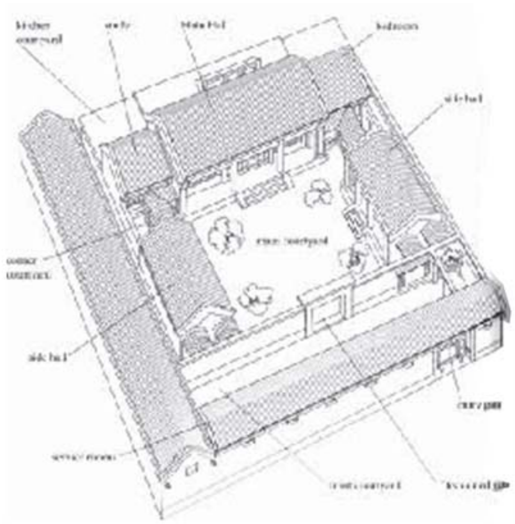


Figure 47: The Perspective of Mei Lanfang's (a celebrated actor) Residence in Beijing

Source: Chinese Houses, by Ronald Knapp, 2005

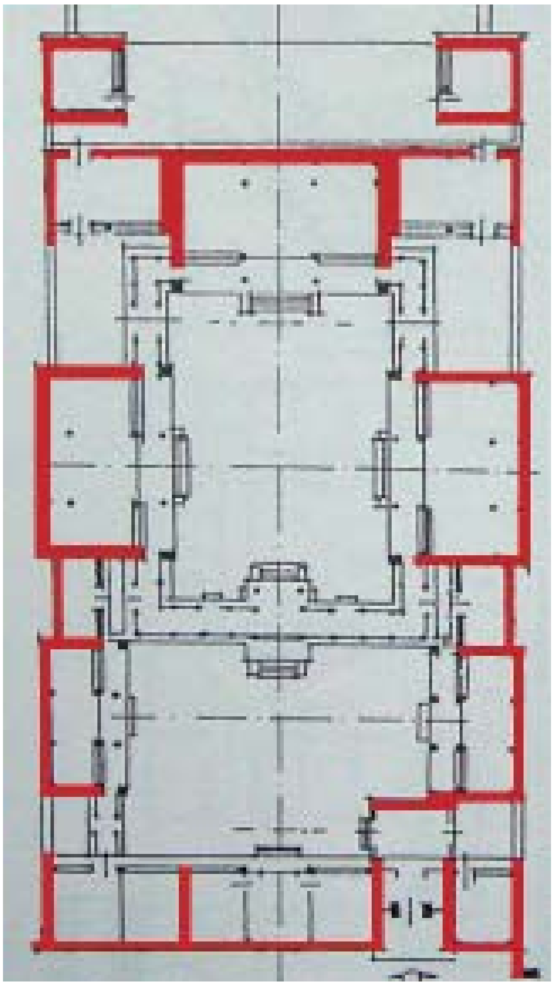


Figure 48: Interior and Exterior

Source: Chinese Houses, by Ronald Knapp, 2005

Figure 49: Solid Boundaries in the Courtyard House

Source: Reinterpretation of Traditional Chinese Courtyard House, Chen Li, 2009

Because of the different placement of building group and different climate and culture, the courtyard in different zone have different form and size. The building group has a closed building space and microclimate with courtyard, and the effect of climate on main rooms will be reduced. With the change of climate zone, the size of courtyard in traditional house is smaller and smaller from north to south in order to adapt the differences of climate (fig. 50, 51).

Figure 50: Courtyard is larger in the cold climate zone (north of China) to gain more sunlight in winter
Source: Internet

Figure 51: Courtyard is smaller in the hot summer and cold winter climate zone (middle of China) to prevent overheat in summer
Source: Internet

4.2. Thermal performance

Winter conditions

The fact that all housing units and the yard are entirely closed towards north helps to protect them from the cold winter winds. In the traditional way of use, the large wooden window screens facing the courtyard normally were covered with two layers of window paper on the inside and outside which also covered the cracks and gaps between the windows, so ventilation heat loss was reduced. Northwestern walls are usually higher than the other walls to protect the inside buildings from the harsh winds in the winter. The rooftop is ridged to retain warmth in the winter. The courtyard archetype is used to allow sunlight to penetrate into the house, is wide and open. In addition, the patio house is an open room sheltered from the cold wind [16].

Summer conditions

Most parts of the courtyard house including the yard itself are shaded by high deciduous trees, which in summer form a dense canopy above the maze of lanes and houses. The exact south orientation allows easy shading of the main façade, the south façade, from the high summer sun with relatively shallow roof overhangs (fig. 53). The stone floors and the 30-50 cm thick walls provide high thermal mass, just like the roof which has a thick layer of clay and tiles above the otherwise wooden structure (fig. 53). Natural shading, natural ventilation from the green courtyard and high thermal mass provided a comfortable climate in summer. While the outside temperature fluctuates between 17°C and 33°C, the inside temperature only swings between 20.5°C and 25.8°C [17], thus not exceeding the comfort range. The temperature curve of the courtyard house unit follows the outside temperature very closely, i.e. the peaks are just about one hour apart because the small room has a very big single glazed and not air tight façade towards the courtyard. However, the temperature curve is much flatter because of the heavy mass (fig 56). This high thermal mass, which is shaded all day by trees and thus kept cool, can further cool down during night, store the coolness and release it slowly during daytime towards the inside. The fact that the average temperature inside the courtyard house is 22.8°C over the measured period of 10 days, while the average of the temperature outside is 24.0°C [18] can also be attributed to the heavy mass and to the fact, that the stone floor is directly connected to the shaded ground that acts as a large radiant cooling device in the hot season.

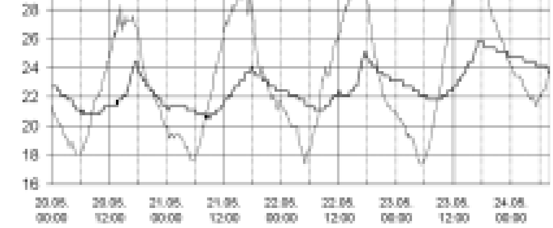
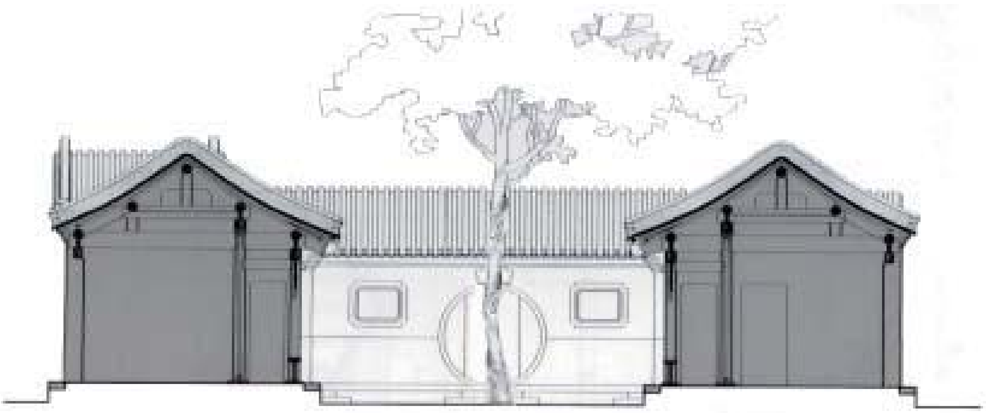
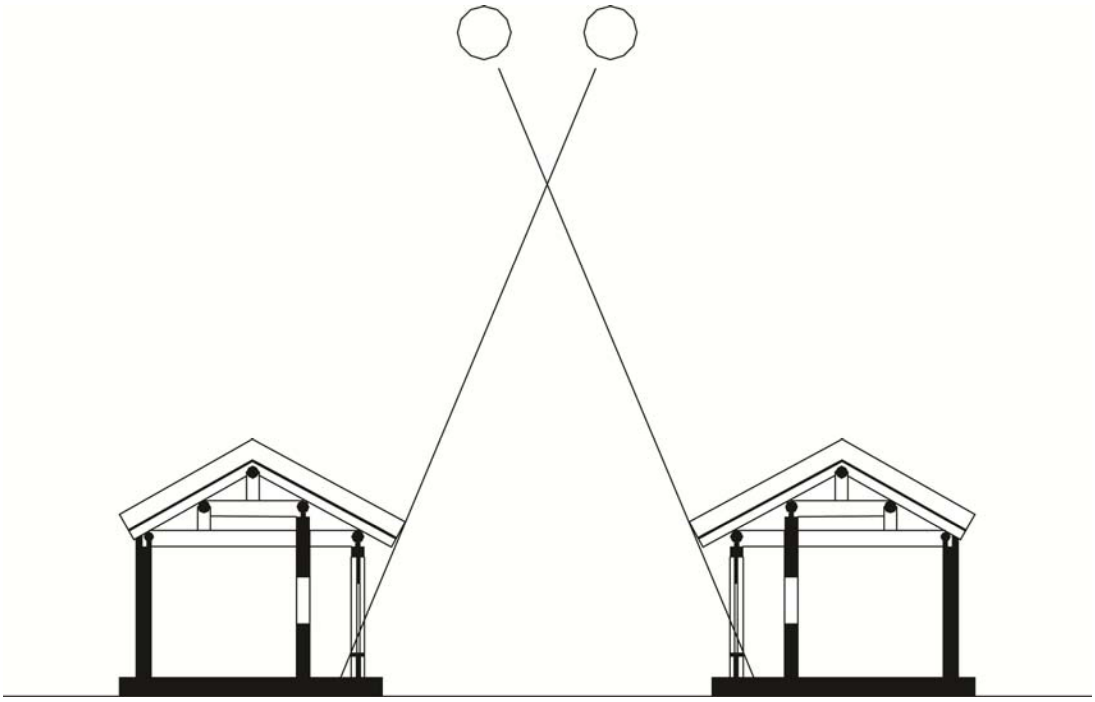
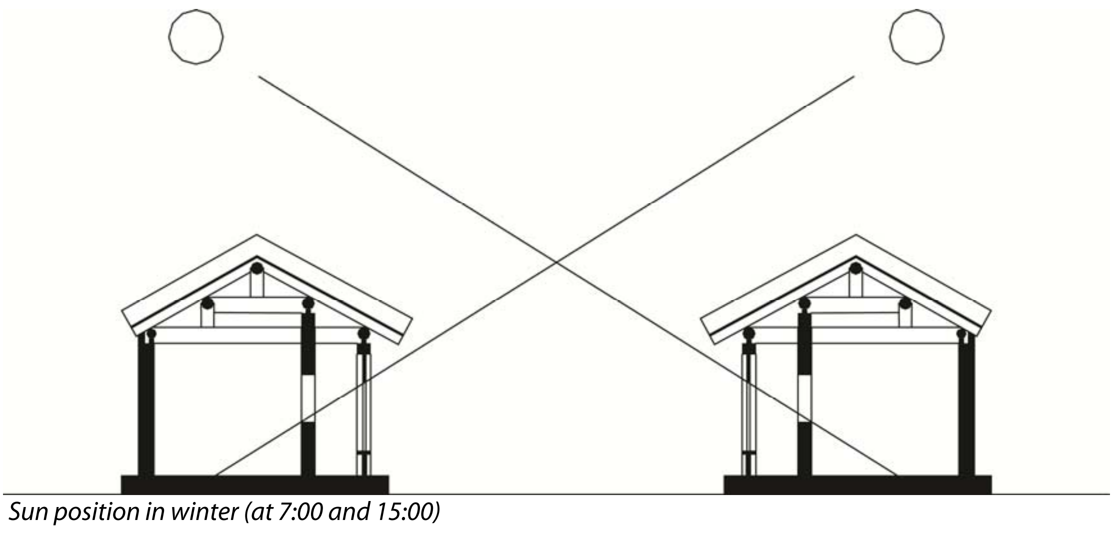


Figure 52: The heavy thermal mass of the courtyard house unit levels the low fluctuation of the inside temperature
Source: The traditional Beijing courtyard house Assessment, Barbara Muench, 2004





Sun position in summer (at 11:00 and 13:00)



Sun position in winter (at 7:00 and 15:00)

Figure 53: Shading, natural ventilation from the green courtyard and high thermal mass provided a comfortable climate in summer and winter *Source: Made by the author*

Natural ventilation

Large parts (more than 2/3) of the facades facing the courtyard are made of fine openable wooden screens, so that the narrow houses can be almost entirely opened towards the green courtyard for ventilation (fig. 54). The green plants and the low ground temperature from the shaded courtyard, help to provide comparatively cool, fresh air for ventilation even on hot summer days.

Figure 54: Fine openable wooden screens between Indoor and Outdoor
Source: Chinese Houses, by Ronald Knapp, 2005)

Daylight

The measured illuminance levels and the respective daylight factors of the eastern housing unit of the courtyard house on a sunny morning (88000 lux in the sun). However, the entire house is heavily shaded by trees (about 4500 lux under the trees taken as basis for daylight factor calculations). It can be seen that the daylight conditions of the relatively small houses are very good, 300 lux [19] indoor as one would expect.

Quality of outdoor space

The courtyard space is very pleasant: Shaded in summer, protected from the strong winds and other people's eyes from all sides, does it offer a green, private space in the middle of the city centre. The courtyard as an outdoor space is also an extension of the indoor. Kinds of supposedly indoor behaviors such as dining and meeting often appear in the courtyard. No solid walls are placed between the courtyard and the rooms. Lattice window panels having translucent paper on the inside provide variable amounts of light, air, and privacy to the interior space and permeate the warm and intimate atmosphere to the exterior courtyard. Another key element of the spatial permeation is the corridor (fig. 55) which is the overlapped space of the indoor and the outdoor. The corridor can be considered part of the interior, owning to the fact that it is shaded by the extended roof and is lifted to the same level with the rooms. On the other hand, the corridor belongs to the exterior, when the doors are closed. This natural transition from one space to another brings the "literal transparency" to the courtyard house, where a "deep and naturalistic space" exists (Rowe, 1976, p166).

Figure 55: Corridors in the Courtyard House
Source: Internet

Chapter 5: Proposals of courtyard house for medium-rise building typology

One of the main goals of the proposals is to *apply the bioclimatic approach* of Chinese courtyard house into the design of medium-rise typology. Beside, the courtyard can work as a sunspace which serves as a buffer zone between the living area and the outside, can preheat ventilation air and increases total amount of sun light. In the courtyard, terrace garden can create a new micro climate, absorbing CO2 and fine dust, returning oxygen and reducing energy for the air-conditioning. The design also aims to provide a good nature day lighting and nature ventilation. Super insulation will help to maintain the comfort indoor temperature. Last of all, these proposals aim to *minimize the heating/cooling energy demand of building envelope* by an appropriate passive solar building design as well as using super insulating material and low emissivity window. The courtyard is considered as major element, always facing to the south and by its different location (in the middle or on one site of the apartment) will form different housing typologies. Beside, the height and the depth of court yard also cause different environments. In this thesis, the author proposes 4 different apartment typologies; three of them are *normal-one storey* and one is *duplex-two storeys*. In a normal apartment the courtyard has 3.5m height and 3.5m to 6m depth; in a duplex apartment the dimension is 7m height and 6m depth.

These first three typologies have the same dimension 7x16x3.5m; each contains 2 bedrooms, a kitchen + dining room, a living room and one room for guest. In the Typology 1 the courtyard is in the middle with the dimension 3.5x8m. The day-rooms (kitchen, dining room and living room) have large window area opens to the courtyard and the night-rooms (2 bedrooms) have smaller one (fig. 56). Typology 2 has a courtyard on one side and a small terrace on another site hence the area exposed to the environment outside is more than Typology 1(fig. 57). Courtyard in typology 1 and 2 has the same dimension 3.5x8m as 28% of the floor area. Typology 3 also has courtyard in the middle but different outline from the others. The courtyard is deeper with 6m depth thus all the rooms can connect directly to it, likes a traditional one – the courtyard is the house's centre. The area of courtyard's mouth is 6x3.5m with wide opening by modifying the wall (fig. 58). By that adaptation, on 21st, December all the partition area on the left side can have sunlight starts from 8:45 and until 15:00 for all the area on the right side. It also means the courtyard can have more passive solar gain in winter. In this case, the courtyard's area is 36m2 as 32.14% of the floor area. The living room here is merged into the courtyard and as a result the space has characters of both – a living space and a courtyard. There is no accurate form for the living room, by organize the interior in different ways we can have different spatial results. One residential block can contains 3 or 4 apartments on the plan (fig. 59). Many options are available to combine these three typologies, horizontally and vertically (fig. 60). The building can be planned by Typology 3 only and with incline section (fig. 61) so that it can increase amount of sun light in the courtyard or either having vertical ventilation from one courtyard to another. The final layout is varied, showing the different building appearances in architecture point of view (fig. 62, 63).

Figure 56: Typology 1-Courtyard in the middle

Figure 57: Typology 2-Courtyard on the site

Figure 58: Typology 3-Courtyard in the middle with 45° wide open to get more sunlight in winter, from 8:45 to 15:00 on 21st, December

Figure 59: Plan forms by three typologies

Figure 60: Different layouts will give different forms (in horizontal and in vertical)

Source: Made by the author

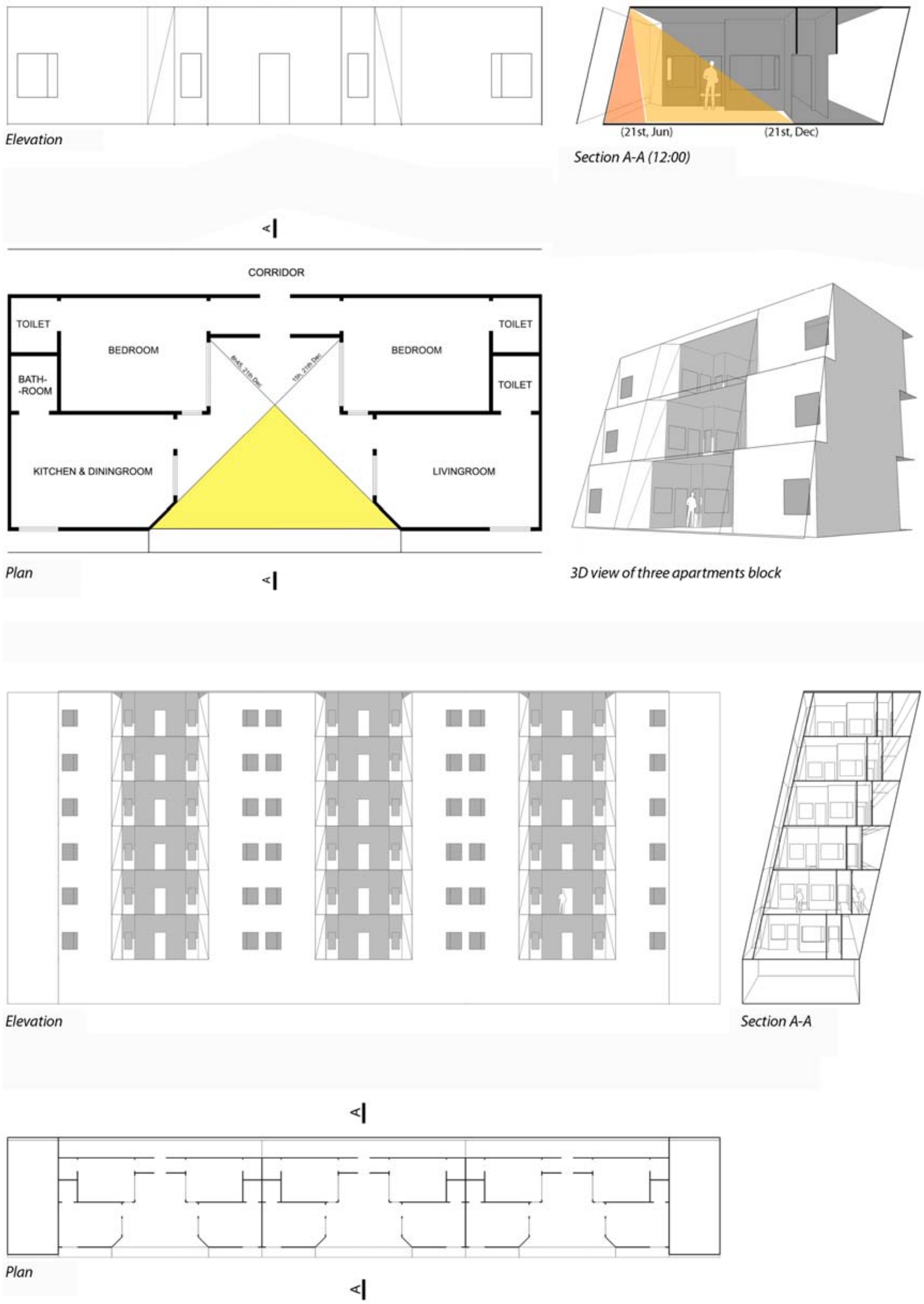
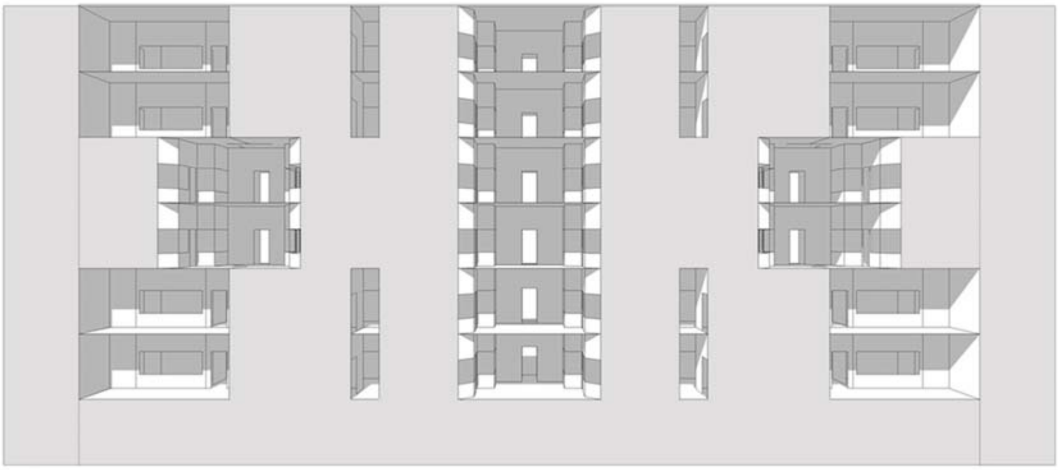
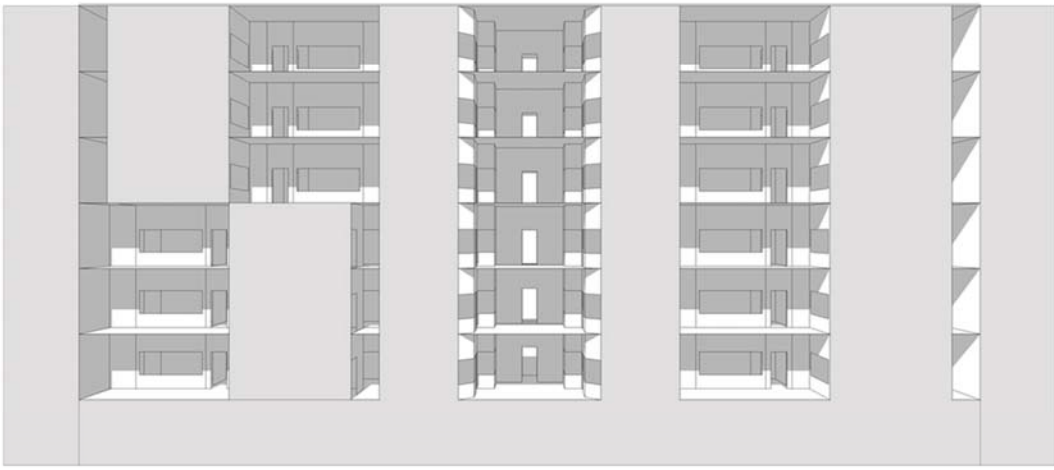


Figure 61: Proposal using only Typology 3

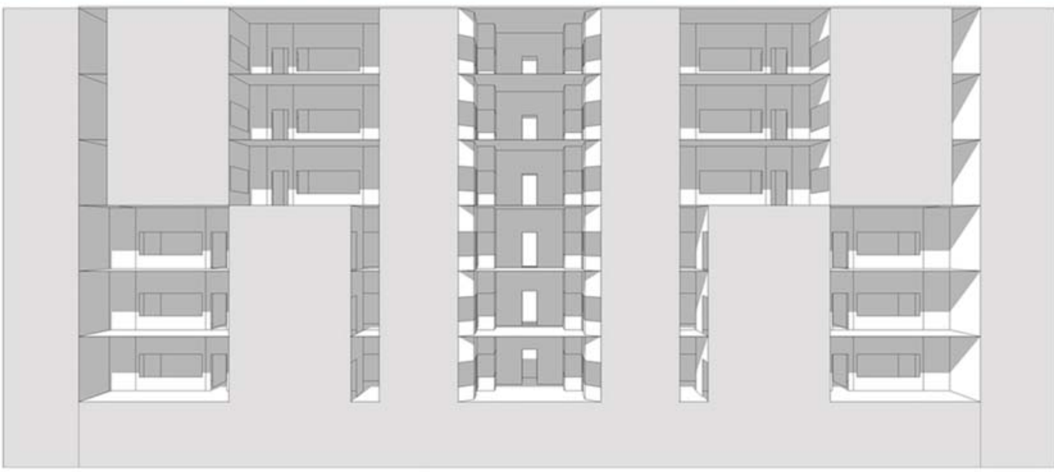
Source: Made by the author



Left and right side: combination of Typology 2 and 3
Middle: only Typology 3

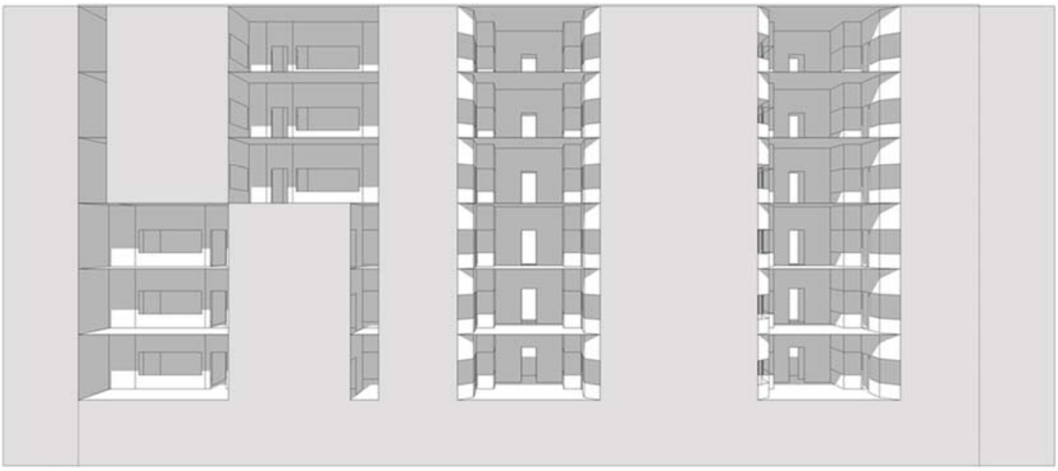


Left and right side: only Typology 2
Middle: only Typology 3

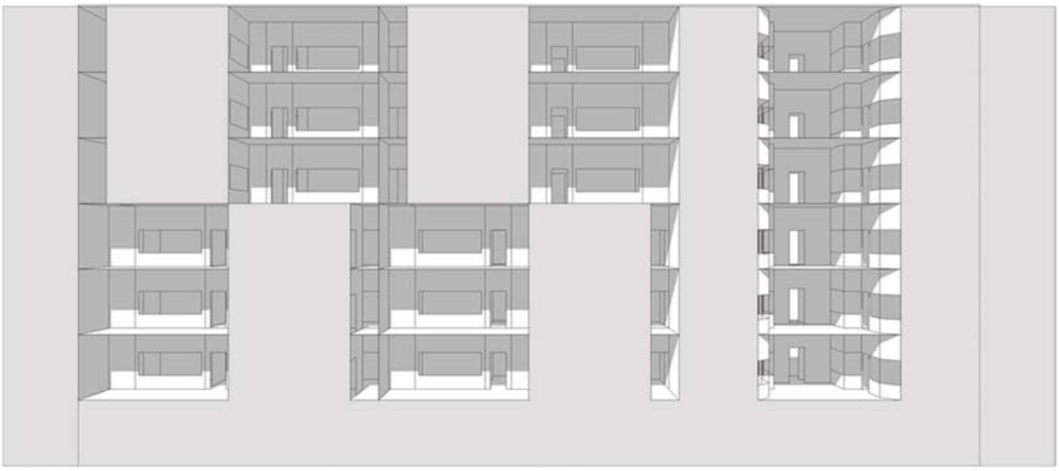


Left and right side: only Typology 2
Middle: only Typology 3

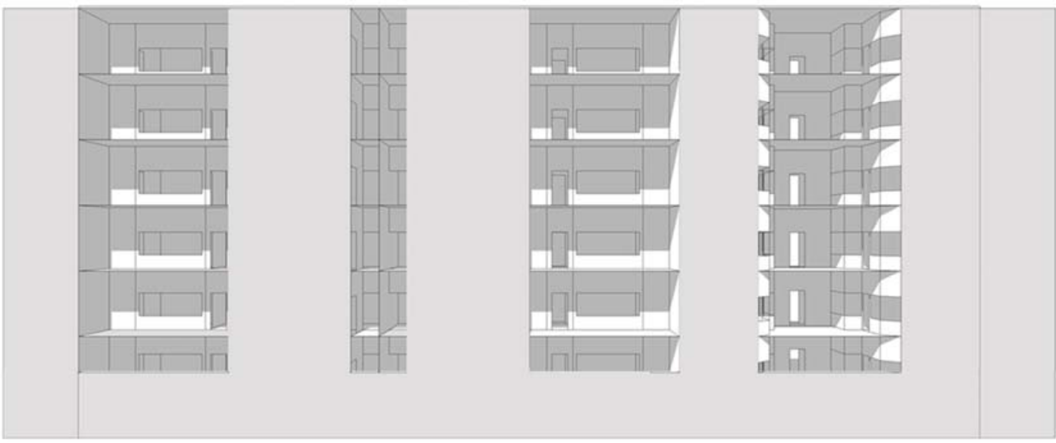
Figure 62: Different layouts of building *Source: Made by the author*



Left side: only Typology 2
Middle and right side: only Typology 3



Left and middle: only Typology 2
Right side: only Typology 3



Left and middle: only Typology 2
Right side: only Typology 3
Figure 63: Different layouts of building 2 *Source: Made by the author*

Chapter 6: Courtyard- Duplex typology

In the last chapter three proposals of three *Normal-one storey apartments* present good lighting and solar gain condition, however they still has problem. The first is the outside corridor on the north façade does not allow the cross ventilation of the building. The second is because the typology is one-storey apartment hence 3 m height of courtyard is quite low and is not appropriate for terrace garden. From that cause, the author proposes a Courtyard-Duplex typology to achieve the best solution.

6.1. Why Duplex?

Courtyard can be adapted to Duplex typology by locating in the middle of 2 apartments. The idea is to have 2 courtyards connected together which allow both cross ventilation and sunlight comes into the building (fig. 64). The first diagram shows that each apartment has one private courtyard aside. However the Duplex typology is linked to corridor in between thus the flat must have 2 storeys in which the entrance on lower floor is open to the middle corridor. On the first floor one flat towards north and another faces to south, both connect to the corridor in the middle. Each house on this floor is divided in 2 parts which have private courtyard in between as a traditional order (fig. 65). On the second floor beside the courtyard, one flat on the left and another on the right; each house has visible connection to its courtyard, furthermore window can be opened to the second courtyard on the second floor level for lighting and ventilation while not invade the neighbor's privacy (fig. 66).

The 2 courtyards on the first floor are totally private, separated with each other by wall and corridor. Nevertheless they are linked together as one semi-public space on the second floor level which allows sun light comes from the south to the north courtyard in winter and cross ventilation of building in summer. The 7 m height now gives the courtyard a possibility to own terrace garden with different high levels of tree.

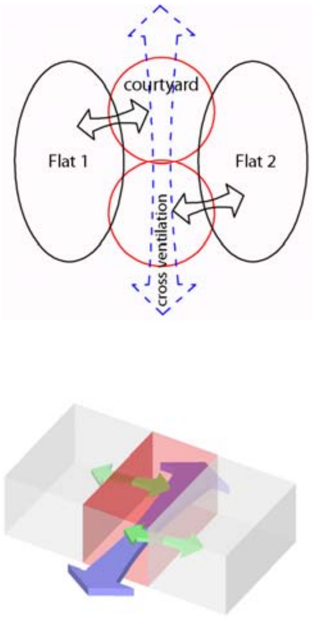


Figure 64: First idea of Duplex typology

Source: Made by the author

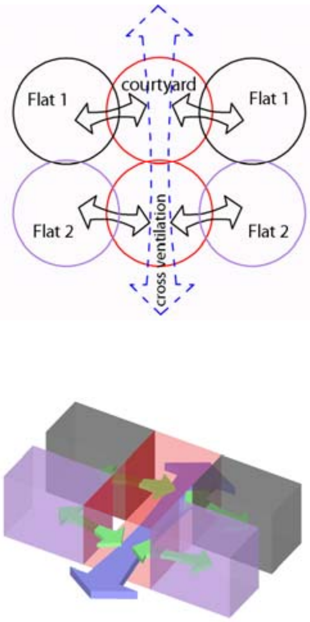


Figure 65: First floor

Source: Made by the author

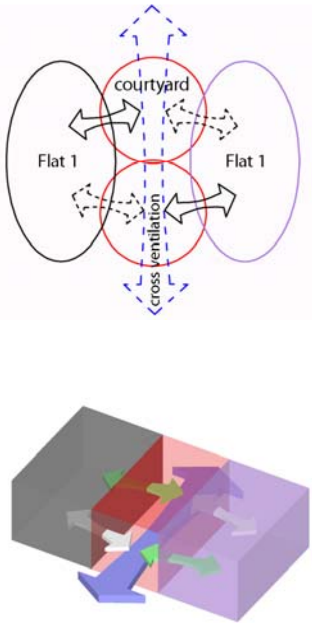


Figure 66: Second floor

Source: Made by the author

6.2. Building form

From those diagrams of Courtyard-Duplex typology, together with the Design Guidelines proposed by Climate Consultant 5 presented in Chapter 1 along with taking in account the Bioclimatic approach presented in Chapter 4, the final form of building is come out. Each 150 sqm apartment has 1 living room which is always facing to the south, 1 kitchen and two bedrooms. The north courtyard is situated in between 2 bedrooms while one the south is in the middle of the living room and the kitchen. Three of four bedrooms face to the north, one to the south. Every room has windows both open to the courtyard and to the outside (fig. 68).

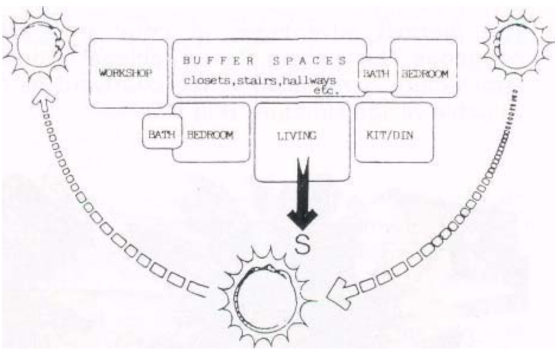


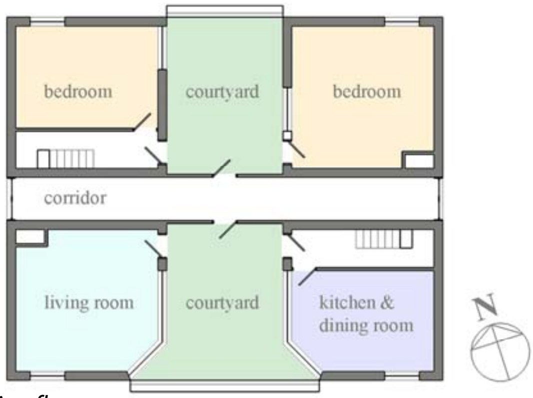
Figure 67: Building layout to follow sun path

Source: Bioclimatic design and energy conservation in buildings, Despina Kyprianou Serghides

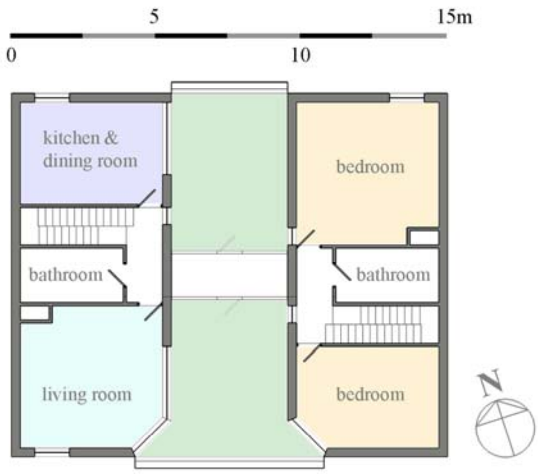
South courtyards can have a regular open or 45° wider open, in order to have more solar gains and sun light, plus guiding summer wind goes inside the house. We will check both cases in the next Chapter by Ecotect simulation tools. Building's plan contains 4 Courtyard-Duplex blocks, 8 apartments in total. Medium-rise building has 6 storeys in which 5 storeys for housing, ground floor for garage and facilities. The dimension of one building is 64x12.5x24.5m; each one has one staircase and 2 elevators in the middle (fig. 69, 70).

In summer, either building's orientation or openable vertical glazing panels will guide the summer wind flows throughout the courtyard, make a cross ventilation in the night (fig. 71). It should be noticed that the humidity in Shanghai is very high thus natural ventilation is important for dehumidification of the house. Cool and dry air flows into the house from the south, throughout all the rooms and courtyards via windows and doors then becomes hot and humid after it gets out on the north. Figure 71 shows us how the cross ventilation could happen in Courtyard-Duplex typology at night.

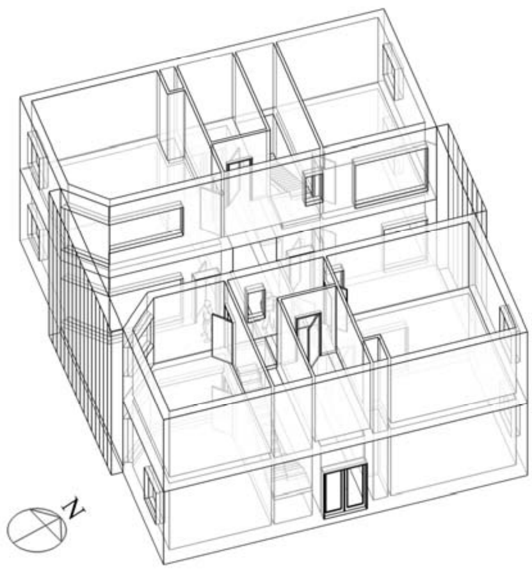
In winter, vertical glazing panels will be closed so that courtyard works as a sunspace, preheats the air and increases total amount of sun light. In the case of 45° wider open courtyard, the total north glazing area is smaller than the area on the south hence it helps to reduce heat losses. Using super insulating material for building construction and double/triple glazed-low emissivity window can highly guarantee the maintenance of indoor thermal comfort. Beside, a good shading design can ensure to block undesirable sun during hotter months, yet allows light penetration at the correct times of the day. A horizontal shading device may suitable for Courtyard-Duplex typology; we will examine the design in the next Chapter with Ecotect Solar Tool.

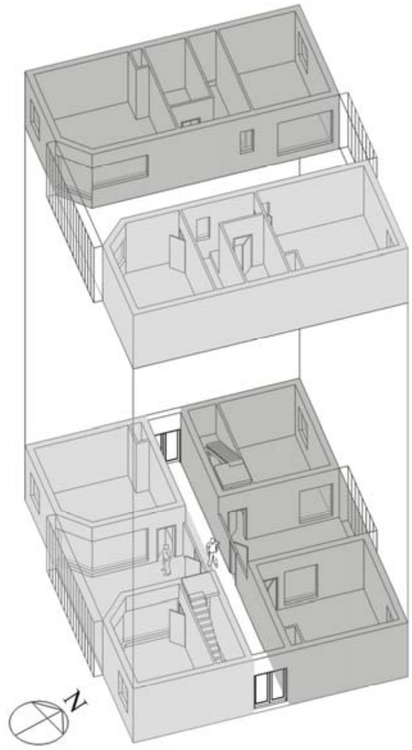


First floor



Second floor





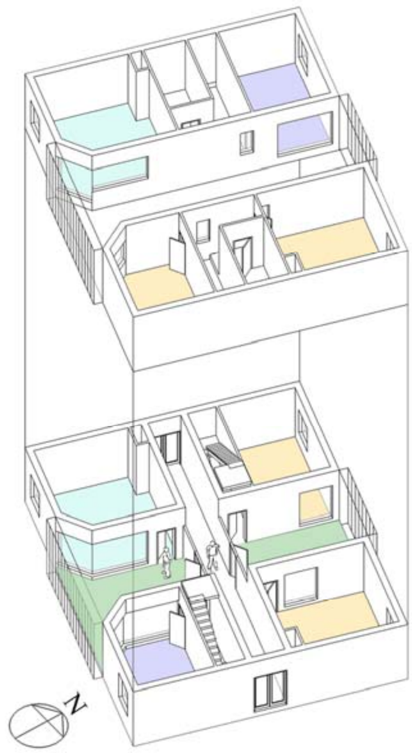
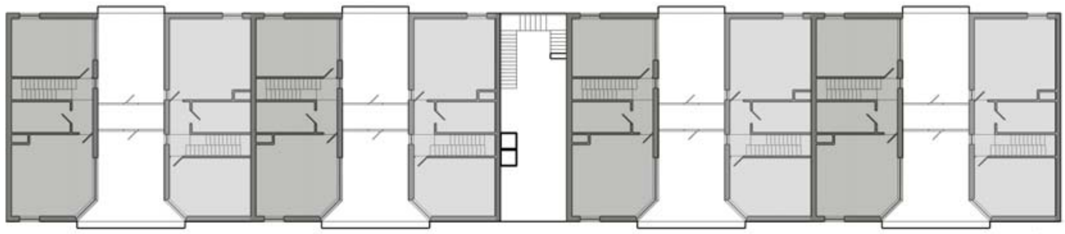


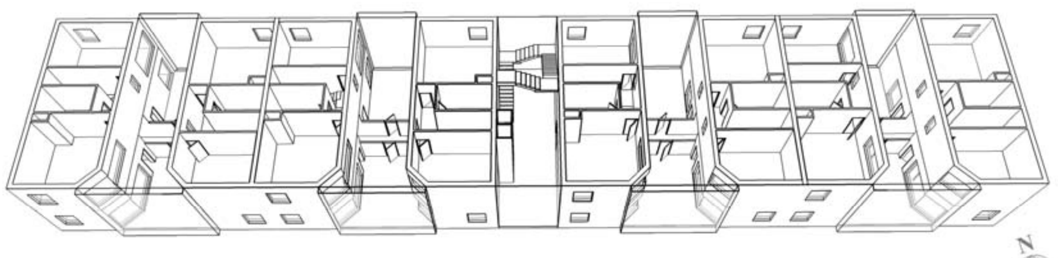
Figure 68: Courtyard-Duplex typology final layout *Courtyard-Duplex typology*

Source: Made by the author

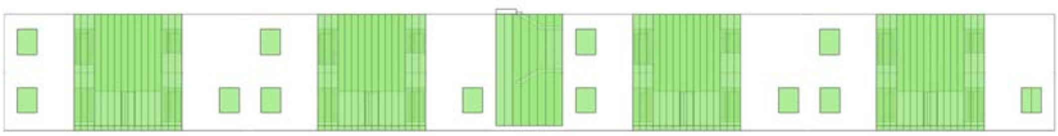
First floor



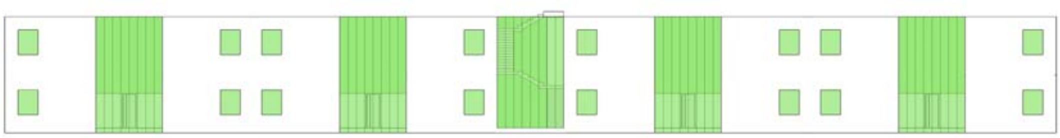
Second floor



Perspective view



South façade

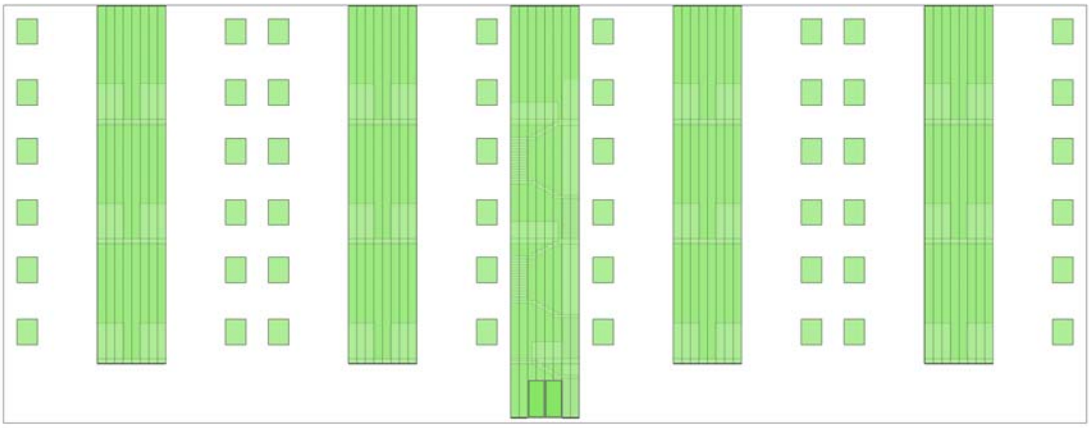


North façade

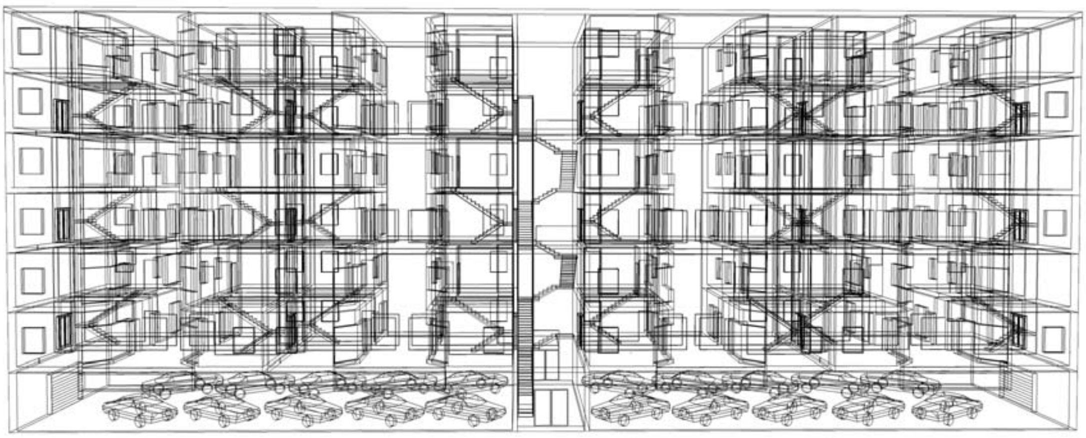
Figure 69: Plans and elevations

Source: Made by the author

South façade

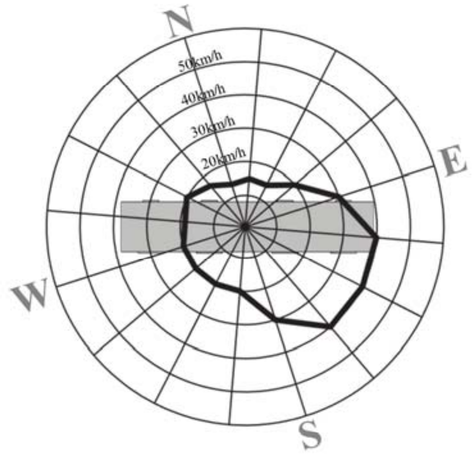


North façade

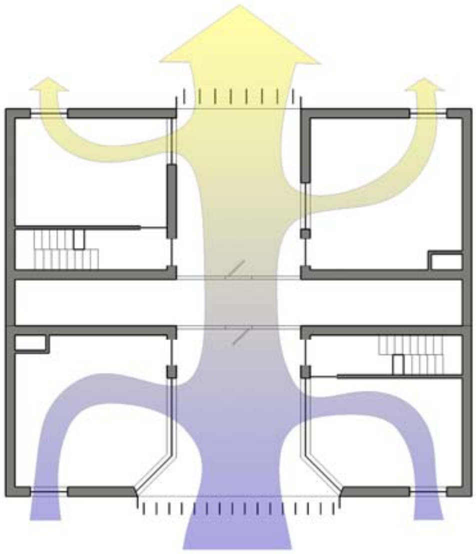


Ground floor is used for garage and technical room

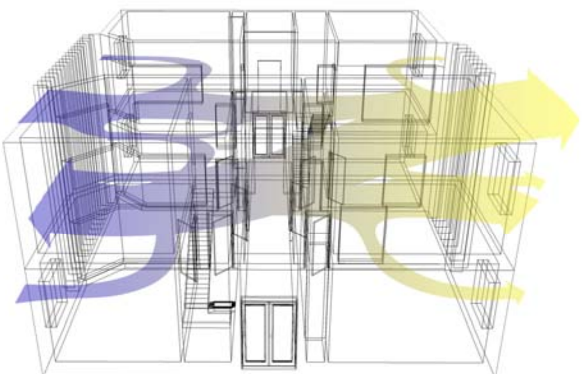
Figure 70: Façades and X-ray view *Source: Made by the author*



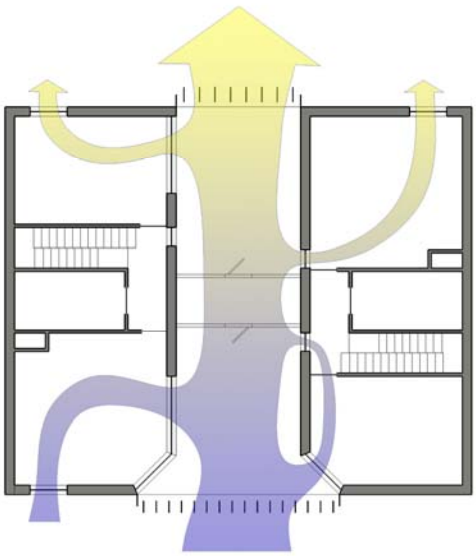
Summer wind rose in Shanghai



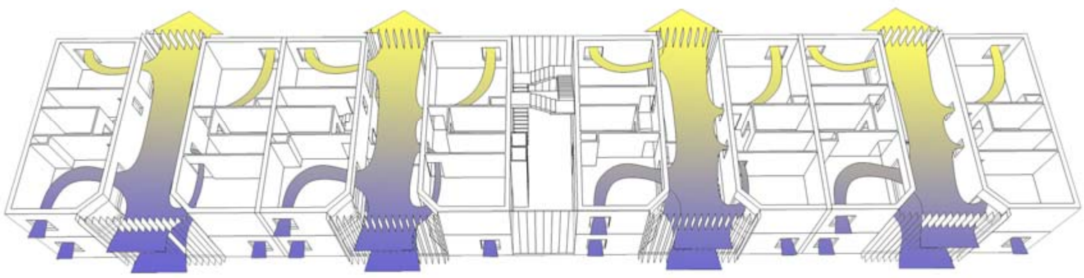
Summer wind flow-First floor



X-ray view



Summer wind flow-Second floor



Cross ventilation in summer

Figure 71: Building ventilation in summer

Source: Made by the author

Chapter 7: Environmental simulation of Courtyard-Duplex typology

7.1. Shadow range simulation

A shadow range refers to the display of shadows over a range of times on a given day. The shadow range is simulated by Ecotect engine on 4 days: 21st of Jun, March, September and December, from 9:00 to 17:00 without shading device (fig. 76 to fig. 80). The results present total amount of sunlight areas and shadow areas on one day. It is useful for the designer to modify the position and size of windows as well as shading device. Furthermore, it can help as an interior design approach, to determine areas for different activities that need shadow or sunlight such as: relaxing, studying, working, reading, cooking and sleeping.

7.2. Daylight simulation

Daylight is an important consideration when designing energy efficient buildings. By using daylight from the sky to illuminate the interior of a building, we can reduce the need for artificial or electrical lighting, which in turn reduces energy use in the building during daylight hours. A well designed daylight system can reduce the required lighting energy by up to 80% [20]. Moreover, natural daylight is very efficient in terms of the amount of illuminance provided compared to the amount of heat generated (termed its luminous efficacy) meaning that it can also reduce cooling loads within the building in summer.

Ecotect can examine daylight level of the house using the analysis grid. The daylight levels simulation is made for 21st, December without shading device, calculated by multiplying the daylight factor (%) by the current Design Sky value (lux). Design Sky values represent the horizontal illuminance that is exceeded 85% of the time between 9am and 5pm throughout the working year. The value of Design Sky values can be calculated from the site's latitude, in Shanghai (lat 31.4°) the Design Sky values is 9000 lux [21]. One test is on the first floor level (+1 m) and one is on the second floor level (+4.5 m) (fig. 77, 78). The results demonstrate that on both floors, the daylight levels of all rooms are qualified, more than 300 lux. The value range of daylight levels is from 0 to 2400 lux on the first floor and 2420 lux on the second floor. Two courtyards have the highest values, 400 up to 2420 lux. The comparison of daylight levels between the regular open of courtyard and the 45° wider open courtyard illustrates that in the modified case, the area which has more than 960 lux is 30% larger than the one in regular case (fig. 79). Beside, the simulation of total sunlight hours give you an idea about how many hours each area can have sunlight on one day. Again, the comparison between regular open of courtyard and 45° wider open shows that in the second case, the area which has 4 hours of sunlight is 2 times larger and in total it has 25% larger area than the one in regular case (fig. 80).

7.3. Strategy for terrace garden from daylight simulation

The results of daylight simulation can be used as a strategy of terrace garden in courtyard, in the way to match different light levels and sunlight areas to appropriate housplants (fig. 81). Base on light levels, there are 3 different levels: 1000 lux or 100 foot-candles is equal *Low light level*; 1500 lux or 150 foot-candles is *Medium light level*; 3000 lux or 300 foot-candles is *Bright light level* [22]. Most area of the courtyards has *Medium light level*, more than 2000 lux. Moreover, the Total sunlight hours examination indicates 4 levels of sunlight condition: 0.5 to 1 hour of sunlight means *Very low level*; 1 to 2.5 hours means *Low level*; 2.5 to 3.5 hours is *Medium level* and more than 4 hours of sunlight is equal *Bright level*. Thanks to these results, we can determine the planting area by simply overlapping the areas of daylight levels and the areas of sunlight levels. Each area will have appropriate plants due to their light condition. For example, in the *Low light area* we can plant such as Chinese evergreen; Parlor palms; Snake plant; Peace lily; Devil's ivy and Cast iron plant. Others like Dracaena; Pothos; Dumbcane; Fig; Spider plant; Grape ivy; Rubber plant; Prayer plant and Pepperomia are suitable for *Medium light area*. In *Bright light area* we can have Norfolk island pine; Areca palm; Ponytail palm; Croton; Zebra plant and False aralia [23].

Shadow range simulation

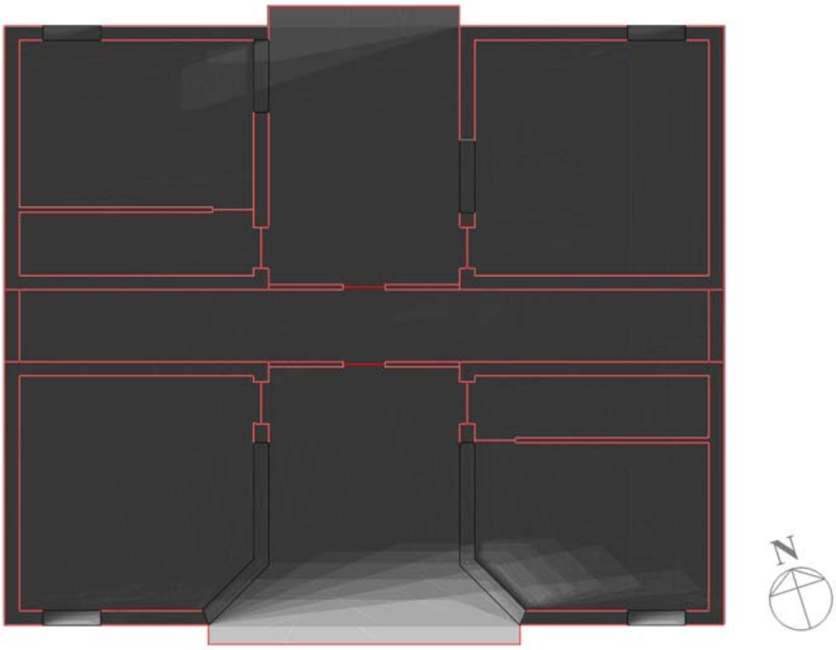


Figure72: 21st, Jun (from 9:00 to 17:00)

Source: Simulated by Ecotect 2010

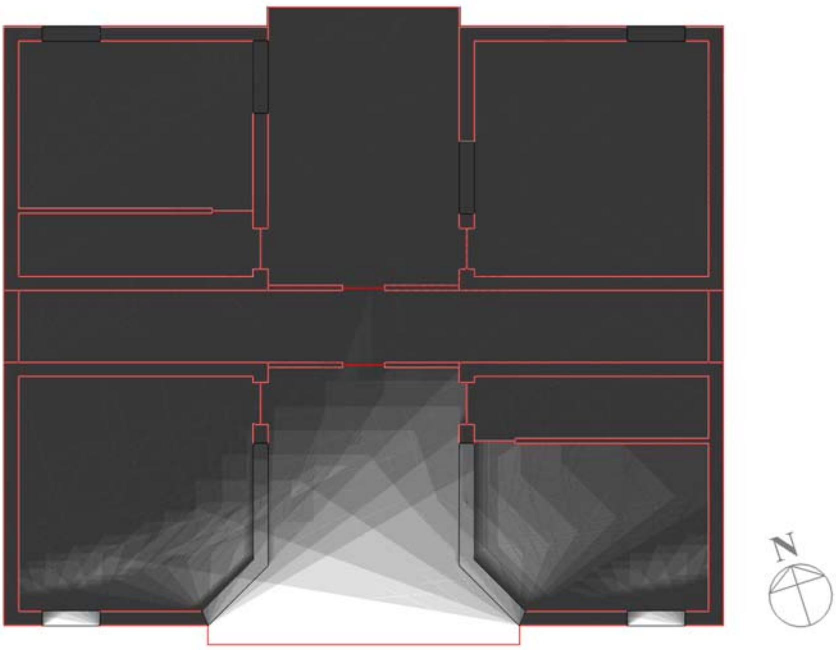


Figure 73: 21st, March (from 9:00 to 17:00) *Source: Ecotect 2010*

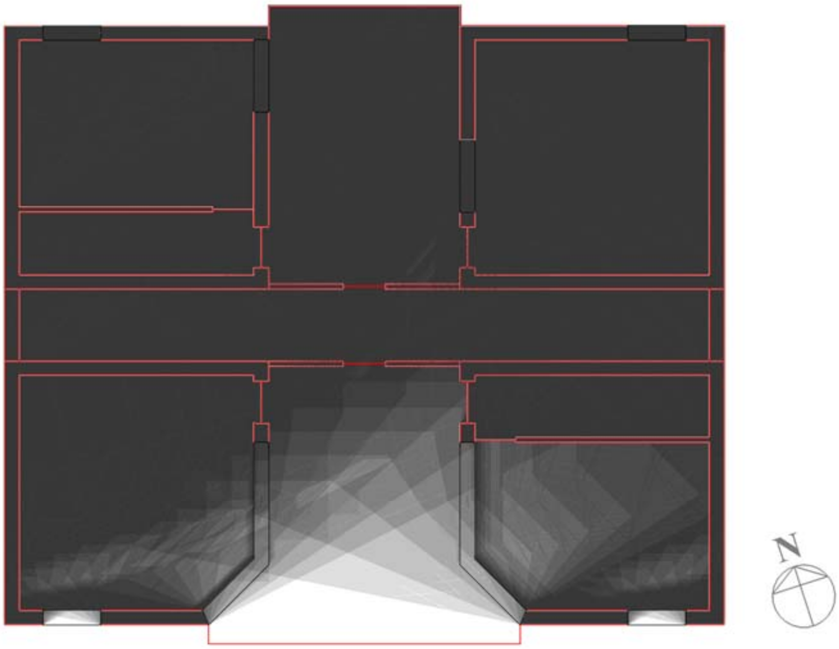


Figure 74: 21st, September (from 9:00 to 17:00

Source: Simulated by Ecotect 2010

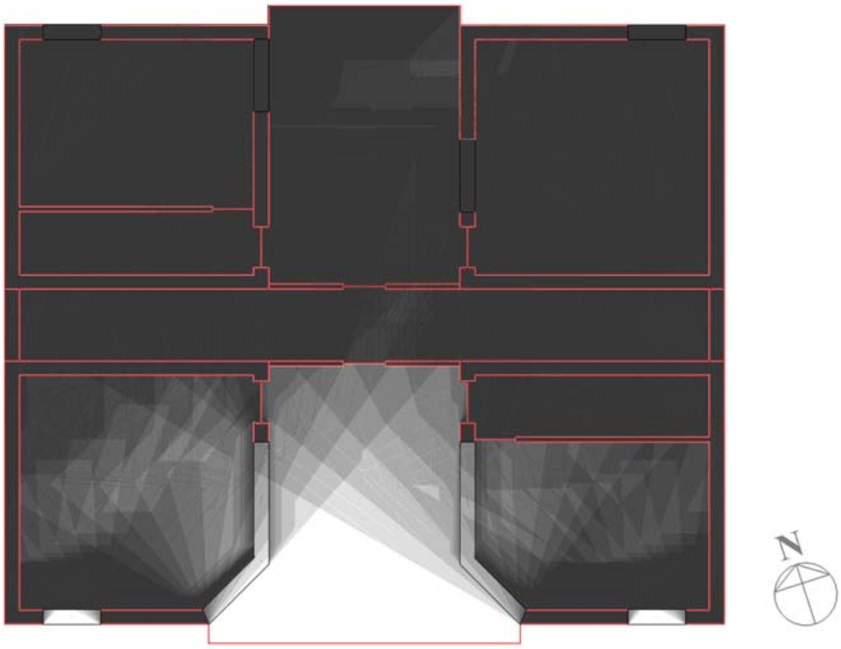
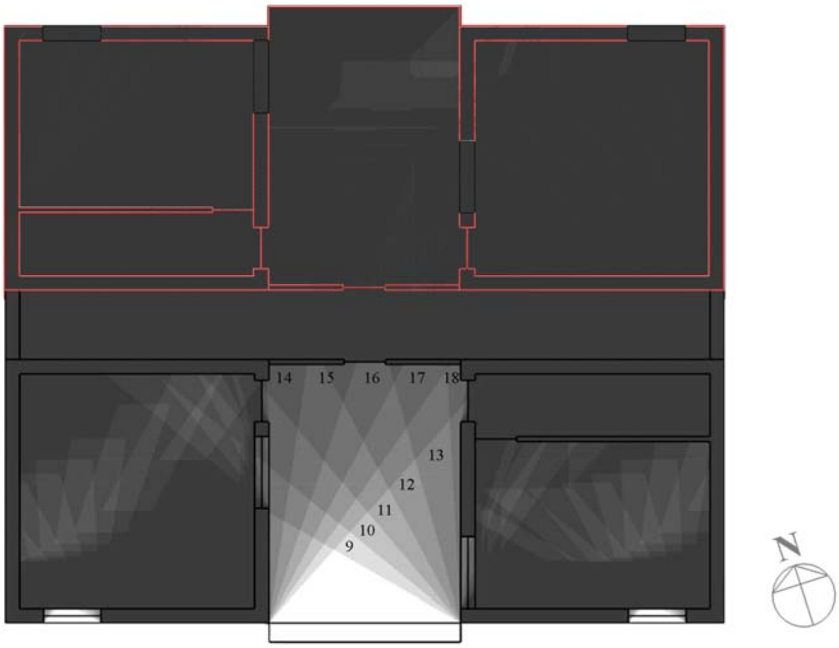
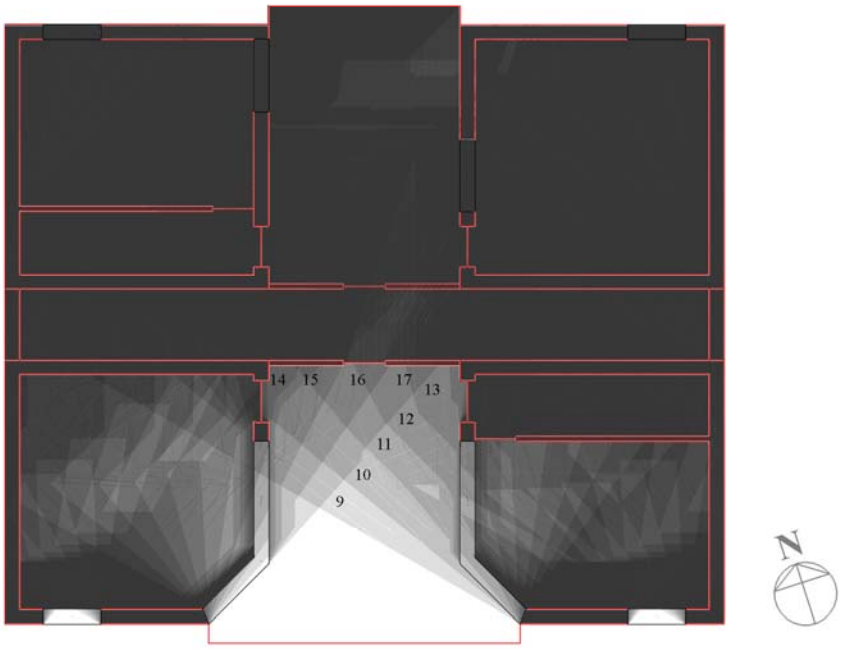


Figure 75: 21st, December (from 9:00 to 17:00   Source: Ecotect 2010



Regular open of south courtyard

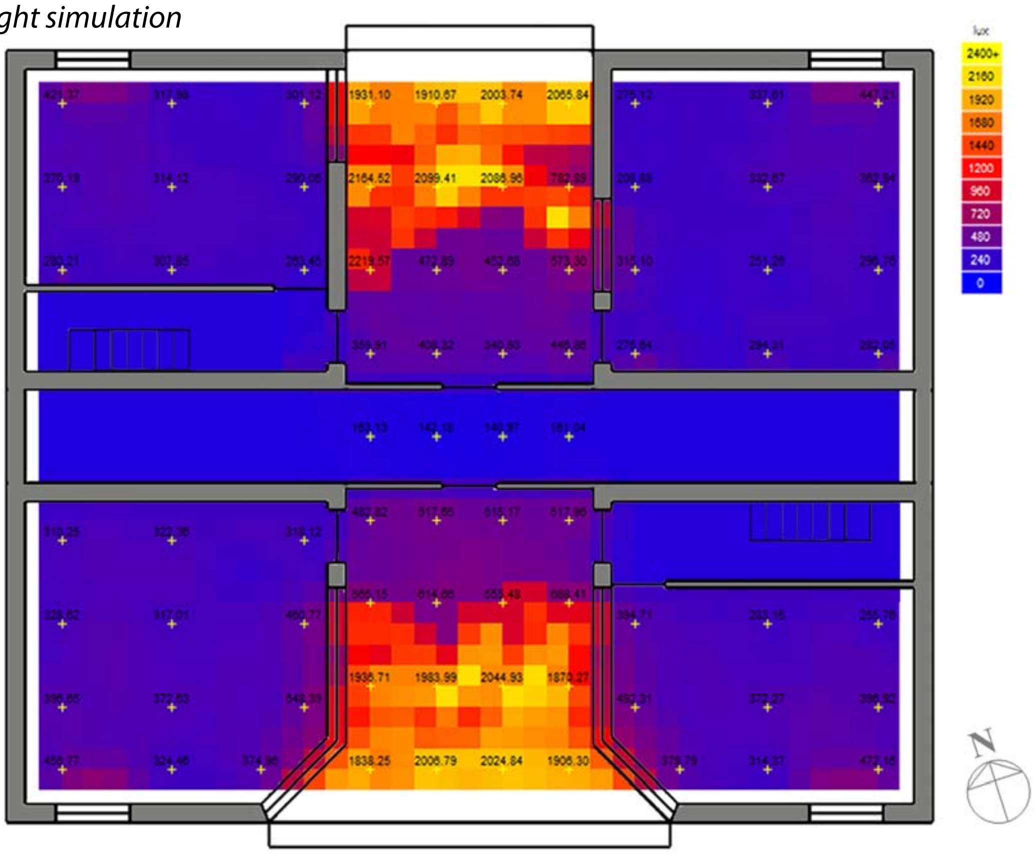


45° wider open will increase natural light performance. Almost half of the south courtyard is out of the shadow on 21st, December

Figure 76: Shadow range comparison between regular open and 45° wider open on 21st, December (from 9:00 to 17:00)

Source: Simulated by Ecotect 2010

Daylight simulation



Daylight levels on the first floor, 21st, December

Design Sky value: 9000 lux*

Value range: 0-2400 lux

Source: Simulated by Ecotect 2010

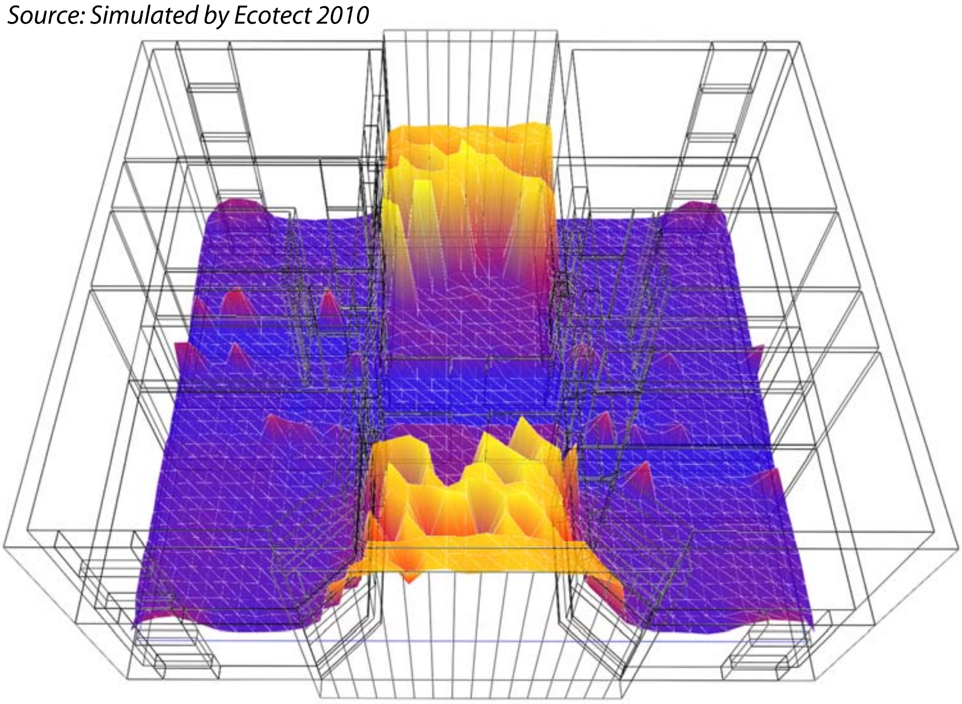


Figure 77: Daylight levels on the first floor, 21st, December

Source: Simulated by Ecotect 2010

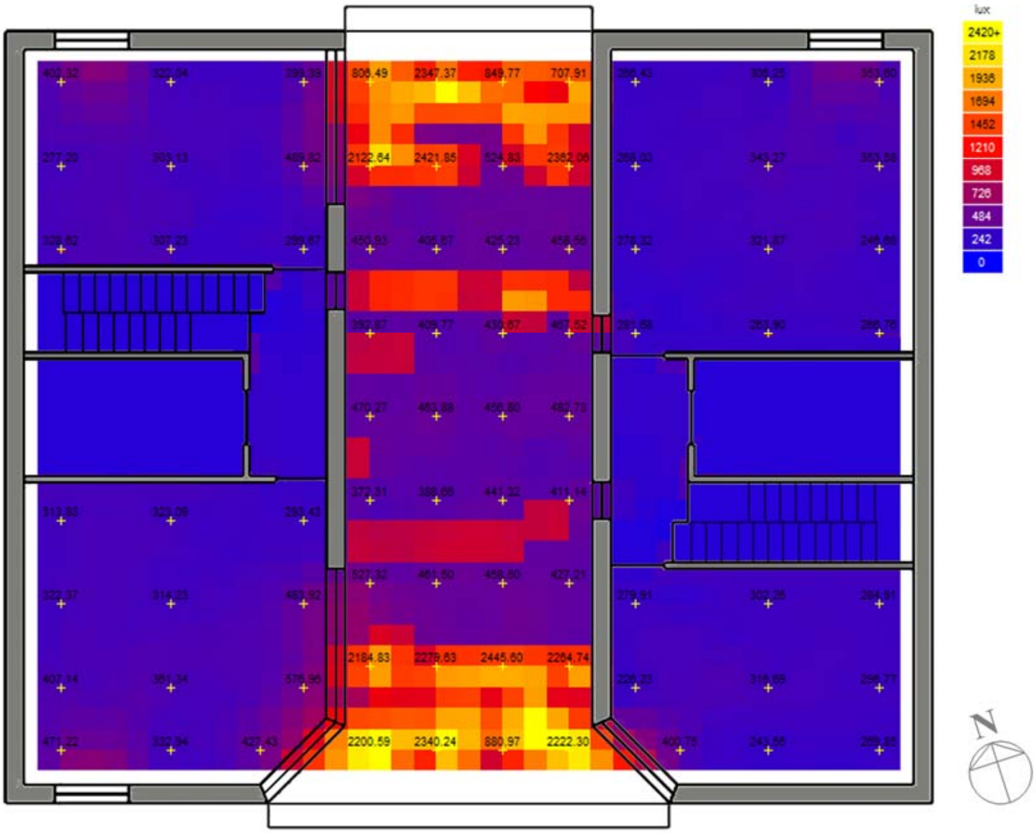
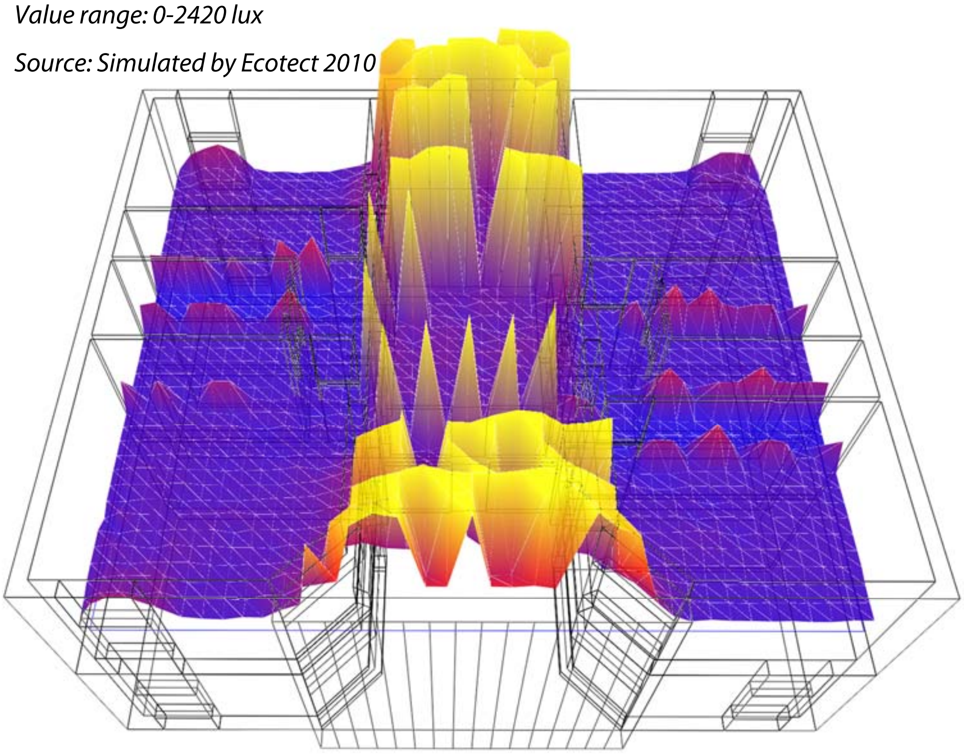


Figure 78: Daylight levels on the second floor, 21st, December

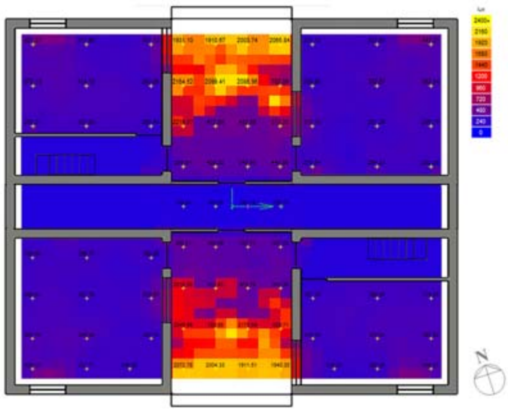
Design Sky value: 9000 lux*

Value range: 0-2420 lux

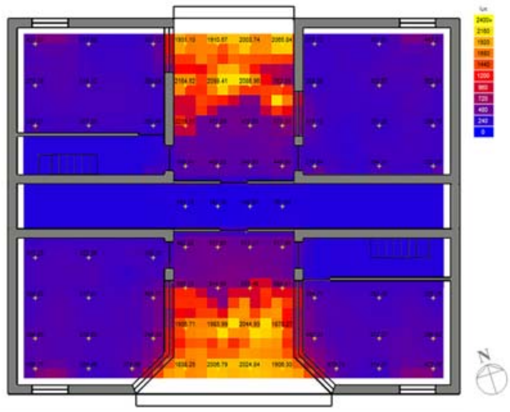
Source: Simulated by Ecotect 2010



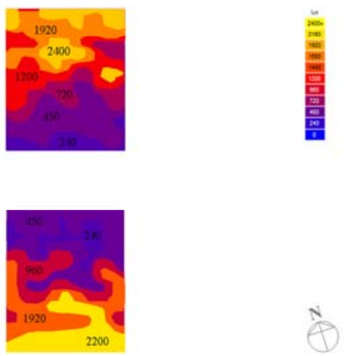
Design Sky value: represents the horizontal illuminance that is exceeded 85% of the time between 9am and 5pm throughout the working year. The value of Design Sky values can be calculated from the site's latitude, in Shanghai (lat 31,4°) the Design Sky values is 9000 lux* [24].



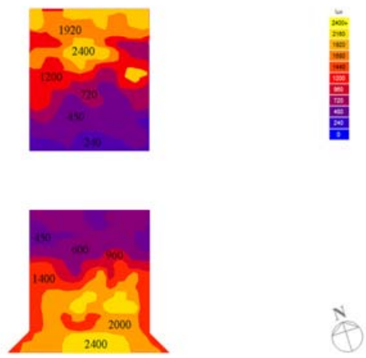
Regular open of south courtyard (first floor)



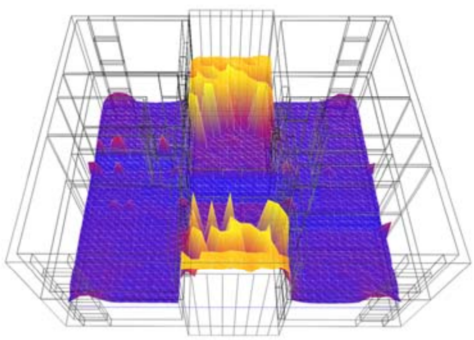
45° wider open allows more sunlight comes into the building (first floor)



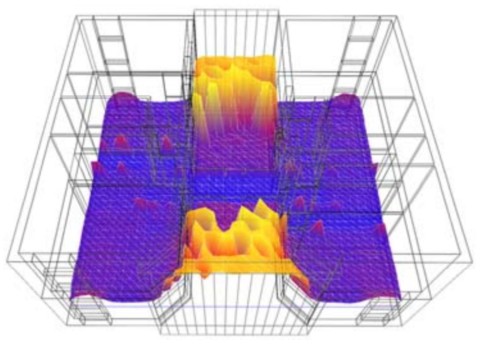
Area defined by daylight levels in regular case



In 45° wider open case, the area that has more than 960 lux is 30% larger than the one in regular case



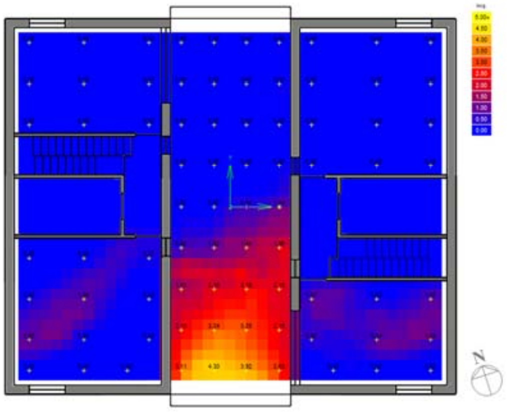
3D in regular case



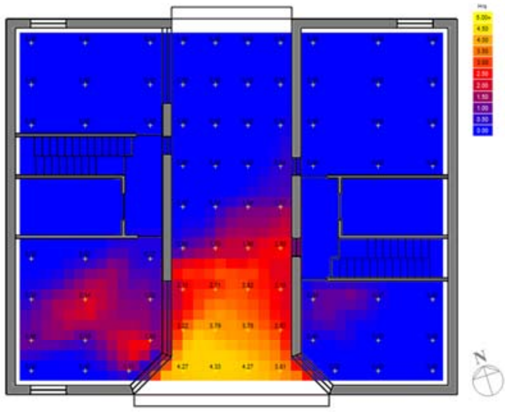
3D graph in 45° wider open case

Figure 79: Comparison of daylight levels between the regular and the 45° wider open courtyard (first floor, 21st, December)

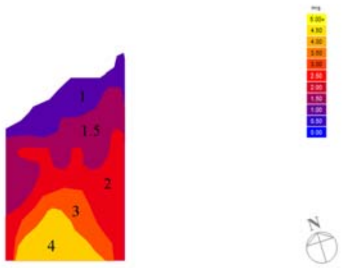
Source: Simulated by Ecotect 2010



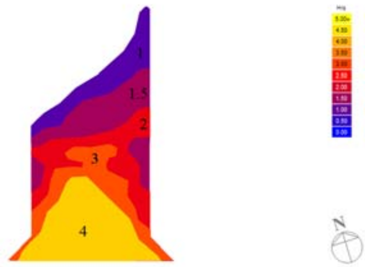
Total sunlight hours of regular open case (second floor, 21st, December)



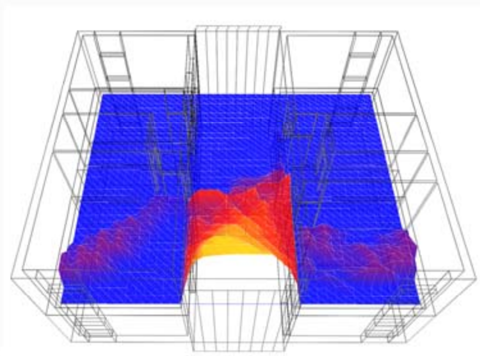
Total sunlight hours of 45° wider open case (second floor, 21st, December)



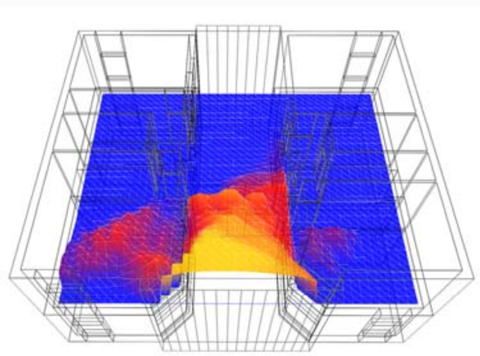
Area defined by total sunlight hours in regular case (from 1 to 4 hours)



In 45° wider open case, the area that has 4 hours of sunlight is 2 times larger than the one in regular case and 25% more area in total



3D in regular case

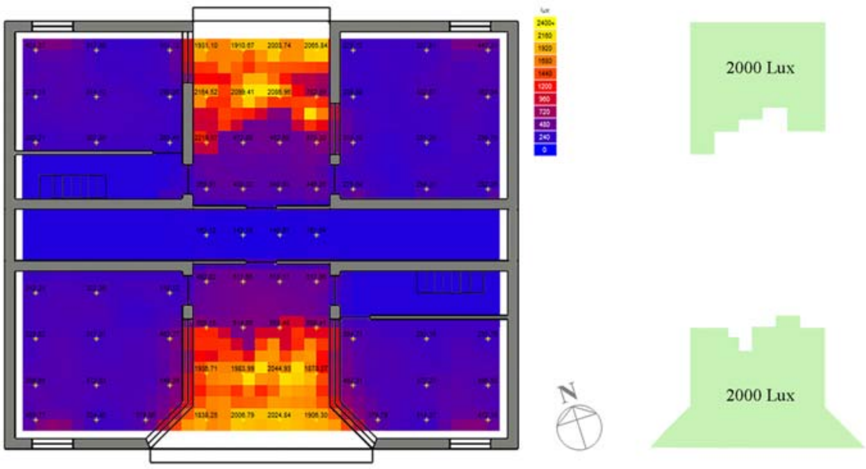


3D graph in 45° wider open case

Figure 80: Comparison of total sunlight hours between the regular and the 45° wider open courtyard (second floor, 21st, December)

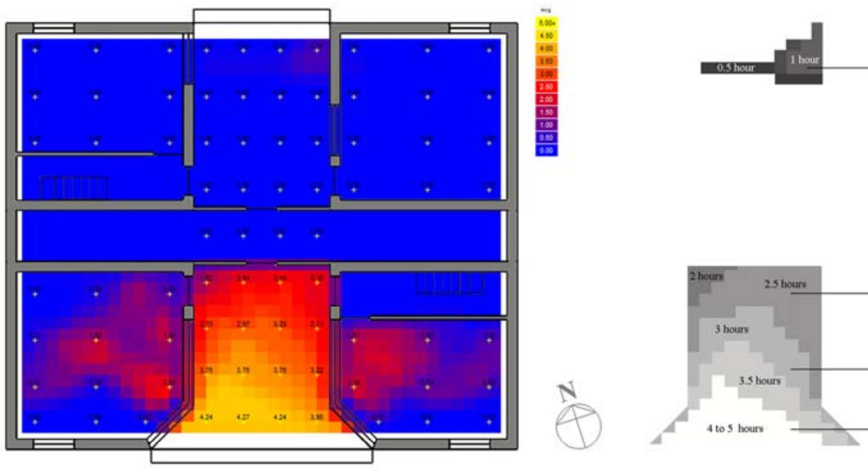
Source: Simulated by Ecotect 2010

Strategy of Terrace garden base one daylight analysis



Daylight levels (first floor, 21st, December)

Low light area:
1000 lux or 100 foot-candles
Medium light area:
1500 lux or 150 foot-candles
Bright light area:
3000 lux or 300 foot-candles



Very low sunlight

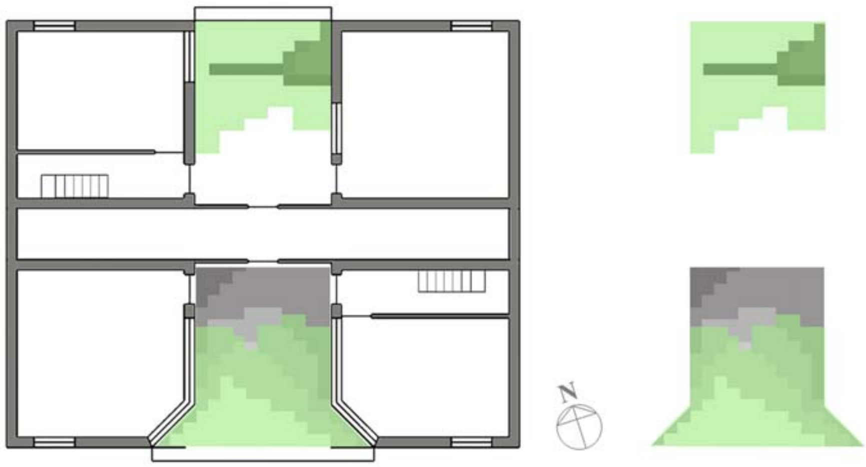
Low sunlight

Medium sunlight

Bright sunlight

Total sunlight hours (first floor, 21st, December)

Determine the planting area by overlapping diagram of daylight level and total sunlight hours. Each area will have appropriate plants due to their need of natural light.



Appropriate area for planting

Figure 81: Strategy of Terrace garden base one daylight analysis *Source: Made by the author*

7.4. Shading device

Designing effective shading devices can be a very complex and time-consuming activity. Not only does the Sun's position in the sky vary with latitude it; also changes at various times and dates throughout the year. Consequently, ensuring a shading device blocks undesirable sun during hotter months, yet allows light penetration at the correct times of the day, requires great design skill and technical knowledge. Many buildings utilise 'off-the-shelf' shading devices that are installed on all of the building's facades regardless of their orientation to the Sun. Too often, these shading systems either fail to stop hot summer sun from entering the building, or prevent the use of natural daylight for illuminating the interior of a building. Consequently, this can significantly increase a building's cooling and lighting loads, decreasing energy efficiency.

Ecotect contains a powerful suite of modelling tools that make it easy to design and analyze the performance of shading devices and structures. With its interactive user interface, the Solar Tool helps designers accurately size and position window overhangs, shading devices and louvers with ease. It provides a 3D model of window that can be interactively manipulated by changing the number of horizontal, vertical or detached shading surfaces. At the same time, it displays the resultant annual shading pattern on a Sun-Path Diagram, showing when in the year the window will be exposed to the Sun or in shade.

In Courtyard-Duplex typology, because of large glazing façade of courtyard facing almost to the south hence the horizontal shading device is needed (fig. 82). The design using Ecotect Solar Tool shows that the Average Shading Coefficients in winter is 73.7% and in summer is 100% (table 1). At last, the combination of openable vertical glazing panels with the horizontal shading is the best solution for courtyard. It provides cross ventilation and good shading in summer as well as qualified solar heat and natural light in winter.

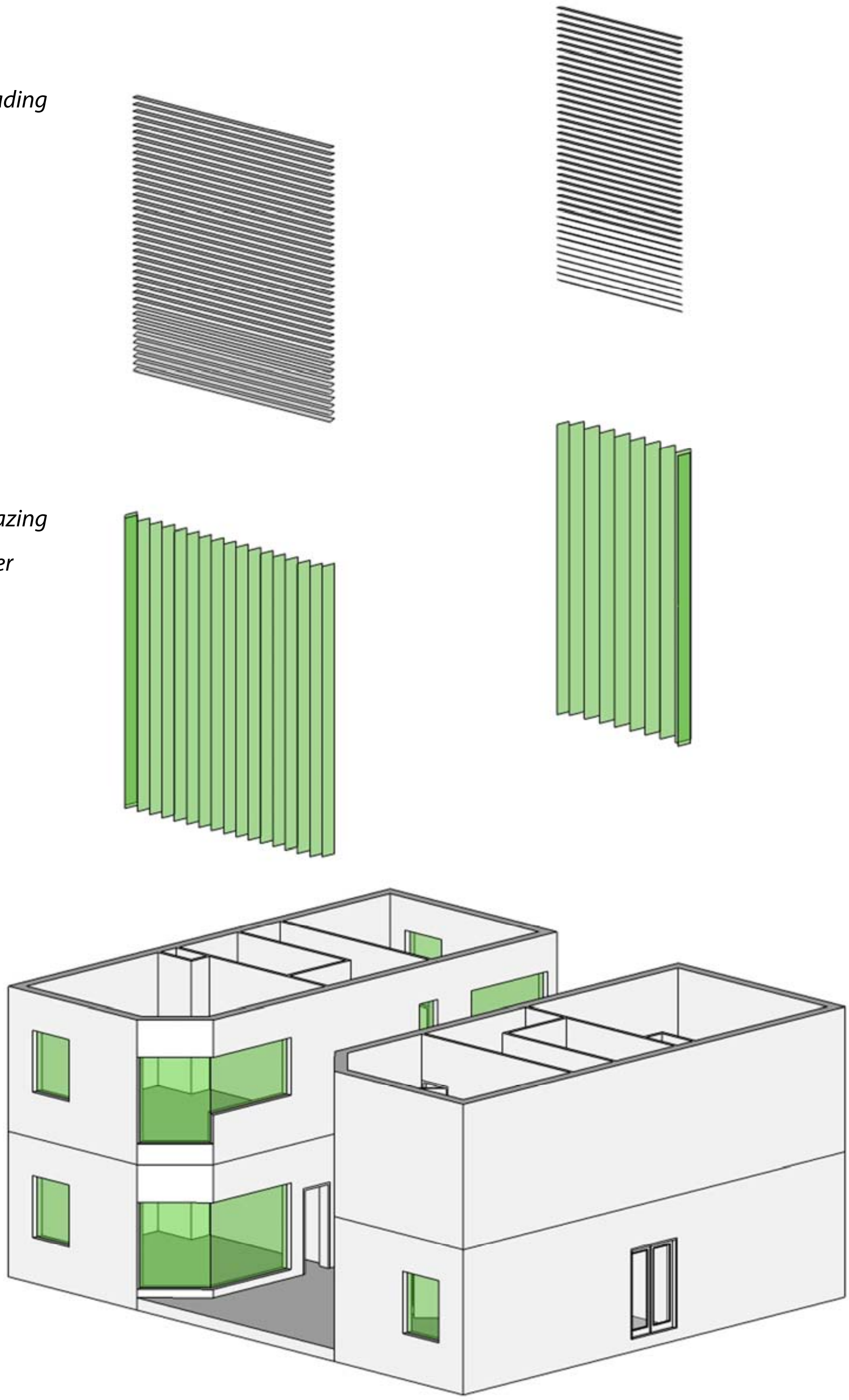
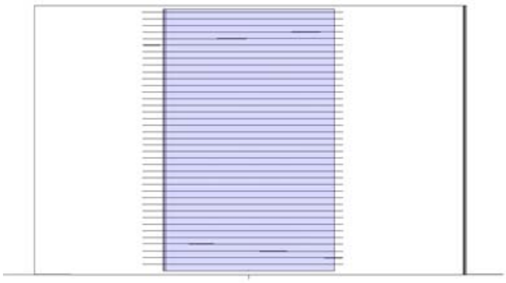


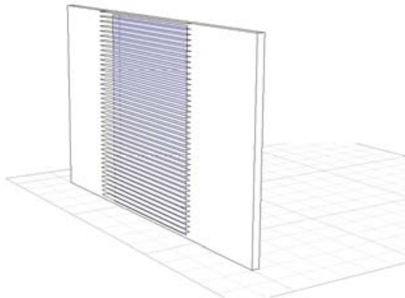
Figure 82: Shading device and openable glazing façade in summer

Source: Made by the author

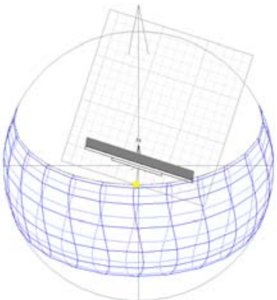
HORIZONTAL SHADING DEVICE



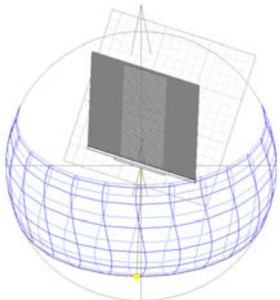
Front view



Perspective view



Shadow on the plan in summer, 21st Jun



Shadow on the plan in winter, 21st Dec

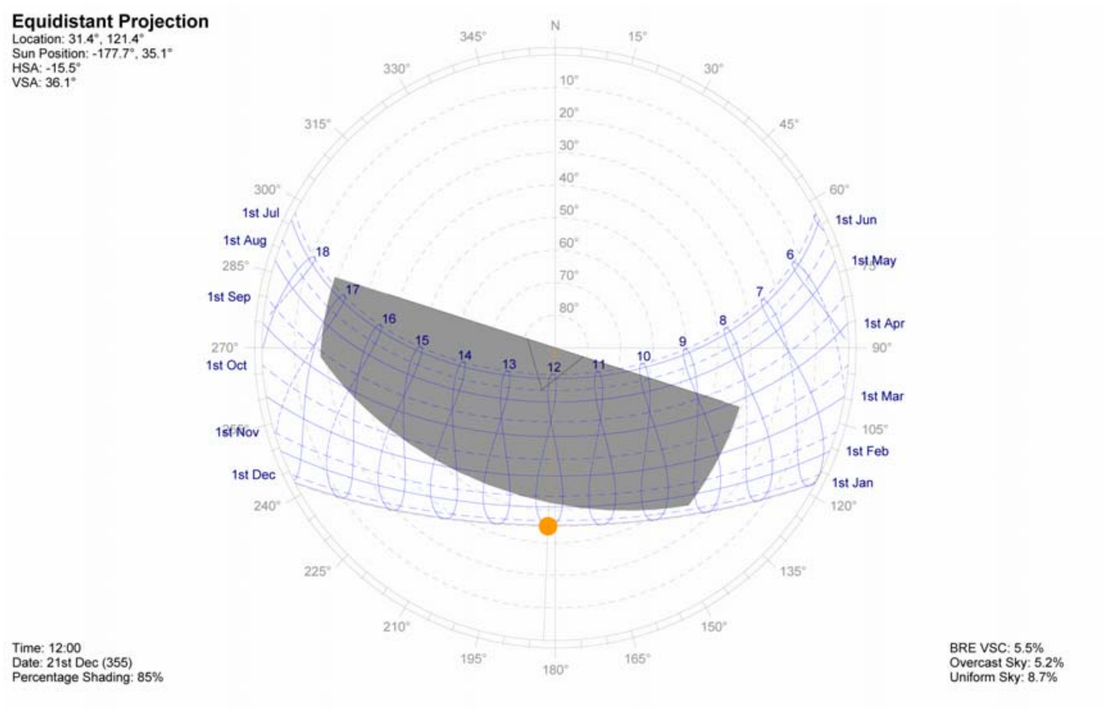


Figure 83: Design of horizontal shading device

Source: Simulated by Ecotect

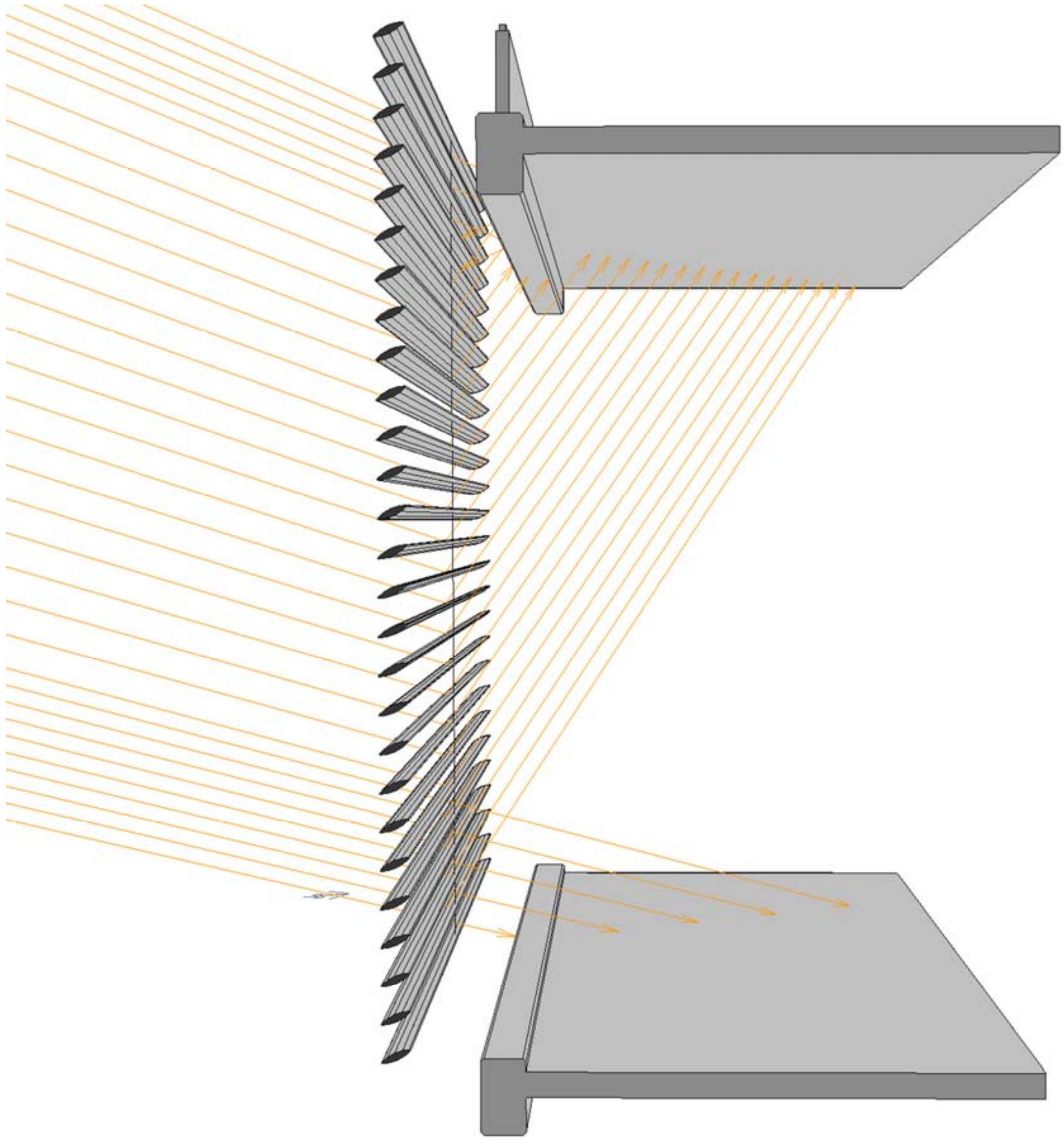


Figure 84: Project solar rays onto a model of horizontal shading device

Source: Simulated by Ecotect

Effective Shading Coefficients

Latitude: 31.4°
Longitude: 121.4°
Timezone: 120.0° [+8.0hrs]
Orientation: 197.8°

Month	Avg.SC	Max.SC	Min.SC
January	72.6%	100.0%	5.0%
February	86.0%	100.0%	8.0%
March	90.6%	100.0%	15.0%
April	99.8%	100.0%	96.0%
May	100.0%	100.0%	100.0%
June	100.0%	100.0%	100.0%
July	100.0%	100.0%	100.0%
August	96.4%	100.0%	36.0%
September	89.7%	100.0%	11.0%
October	81.4%	100.0%	8.0%
November	69.8%	100.0%	5.0%
December	62.3%	97.0%	4.0%
Winter	**73.7%**	**99.0%**	**5.7%**
Summer	**100.0%**	**100.0%**	**100.0%**
Annual	**87.4%**	**99.8%**	**40.7%**

Table 1: Effective shading coefficients

Source: Simulated by Ecotect

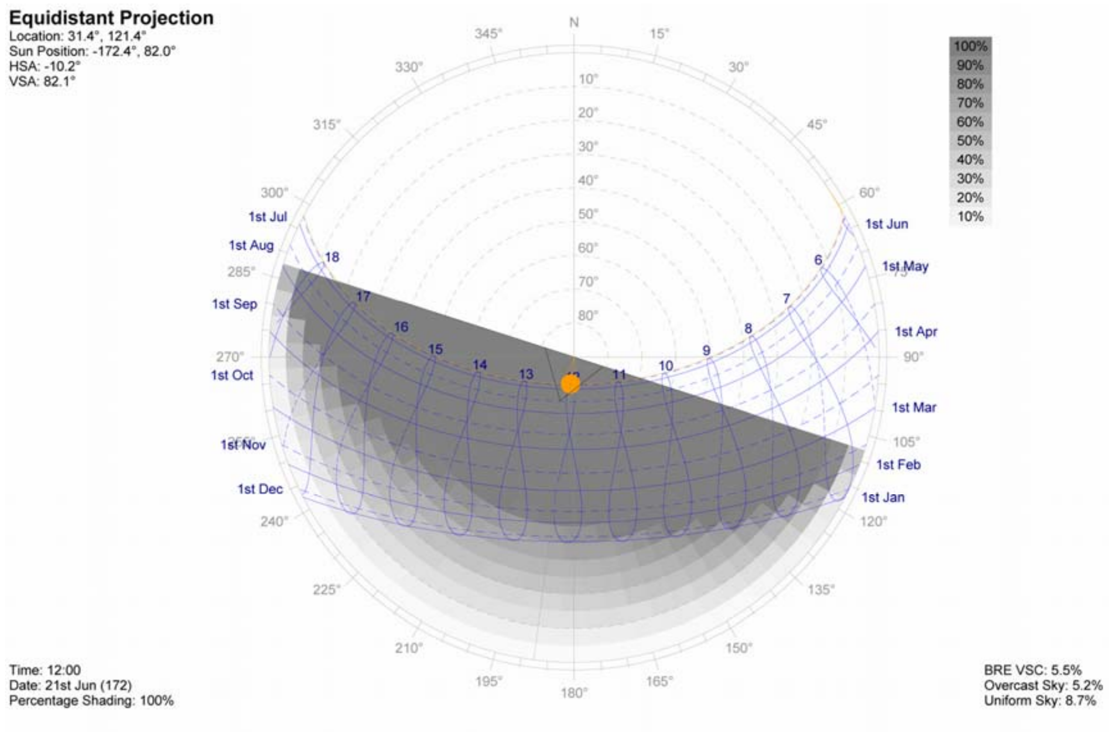


Figure 85: Percentage shade on Equidistant Projection

Source: Simulated by Ecotect

Tabulated Daily Solar Data

Latitude: 31.4°
Longitude: 121.4°
Timezone: 120.0° [+8.0hrs]
Orientation: 197.8°

Date: 21st June
Julian Date: 172
Sunrise: 04:54
Sunset: 18:57

Local Correction: 4.1 mins
Equation of Time: -1.6 mins
Declination: 23.4°

Local	(Solar)	Aziumuth	Altitude	HSA	VSA	Shading
05:00	(05:04)	62.9°	1.0°	-134.9°	178.5°	[Behind]
05:30	(05:34)	66.7°	6.8°	-131.1°	169.7°	[Behind]
06:00	(06:04)	70.2°	12.8°	-127.6°	159.6°	[Behind]
06:30	(06:34)	73.5°	18.9°	-124.3°	148.8°	[Behind]
07:00	(07:04)	76.8°	25.1°	-121.0°	137.8°	[Behind]
07:30	(07:34)	80.0°	31.3°	-117.8°	127.5°	[Behind]
08:00	(08:04)	83.2°	37.7°	-114.6°	118.3°	[Behind]
08:30	(08:34)	86.7°	44.0°	-111.1°	110.4°	[Behind]
09:00	(09:04)	90.4°	50.4°	-107.4°	103.9°	[Behind]
09:30	(09:34)	94.7°	56.8°	-103.1°	98.4°	[Behind]
10:00	(10:04)	100.0°	63.2°	-97.8°	93.9°	[Behind]
10:30	(10:34)	107.4°	69.4°	-90.4°	90.1°	[Behind]
11:00	(11:04)	119.3°	75.3°	-78.5°	87.0°	100%
11:30	(11:34)	142.7°	80.2°	-55.1°	84.4°	100%
12:00	(12:04)	-173.2°	82.0°	-11.0°	82.1°	100%
12:30	(12:34)	-134.4°	79.0°	27.8°	80.3°	100%
13:00	(13:04)	-115.3°	73.7°	46.9°	78.7°	100%
13:30	(13:34)	-105.1°	67.7°	57.1°	77.4°	100%
14:00	(14:04)	-98.4°	61.4°	63.8°	76.5°	100%
14:30	(14:34)	-93.5°	55.1°	68.7°	75.8°	100%
15:00	(15:04)	-89.3°	48.7°	72.9°	75.5°	100%
15:30	(15:34)	-85.7°	42.3°	76.5°	75.6°	100%
16:00	(16:04)	-82.3°	35.9°	79.9°	76.3°	100%
16:30	(16:34)	-79.1°	29.6°	83.1°	78.1°	100%
17:00	(17:04)	-75.9°	23.3°	86.3°	81.6°	100%
17:30	(17:34)	-72.6°	17.2°	89.6°	88.7°	100%
18:00	(18:04)	-69.2°	11.1°	93.0°	104.8°	[Behind]
18:30	(18:34)	-65.7°	5.2°	96.5°	141.2°	[Behind]

Table 2: Daily solar data on 21st, Jun

Source: Simulated by Ecotect

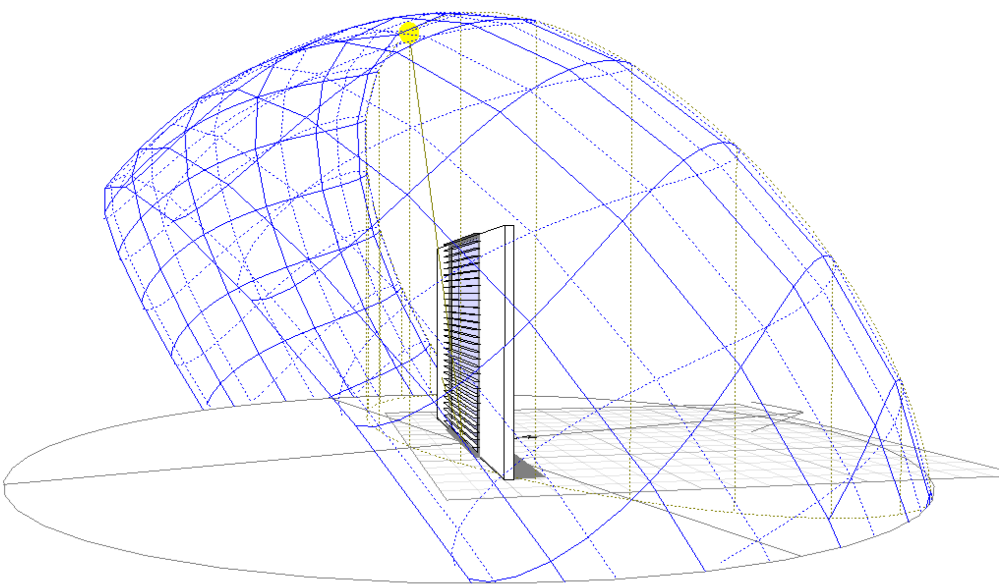


Figure 86: Model of horizontal shading device on 21st, Jun

Source: Simulated by Ecotect

Tabulated Daily Solar Data

Latitude: 31.4°
Longitude: 121.4°
Timezone: 120.0° [+8.0hrs]
Orientation: 197.8°

Date: 21st December
Julian Date: 355
Sunrise: 06:53
Sunset: 16:50

Local Correction: 7.8 mins
Equation of Time: 2.1 mins
Declination: -23.5°

Local	(Solar)	Aziumuth	Altitude	HSA	VSA	Shading
07:00	(07:07)	118.6°	1.2°	-79.2°	6.3°	18%
07:30	(07:37)	122.8°	6.7°	-75.0°	24.4°	63%
08:00	(08:07)	127.3°	11.9°	-70.5°	32.3°	77%
08:30	(08:37)	132.3°	16.9°	-65.5°	36.2°	85%
09:00	(09:07)	137.7°	21.4°	-60.1°	38.1°	97%
09:30	(09:37)	143.8°	25.4°	-54.0°	39.0°	89%
10:00	(10:07)	150.5°	28.9°	-47.3°	39.2°	81%
10:30	(10:37)	157.8°	31.7°	-40.0°	38.9°	91%
11:00	(11:07)	165.6°	33.7°	-32.2°	38.3°	78%
11:30	(11:37)	173.8°	34.9°	-24.0°	37.3°	76%
12:00	(12:07)	-177.8°	35.1°	-15.6°	36.1°	85%
12:30	(12:37)	-169.5°	34.4°	-7.3°	34.6°	69%
13:00	(13:07)	-161.5°	32.8°	0.7°	32.8°	69%
13:30	(13:37)	-153.9°	30.3°	8.3°	30.6°	69%
14:00	(14:07)	-146.9°	27.2°	15.3°	28.0°	59%
14:30	(14:37)	-140.6°	23.4°	21.6°	25.0°	51%
15:00	(15:07)	-134.8°	19.1°	27.4°	21.3°	40%
15:30	(15:37)	-129.6°	14.3°	32.6°	16.9°	29%
16:00	(16:07)	-124.9°	9.2°	37.3°	11.6°	17%
16:30	(16:37)	-120.6°	3.9°	41.6°	5.2°	4%

Table 3: Daily solar data on 21st, December

Source: Simulated by Ecotect

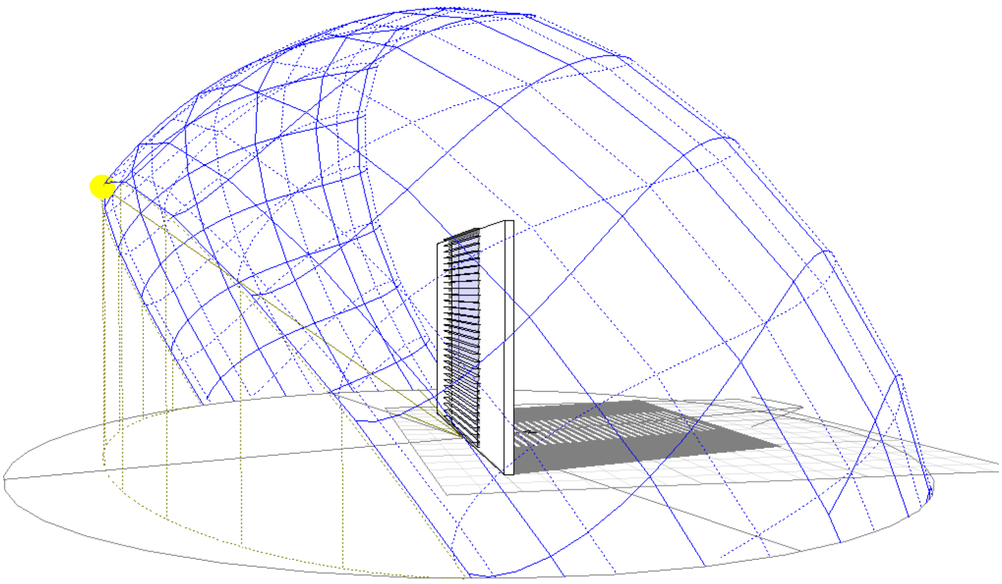


Figure 87: Model of horizontal shading device on 21st, December

Source: Simulated by Ecotect

Chapter 8: Material and Insulation of Courtyard-Duplex typology

This chapter presents super insulating materials which are available to apply on the Courtyard-Duplex typology, in terms of building envelope (wall, floor, roof and window).

8.1. Heavy solid insulating brick

Heavy_solid_insulating_brick

Heavy solid insulating brick with external Polystyrene Foam (High Density) insulation.

	Internal	External
Colour (Reflect.):	(R:0.561)	(R:0.561)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

U-Value (W/m2.K):	0.100
Admittance (W/m2.K):	1.760
Solar Absorption (0-1):	0.495
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.22
Thermal Lag (hrs):	7.8
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	302.0
Weight (kg):	106.760

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Concrete 1-4 Dry	10.0	2300.0	656.900	0.753	35
2.	Rubber Polyurethane Elasto	2.0	1250.0	1674.000	0.293	45
3.	Polystyrene Foam (High Der	60.0	46.0	1130.000	0.008	45
4.	Brick Kaolin Insulating	220.0	300.0	774.000	0.084	25
5.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85

Table 4: Properties and Layers of Heavy solid insulating brick *Source: Ecotect 2010 material*

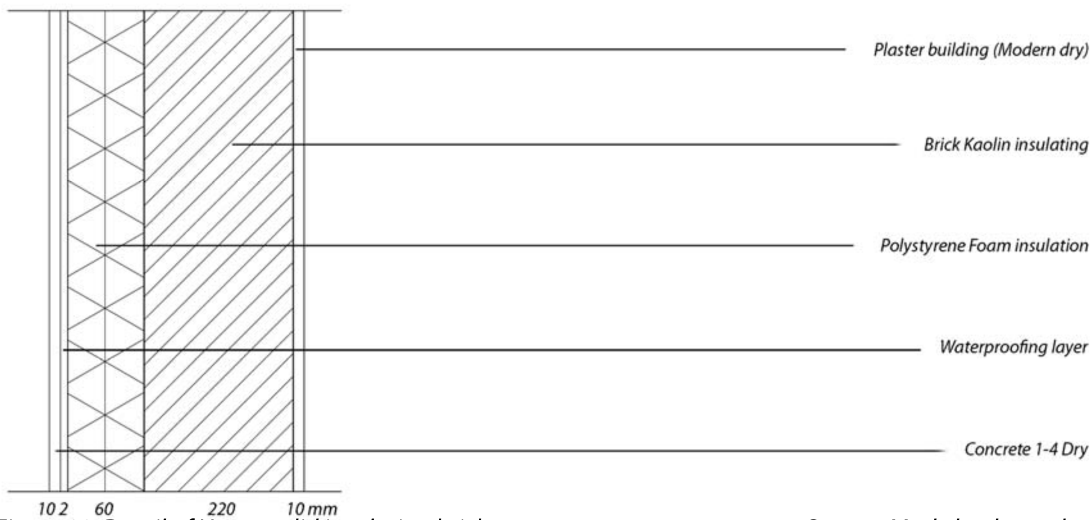


Figure 88: Detail of Heavy solid insulating brick *Source: Made by the author*

8.2. Super insulating concrete floor

Super_insulating_concrete_floor

100mm thick concrete floor plus 2 layers of 70mm Polystyrene Foam (High Density) insulation, timber finish and plaster ceiling underneath.

	Internal	External
Colour (Reflect.):	(R:0.750)	(R:0.750)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

U-Value (W/m2.K):	0.060
Admittance (W/m2.K):	2.550
Solar Absorption (0-1):	0.333165
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.01
Thermal Lag (hrs):	0.7
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	490.0
Weight (kg):	285.950

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Plaster Board	10.0	1250.0	1088.000	0.431	85
2.	Polystyrene Foam (High I	70.0	46.0	1130.000	0.008	45
3.	Air Gap	200.0	1.3	1004.000	5.560	0
4.	Concrete slaps	100.0	2300.0	656.900	0.753	35
5.	Polystyrene Foam (High I	70.0	46.0	1130.000	0.008	45
6.	Concrete Lightweight	30.0	950.0	656.900	0.209	35
7.	Wood Oak White Live (A	10.0	825.0	2385.000	0.209	93

Table 5: Properties and Layers of Super insulating concrete floor *Source: Ecotect 2010*

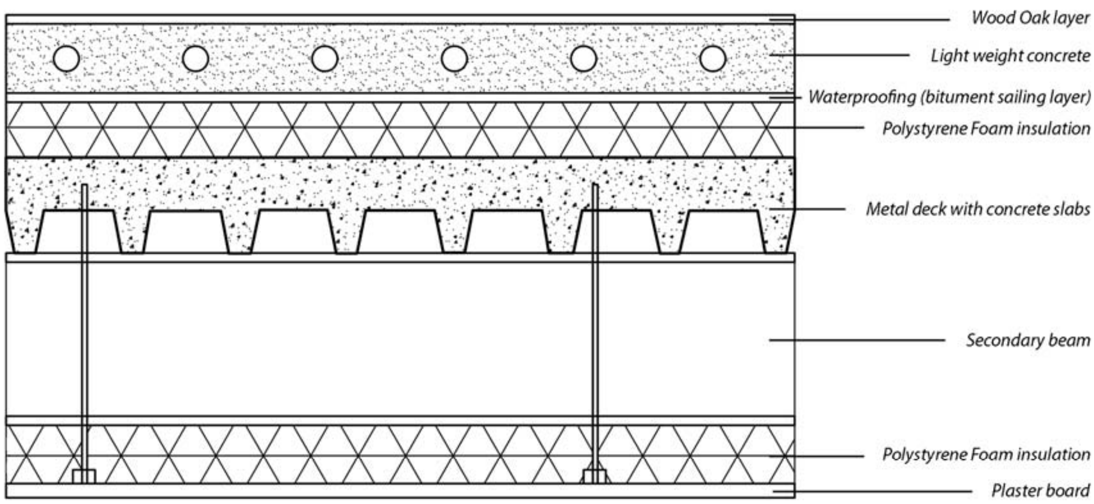


Figure 89: Detail of Super insulating concrete floor

Source: Made by the author

8.3. Super insulating concrete roof

Super_insulating_concrete_roof

100mm thick concrete slaps plus 2 layers of 70mm Polystyrene Foam (High Density) insulation.

	Internal	External
Colour (Reflect.):	(R:0.750)	(R:0.750)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

U-Value (W/m2.K):	0.050
Admittance (W/m2.K):	2.410
Solar Absorption (0-1):	0.333165
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0
Thermal Lag (hrs):	0.7
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	650.0
Weight (kg):	439.200

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Plaster Board	10.0	1250.0	1088.000	0.431	85
2.	Polystyrene Foam (High I	70.0	46.0	1130.000	0.008	45
3.	Air Gap	200.0	1.3	1004.000	5.560	0
4.	Concrete slaps	100.0	2300.0	656.900	0.753	35
5.	Polystyrene Foam (High I	70.0	46.0	1130.000	0.008	45
6.	Concrete Lightweight	200.0	950.0	656.900	0.209	35

Table 6: Properties and Layers of Super insulating concrete roof *Source: Ecotect 2010*

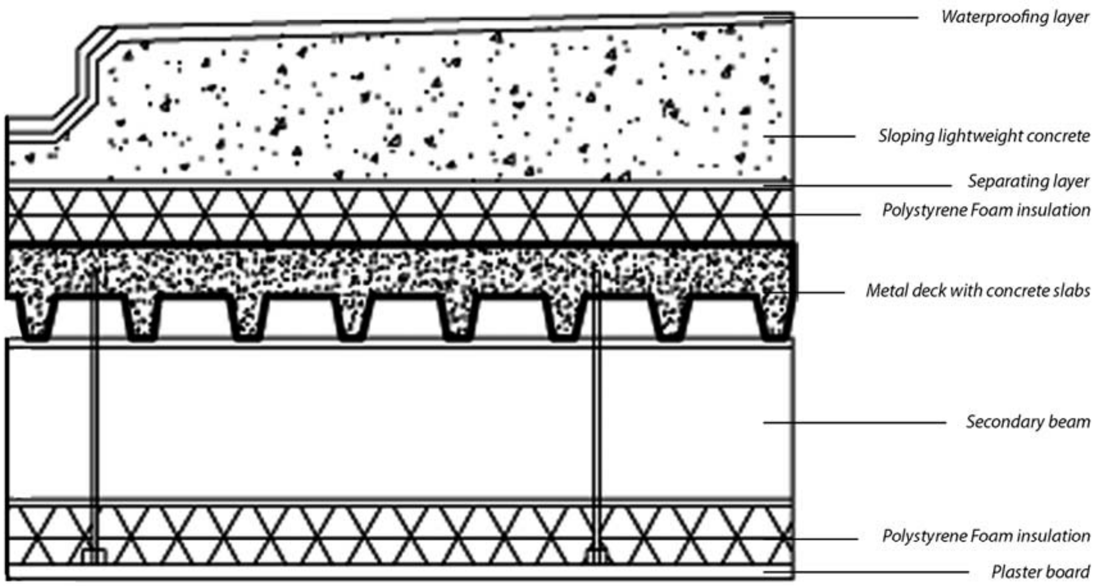


Figure 90: Detail of Super insulating concrete roof

Source: Made by the author

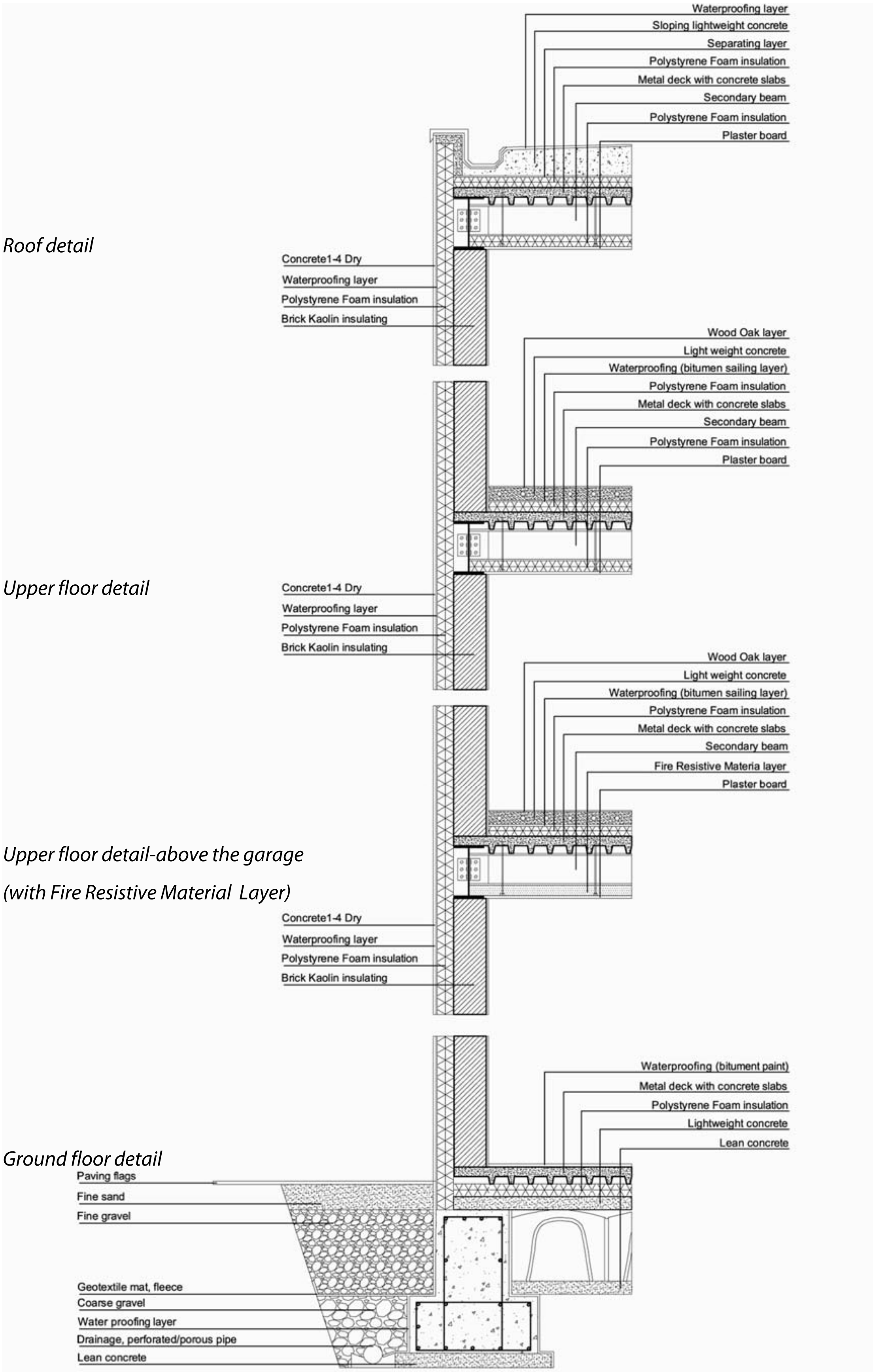


Figure 91: Structural detail *Source: Made by the author*

8.4. High insulating-low emissivity window

Most of the heat loss or gain occurs through windows and doors. As a window becomes more energy efficient, the price of the window will be higher, but the higher price will be justified by the savings money for heating and cooling bills.

There are many ways to boost the thermal efficiency of a window though glass options. Most windows today use insulated glass units (IGUs), as these perform better than a single pane of glass. A single pane of glass has an insulating value of approximately R-1 [25]. The single pane window can account for considerable heat loss or gain in a home. The traditional approach to a more energy efficient window has been to add more panes of glass to the unit, because the multiple panes increase the ability of a window to resist heat transfer. These multiple pane IGUs can be improved upon by adding an inert gas such as Argon or Krypton to the airspace between the panes of glass. The inert gas improves the thermal efficiency of an IGU because the molecules of the inert gas are heavier than air molecules, and this means that it takes a longer time for heat to transfer through these molecules [26]. Low-E glass is another option to consider for energy savings. Low emissivity glass is placed on the outside pane of the IGU and the Low-E coating will reduce heat loss in the winter, yet reflect the re-radiated long wave energy thus keeping the home cooler in summer.

Accordingly, two types of window are chosen for Courtyard-Duplex typology. One is Double glazed-Low emissivity, U value=1.4 and another one is Triple glazed-Low emissivity, U value=0.8 (fig. 93).

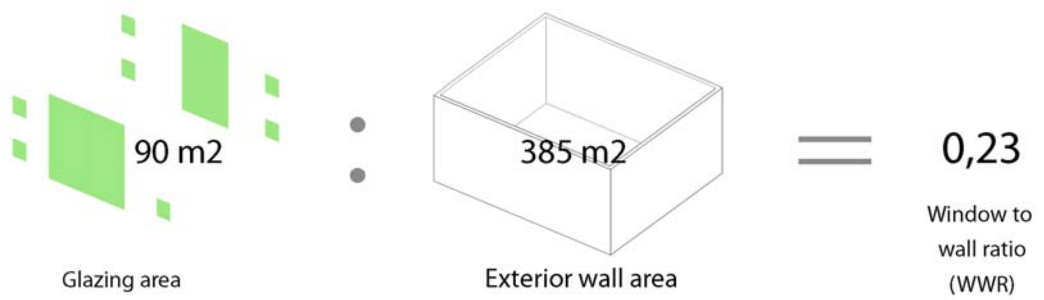


Figure 92: Window to wall ratio of Courtyard-Duplex system *Source: Made by the author*

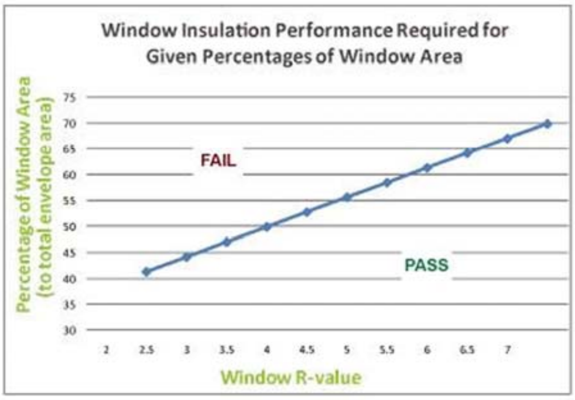


Figure 93: Insulation performance required for Given Percentages of Window Area
Source: "Effective Early Collaboration between Engineers and Architects for Successful Energy-Efficient Design" by Thomas White, Mitchell Dec, Dana Troy, and Brain Thornton

Table 3 Maximum Heat Transfer Coefficient or U-factors Unit: watt/(m²•K)

		Severe Cold Zone A		Severe Cold Zone B		Cold Zone		HSCW	HSWW
		SC ≤0.3	0.3< SC ≤0.4	SC ≤0.3	0.3< SC ≤0.4	SC ≤0.3	0.3< SC ≤0.4		
Roof		≤0.35	≤0.30	≤0.45	≤0.35	≤0.55	≤0.45	≤0.70	≤0.90
Exterior wall (including non-transparent curtain wall)		≤0.45	≤0.40	≤0.50	≤0.45	≤0.60	≤0.50	≤1.0	≤1.5
Overhead or protruding floor that contacts outdoor air		≤0.45	≤0.40	≤0.50	≤0.45	≤0.60	≤0.50	≤1.0	≤1.5
Partition wall or floor of non-heated and heated rooms		≤0.6	≤0.6	≤0.8	≤0.8	≤1.5	≤1.5	N.A.	N.A.
Single-orientation exterior windows (including transparent curtain walls)	WWR ≤0.2	≤3.0	≤2.7	≤3.2	≤2.8	≤3.5	≤3.0	≤4.7	≤6.5
	0.2< WWR ≤0.3	≤2.8	≤2.5	≤2.9	≤2.5	≤3.0	≤2.5	≤3.5	≤4.7
	0.3< WWR ≤0.4	≤2.5	≤2.2	≤2.6	≤2.2	≤2.7	≤2.3	≤3.0	≤3.5
	0.4< WWR ≤0.5	≤2.0	≤1.7	≤2.1	≤1.8	≤2.3	≤2.0	≤2.8	≤3.0
	0.5< WWR ≤0.7	≤1.7	≤1.5	≤1.8	≤1.6	≤2.0	≤1.8	≤2.5	≤3.0
Skylight		≤2.5		≤2.6		≤2.7	≤2.7	≤3.0	≤3.5

Table 7: Maximum Heat Transfer Coefficient of U-factor
Source: Chinese National Design Standard for Energy Efficiency in Residential Building, 2005

Glazing assembly	U-factor		R-value		SHGC	VT
unit ->	W/(K·m²)	BTU/(h·ft²·°F)	K·m²/W	h·ft²·°F/BTU	%	%
standard double-pane IGU (Insulating Glass Unit)	2.84	0.50	0.35	2.0	76	81
Medium-SHGC, low-e(SHGC: Solar heat gain coefficient)	1.48	0.26	0.68	3.8	58	78
Triple glazed with glass, low-e (German passive house standard)	0.8	0.15	1.2	7	33...51	0.6
For comparison:						
single glass	6.25	1.10	0.16	0.90	87	90
standard wood wall, 2x6, R-19 fiberglass	0.49	0.09	2.06	11.7		

Table 8: Single, Double and Triple glazing's properties

Source: "Residential Energy: Cost Saving and Comfort for Existing Building" by John Krigger & Chris Dorsi

DoubleGlazed_LowE

Double glazed with vinyl frame (no thermal break), emissivity of 0.10, vacuum insulating in between..

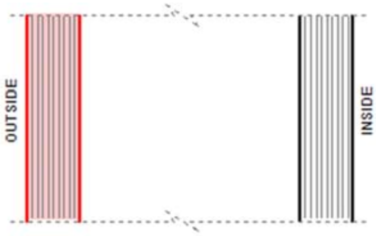
	Internal	External
Colour (Reflect.):	(T:0.839)	(T:0.839)
Emissivity:	0.78	0.78
Specularity:	0	0
Roughness:	0	0

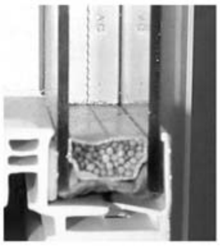
U-Value (W/m2.K):	1.400
Admittance (W/m2.K):	0.840
Solar Heat Gain Coeff. (0-1):	0.75
Visible Transmittance (0-1):	0.839
Refractive Index of Glass:	0.06
Alt Solar Gain (Heavywt):	0.21
Alt Solar Gain (Lightwt):	0.29
Thickness (mm):	37.0
Weight (kg):	27.600

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Glass Standard	6.0	2300.0	836.800	1.046	75
2.	Vacuum Insulating	25.0	0.0	0.000	0.000	0
3.	Glass Standard	6.0	2300.0	836.800	1.046	75

Table 9: Properties and Layers of Double glazed with low-conductivity frame (vinyl), emissivity of 0.10

Source: Ecotect 2010 material library





Window vinyl frame cutaway with double pane insulated glazing

Source: www.airchek-windowdepot .com/glassopti

TripleGlazed_LowE

Tripleglazing with vinyl frame (no thermal break), emissivity of 0.10, Krypton gas insulation in between.

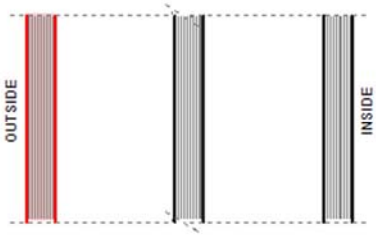
	Internal	External
Colour (Reflect.):	(T:0.839)	(T:0.839)
Emissivity:	0.78	0.78
Specularity:	0	0
Roughness:	0	0

U-Value (W/m2.K):	0.500
Admittance (W/m2.K):	0.870
Solar Heat Gain Coeff. (0-1):	0.75
Visible Transmittance (0-1):	0.839
Refractive Index of Glass:	0.02
Alt Solar Gain (Heavywt):	0.21
Alt Solar Gain (Lightwt):	0.29
Thickness (mm):	68.0
Weight (kg):	41.420

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Glass Standard	6.0	2300.0	836.800	1.046	75
2.	Krypton Gas	25.0	0.4	246.900	0.009	0
3.	Glass Standard	6.0	2300.0	836.800	1.046	75
4.	Krypton Gas	25.0	0.4	246.900	0.009	0
5.	Glass Standard	6.0	2300.0	836.800	1.046	75

Table 10: Properties and Layers of Triple glazed with low-conductivity frame (vinyl), emissivity of 0.10

Source: Ecotect 2010 material library



Window vinyl frame cutaway with insulated triple glazing

Source: www.airchek-windowdepot .com/glassopti.html

Figure 94: Cutaway of double and triple glaze-vinyl frame window

Chapter 9: Thermal performance of Courtyard-Duplex typology

The idea is to *minimize the heating/cooling energy demand of building envelope* by an appropriate passive solar building design as well as using super insulating material and low emissivity window. Hence the thermal performance of Courtyard-Duplex typology is simulated by Ecotect engine, containing Annual Temperature Distribution, Hourly Heat Gains/Losses, Passive Gains Breakdown and Monthly Heating/Cooling Loads, in order to demonstrate the advantage of Courtyard-Duplex typology. The model is constructed by heavy weight, super insulating materials (Super insulating concrete floor/roof-U value=0.06; Heavy solid insulating brick-U value=0.1; and Triple glazing, low emissivity window-U value=0.8).

9.1. Annual Temperature Distribution

Natural Ventilation is simply means that, during the operational period, if the outside conditions are closer to the defined comfort band than the inside conditions, the occupants will open the windows and the air change rate will increase proportional to the area of window in each direction and the current wind speed. This additional air change rate is over and above that in the Air Change Rate settings for the zone [27].

Mixed-Mode system is a combination of air-conditioning and natural ventilation where the HVAC system shuts down whenever outside conditions are within the defined thermostat range. It should be noted that Ecotect assumes that either the system continues running on an supplying mechanical ventilation or the windows are opened. In either case, the air change rate increases as described above. Note also that Ecotect does not consider energy used in the ducting of air when it calculates heating and cooling loads - these are both given as space loads not plant loads [28].

Calculation in the case of using only Natural Ventilation system in Courtyard zones and Corridor zone showed that except these zones have only 30% of total hour in comfort, all other thermal zones which use Mixed-Mode system have 100% of total hour in comfort (fig. 95). The result in the case of using Mixed-Mode system in all thermal zones showed that all the zones have 100% of total hour in comfort (fig. 96).

9.2. Hourly Heat Gains/Losses

Hourly heat gain graphs display the magnitude of all the different heat flow paths acting on thermal zones in the model over a 24-hour period. In this thesis, the examination was made in the coldest day, 30th January. Calculation in the case of using only Natural Ventilation system in Courtyard zone and Corridor zone showed that the HVAC Load in the coldest day is much lower than in the case of using Mixed-Mode system (fig. 97). The result in the case of using Mixed-Mode system in all thermal zones showed that the HVAC Load is increased; however all the zones will have 100% of total hours in comfort (fig. 98).

9.3. Passive Gains Breakdown

It shows the relative contribution of each component to overall losses and gains over a year (from 1st January to 31st December). This is useful for determining the most important items to address in a design. The following two graphs compare results from the same Courtyard-Duplex model, the first constructed of lightweight materials, in this case uninsulated concrete floor (U value=2.9) with 110mm brick wall (U value=2.6), and the second from super insulating concrete floor (U value=0.06) and heavy solid insulating brick (U value=0.1) (fig 99, 100). The graphs show how heavyweight insulating materials reduce the overall amount of heat loss by conduction in winter, 3 times less than the one of lightweight construction (fig. x). In the case constructed by lightweight materials, 75.5% of overall heat loss is by conduction, 24.7% by ventilation. In heavyweight insulated construction, 53.0% of overall heat loss is by conduction, 45.2% by ventilation.

9.4. Monthly Heating/Cooling Loads

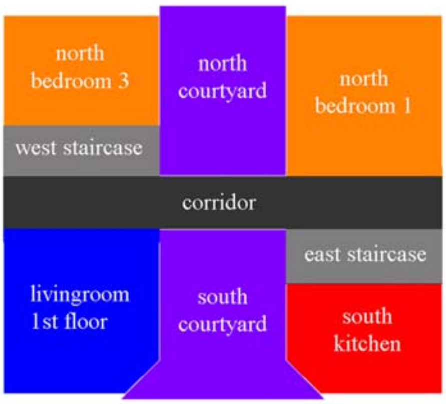
Monthly space load graphs display total heating and cooling loads for each zone. Heating loads are displayed in red and project above the centre line of the graph whereas cooling loads are blue and project below. It should be noted that these are heating and cooling loads, not energy loads. Obviously for the same space load requirement we could install a very efficient system or totally inefficient one. The inefficient system, whilst servicing the same space loads, would require a far greater amount of energy than the efficient one.

The first simulation is made for one duplex, its total heating load is 2493 kWh/year and total cooling load is 2455 kWh/year. The heating and cooling energy demand in total is 23.8 kWh/sqm year (table 12). The second simulation is made for 2 duplexes on one floor and the result is 23.8 kWh/sqm year for total heating and cooling loads (table 13). The last test is made for 4 duplexes on 2 floors and the result for heating and cooling loads is less than the previous results, 23.3 kWh/sqm year (table 14). Therefore we can assume that the maximum heating and cooling energy demand for medium-rise building which contains 24 duplex units is 23.8 kWh/sqm year.

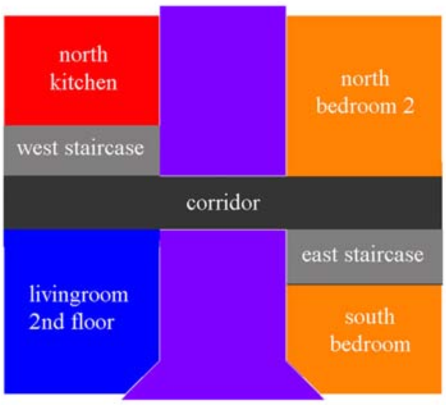
According to the values reported in the paper *"Feasibility Study for Renewable and Low-energy Applications in Urban Building Sector"* by F. Butera, S. Ferrari, R.S. Adhikari and P. Caputo 2007, the limit annual heating and cooling demand of present building in Shanghai is 54 kWh/sqm year and 51 kWh/sqm year [29], means 105 kWh/sqm year in total. Comparing with 23.8 kW/sqm year of Courtyard-Duplex typology, its annual heating and cooling demand reduces almost 4 times less than the case of recent building. Consequently the result demonstrates that with Courtyard-Duplex typology we can minimize the heating and cooling energy demand of the building envelope by an appropriate passive solar building design as well as using super insulating material and low emissivity window.

Ecotect Summary Report

	Areas							
	Floor	Surface	Exposed	Window	Volume	HVAC	Temp.	Operation
Zone Name	(m2)	(m2)	(m2)	(m2)	(m3)	System	Range	Hours
livingroom 1st floor	23.433	113.263	30.540	1.800	82.087	Mixed Mode	18.0-26.0	09-22/10-22
livingroom 2 nd floor	23.433	111.565	53.973	1.800	82.087	Mixed Mode	18.0-26.0	09-22/10-22
south kitchen	16.573	89.743	25.640	1.800	58.008	Mixed Mode	18.0-26.0	18-22/09-22
north kitchen	17.150	92.627	46.550	1.800	60.048	Mixed Mode	18.0-26.0	18-22/09-22
south courtyard	23.162	202.412	73.576	46.563	162.263	Mixed Mode	18.0-26.0	09-22/10-22
north courtyard	21.600	174.799	54.845	29.400	151.320	Mixed Mode	18.0-26.0	09-22/10-22
south bedroom	16.573	89.743	43.277	1.063	57.984	Mixed Mode	18.0-26.0	22-07/22-09
north bedroom 1	24.010	116.620	58.310	1.800	84.070	Mixed Mode	18.0-26.0	22-07/22-09
north bedroom 2	24.010	116.620	35.000	2.500	84.070	Mixed Mode	18.0-26.0	22-07/22-09
north bedroom 3	17.150	93.100	30.100	2.500	60.048	Mixed Mode	18.0-26.0	22-07/22-09
corrridor	26.029	276.397	53.499	3.600	182.294	Mixed Mode	18.0-26.0	09-22/09-22
west staircase	7.840	106.680	19.040	0.000	54.880	None	18.0-26.0	00-24/00-24
east staircase	8.449	109.638	21.726	0.000	59.143	None	18.0-26.0	00-24/00-24
TOTAL	249.412	1693.209	546.075	94.627	1178.303			



Thermal zones on the first floor



Thermal zones on the second floor

Table 11: Ecotect Summary Report

Source: Simulated by Ecotect

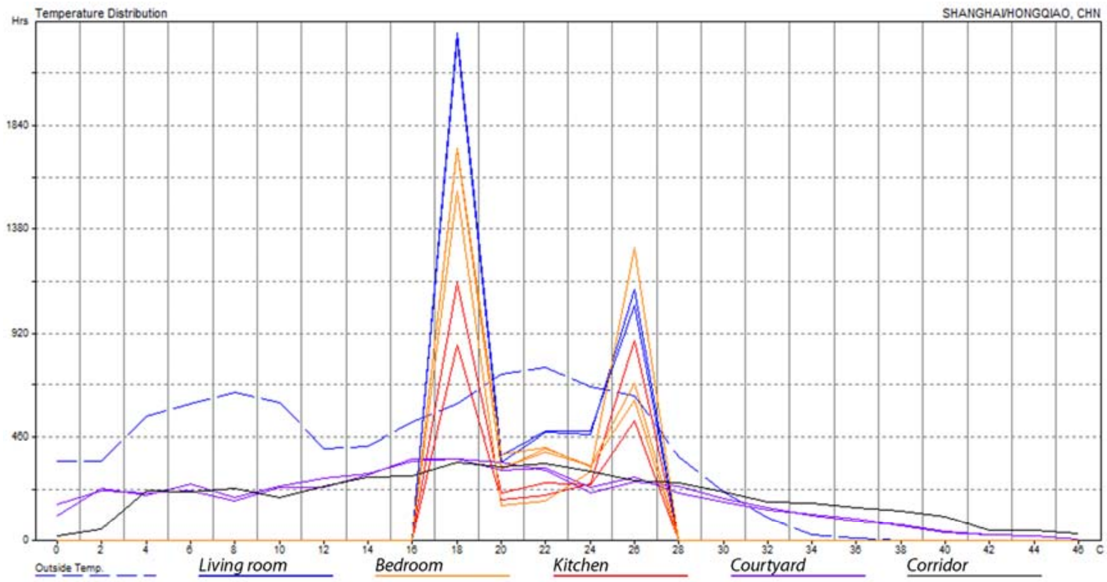


Figure 95: Annual Temperature Distribution (Mixed-Mode system for Living room, Bedroom, Kitchen; Natural Ventilation system for Courtyard, Corridor)

Source: Simulated by Ecotect 2010

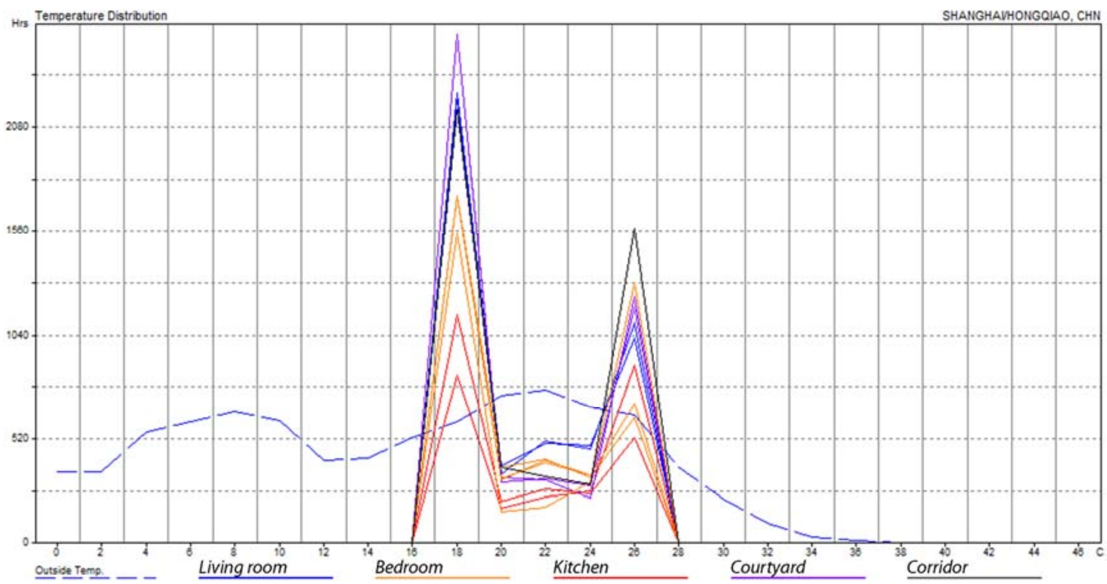


Figure 96: Annual Temperature Distribution (Mixed-Mode system for all thermal zones)

Source: Simulated by Ecotect 2010

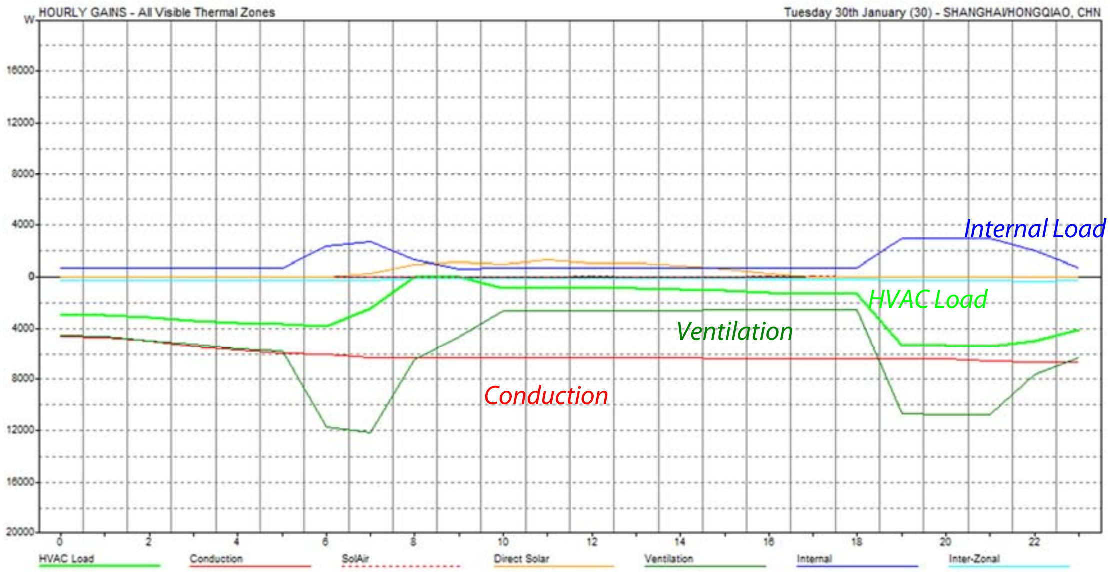


Figure 97: Hourly Heat Gains/Losses in the coldest day-31st, January (Type of HVAC system: Mixed-Mode for Living room, Bedroom, Kitchen; Natural Ventilation for Courtyard, Corridor)

Source: Simulated by Ecotect 2010

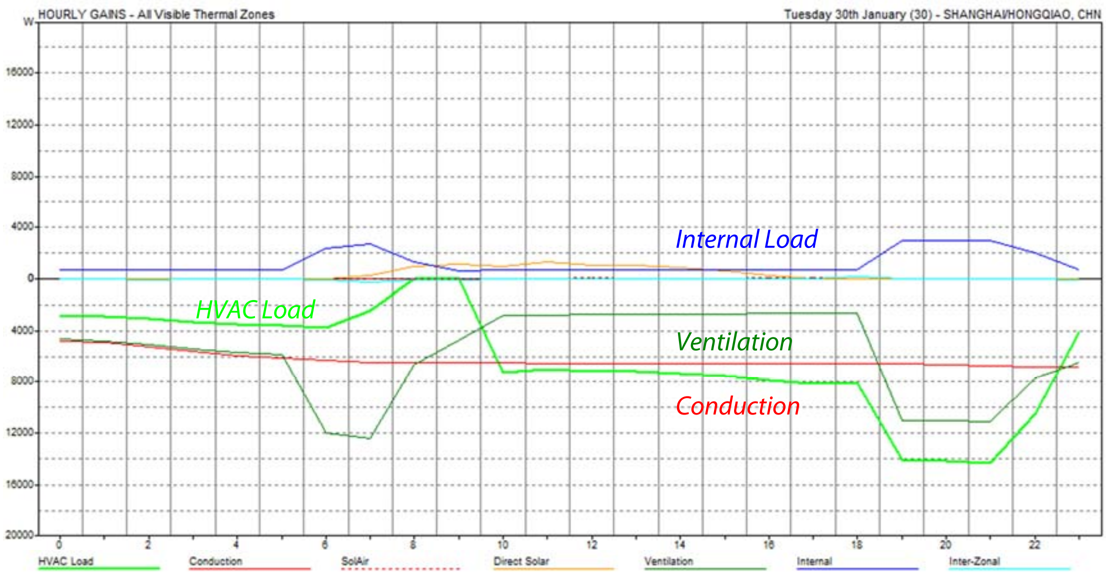


Figure 98: Hourly Heat Gains/Losses in the coldest day-31st, January (Type of HVAC system: Mixed-Mode for all thermal zones)

Source: Simulated by Ecotect 2010

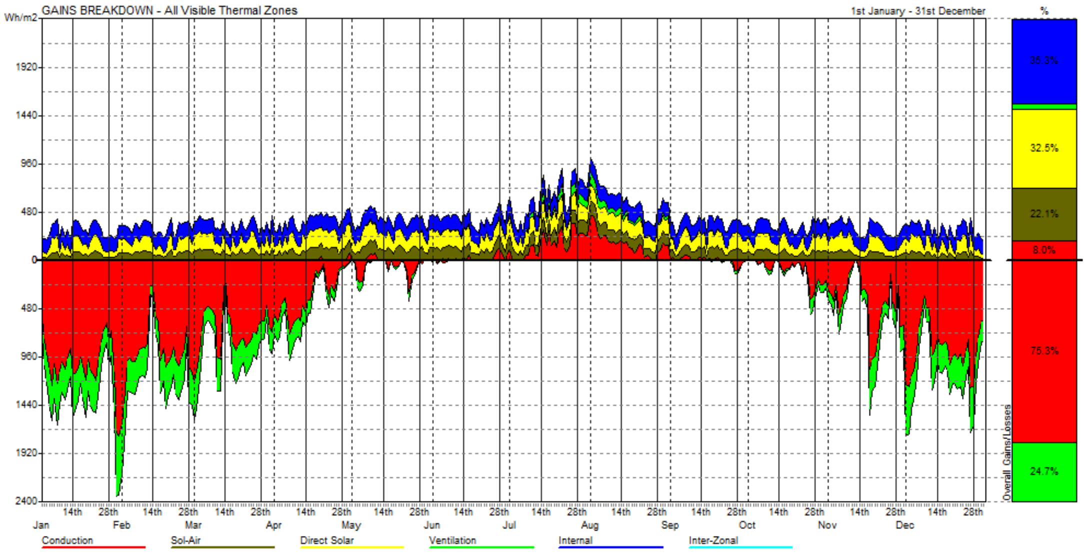


Figure 99: Passive Gains Breakdown of lightweight construction

Source: Simulated by Ecotect 2010

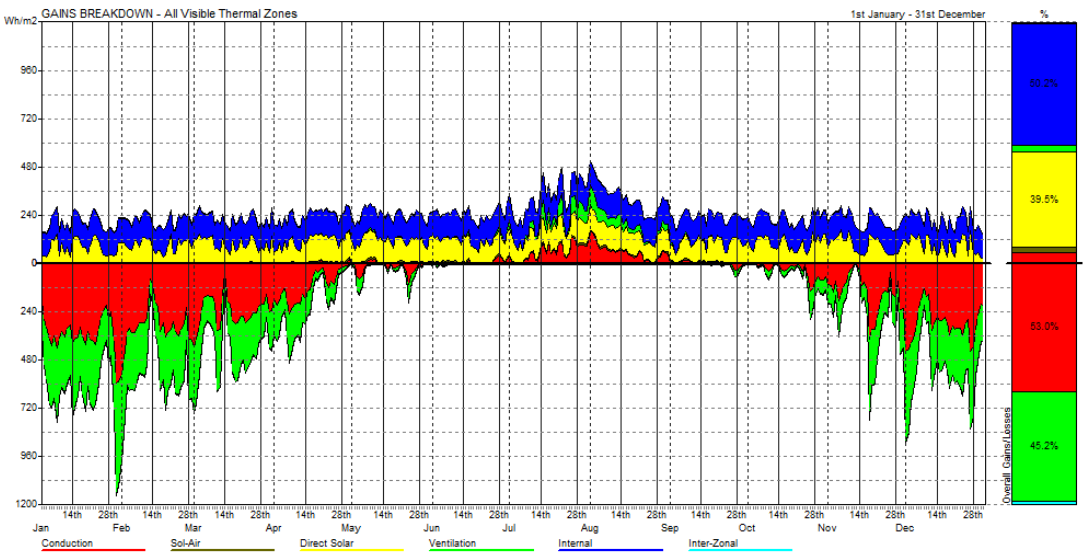


Figure 100: Passive Gains Breakdown of heavy weight, super insulated construction

Source: Simulated by Ecotect 2010

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MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones

Comfort: Zonal Bands

Max Heating: 7388 W at 21:00 on 30th January

Max Cooling: 6747 W at 11:00 on 21st July

	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	714863	0	714863
Feb	544539	22275	566814
Mar	382542	74494	457036
Apr	100912	162315	263227
May	674	150075	150748
Jun	0	133455	133455
Jul	0	799346	799346
Aug	0	830027	830027
Sep	0	207515	207515
Oct	9504	23106	32610
Nov	174449	52305	226754
Dec	566409	0	566409
TOTAL	**2493891**	**2454914**	**4948804**
PER M²	**12042**	**11854**	**23896**
Floor Area:		**207.094 m2**	

end of report

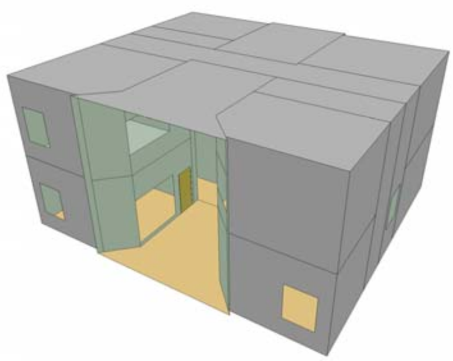

Table 12: Heating/Cooling loads of one duplex

Source: Simulated by Ecotect 2010

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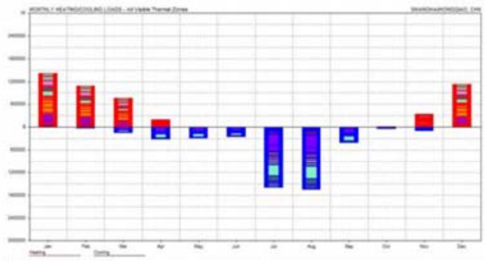
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones

Comfort: Zonal Bands

Max Heating: 14760 W at 21:00 on 30th January

Max Cooling: 13500 W at 11:00 on 21st July



MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	1422739	0	1422739
Feb	1084045	45249	1129295
Mar	760829	154856	915685
Apr	199588	329159	528747
May	1300	304626	305926
Jun	0	268591	268591
Jul	0	1598998	1598998
Aug	0	1660814	1660814
Sep	0	416324	416324
Oct	17386	47741	65127
Nov	342340	109128	451468
Dec	1126394	894	1127288
TOTAL	**4954621**	**4936381**	**9891002**
PER M²	**11962**	**11918**	**23880**
Floor Area:		**414.189 m2**	

end of report

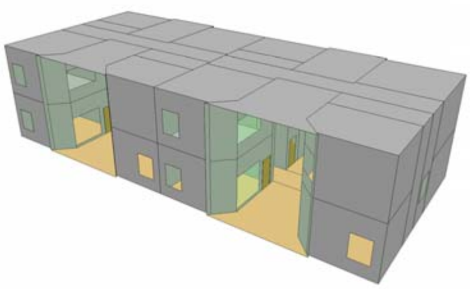


Table 13: Heating/Cooling loads of 2 duplexes on one floor

Source: Simulated by Ecotect 2010

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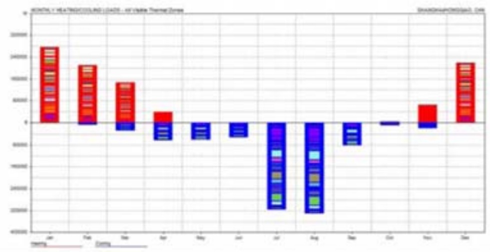
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones

Comfort: Zonal Bands

Max Heating: 29112 W at 21:00 on 30th January

Max Cooling: 26720 W at 11:00 on 21st July



	HEATING	COOLING	TOTAL
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	2763769	0	2763769
Feb	2106206	87277	2193483
Mar	1470273	291987	1762260
Apr	380746	638247	1018994
May	2280	607595	609875
Jun	0	527456	527456
Jul	0	3172342	3172342
Aug	0	3303436	3303436
Sep	0	828168	828168
Oct	31908	106390	138298
Nov	653688	214674	868361
Dec	2184336	1788	2186124
TOTAL	**9593206**	**9779361**	**19372568**
PER M²	**11581**	**11805**	**23386**
Floor Area:		**828.377 m2**	

end of report

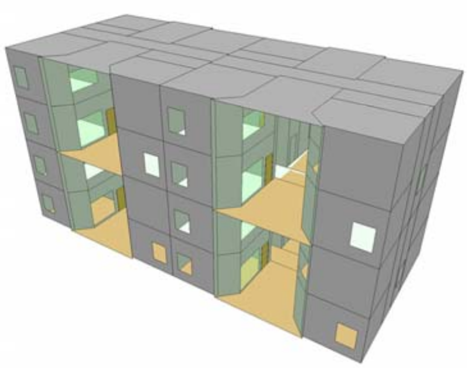


Table 14: Heating/Cooling loads of 4 duplexes on 2 floors

Source: Simulated by Ecotect 2010

Reference

[1] The Fourth Assessment Report: *"Climate Change 2007"* (AR4). The Intergovernmental Panel on Climate Change (IPCC), (2007).

[2] Mcgranahan, Balk and Anderson, report: *"The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones "*. Britain-based International Institute of Environment and Development (IIED), (2007).

[3] Bezlova, article: *"Country Water Action: People's Republic of China, Shanghai prepares for Climate Change"*. Asia Water Wire, (2007)

[4] Shi, Jun; Tang, Xu; Cui, Linli; Gao, Zhiqiang, paper: *"Temperature change and its effect factors in the Yangtze Delta, China"*, (2007).

[5 Roaf, Crichton, Nicol, *"Adapting Buildings and Cities for Climate Change: A 21st Century Survival Guide"*. Architectural Press; illustrated edition (14 Dec 2004).

[6] Augenbroe and Hensen, Editorial for special issue: *"Building and Environment Simulation for better building design"*, pg 1, (2004).

[7] *"Autodesk Ecotect Analysis 2010 Brochure"*. Autodesk Inc, (2009).

[8] Serghides, *"Bioclimatic design and energy conservation in buildings"*, pg 1. AA Dipt. RIBA II, AA Grad. Dipt. Energy and Environmental Studies.

[9] Serghides, *"Bioclimatic design and energy conservation in buildings"*, pg 12. AA Dipt. RIBA II, AA Grad. Dipt. Energy and Environmental Studies.

[10] M.Umbach and B.Huppauf, *"Vernacular Modernism: Heimat, Globalization, and the Built Environment"*. Stanford University Press, (2005).

[11] A. Tzonis, L. Lefaivre and B. Stagno, *"Tropical Architecture: Critical Regionalism in the Age of Globalization"*. Wiley-Academy, (2001).

[12] C. Li, *"Reinterpretation of Traditional Chinese Courtyard House"*, pg 13. Master's Thesis, University of Tennessee, (2009)

[13] Antarikananda, Douvlou and McCartney, *"Lessons from traditional architecture: Design for a climatic responsive contemporary house in Thailand"*, pg 1. PLEA2006 - The 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, (6-8 September 2006).

[14] C. Li, *"Reinterpretation of Traditional Chinese Courtyard House"*, pg 13. Master's Thesis, University of Tennessee, (2009).

[15] C. Li, *"Reinterpretation of Traditional Chinese Courtyard House"*, pg 14. Master's Thesis, University of Tennessee, (2009).

[16] Jaime J. Ferrer Forés, *"Courtyard housing: Environmental Approach in Architectural Education"*, pg 2, Universitat Politècnica de Catalunya, Spain, (2002).

[17] Barbara Muench, *"The traditional Beijing courtyard house: Assessment of its environmental performance under changing historic circumstances"*, pg 3, Plea2004 - The 21th Conference on Passive and Low Energy Architecture. Eindhoven, Netherlands, (19-22 September 2004).

[18] Barbara Muench, *"The traditional Beijing courtyard house: Assessment of its environmental performance under changing historic circumstances"*, pg 4, Plea2004 - The 21th Conference on Passive and Low Energy Architecture. Eindhoven, Netherlands, (19-22 September 2004).

[19] Barbara Muench, *"The traditional Beijing courtyard house: Assessment of its environmental performance under changing historic circumstances"*, pg 4, Plea2004 - The 21th Conference on Passive and Low Energy Architecture. Eindhoven, Netherlands, (19-22 September 2004).

[20] David Carter, "Catching the light", University of Liverpool, Research Intelligent, Issue 25, (August-2005).

[21] Design Sky Illuminance, Lighting analysis, Calculate, Autodesk Ecotect Analysis 2010.

[22] Sandra Mason, article: *"Matching Light Levels to Houseplants"*, Horticulture & Environment Champaign County Unit, (November 22-2003).

[23] Sandra Mason, article: *"Matching Light Levels to Houseplants"*, Horticulture & Environment Champaign County Unit, (November 22-2003).

[24] Design Sky Illuminance, Lighting analysis, Calculate, Autodesk Ecotect Analysis 2010.

[25] *"Glass Options Mean Energy Savings"*, http://www.airchek-windowdepot.com/glassopti.html.

[26] *"Glass Options Mean Energy Savings"*, http://www.airchek-windowdepot.com/glassopti.html.

[27] Natural Ventilation, Helps, Thermal Analysis, Calculate, Autodesk Ecotect Analysis 2010.

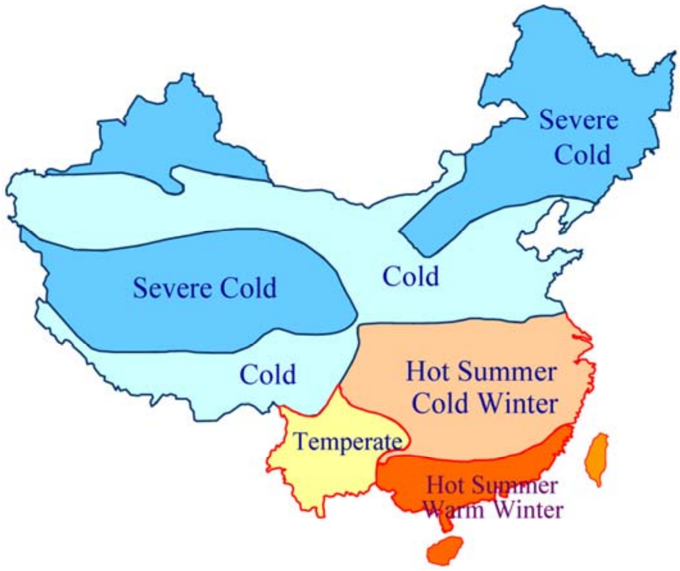
[28] Mixed-Mode, Helps, Thermal Analysis, Calculate, Autodesk Ecotect Analysis 2010.

[29] F. Butera, S. Ferrari, R.S. Adhikari and P. Caputo, paper: "Feasibility Study for Renewable and Low-energy Applications in Urban Building Sector", pg 4. Dept. Building Environment Science & Technology, Politecnico di Milano (2007).

Appendix

Appendix 1

China's building energy standards identify five climate zones, including (1)-Severe cold, (2)-Cold, (3)Hot summer and cold winter (HSCW), (4)-Temperate, and (5)-Hot summer and warm winter (HSWW).



China's Climate Zones

Source: Lin, 2008; Huang and Deringer, 2007

Appendix 2

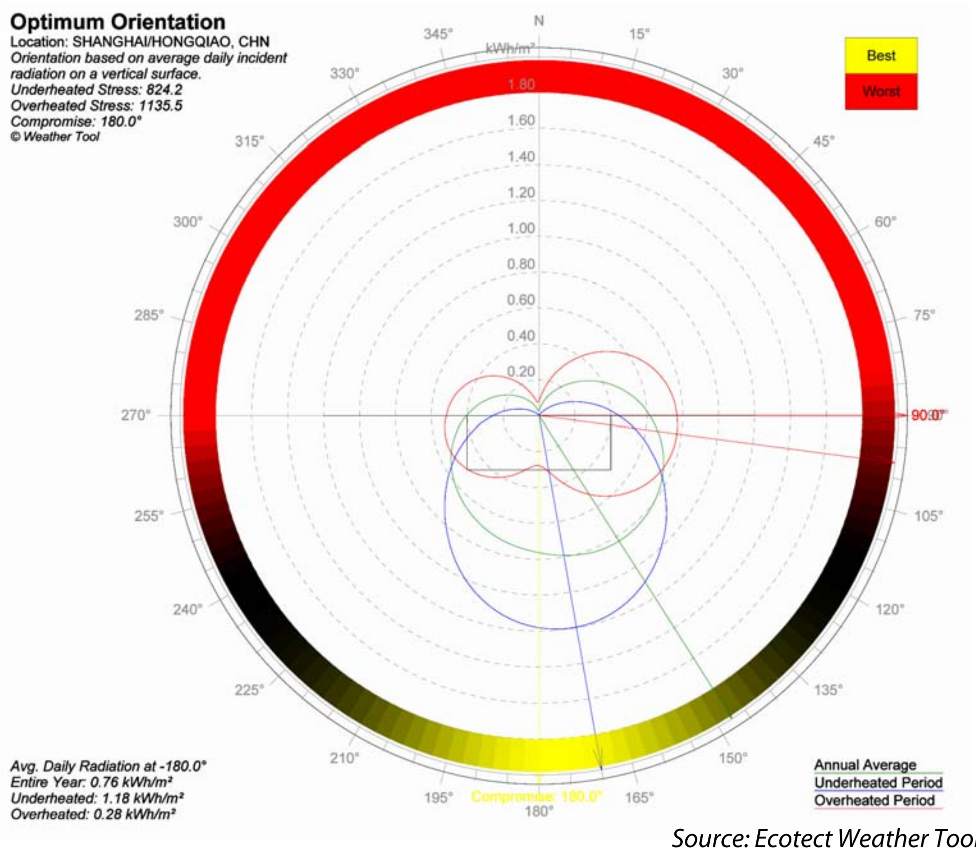
Climate Zone	Mean Temperature in			
	Coldest Month	Hottest Month	HDD °18	CDD °18
Severe Cold	≤ −10 °C		3800 — 8000	
Cold	−10 — 0 °C		2000 — 3800	100 — 200
HSCW	0 — 10 °C	25 — 30 °C	600 — 1000	50 — 300
HSWW	>10 °C	25 — 29 °C	≤600	>200
Temperate	0 — 13 °C	18 — 25 °C	600 — 2000	≤ 50

Mean Temperatures in Architectural Climate Zones

Source: Lin, 2008; Huang and Deringer, 2007

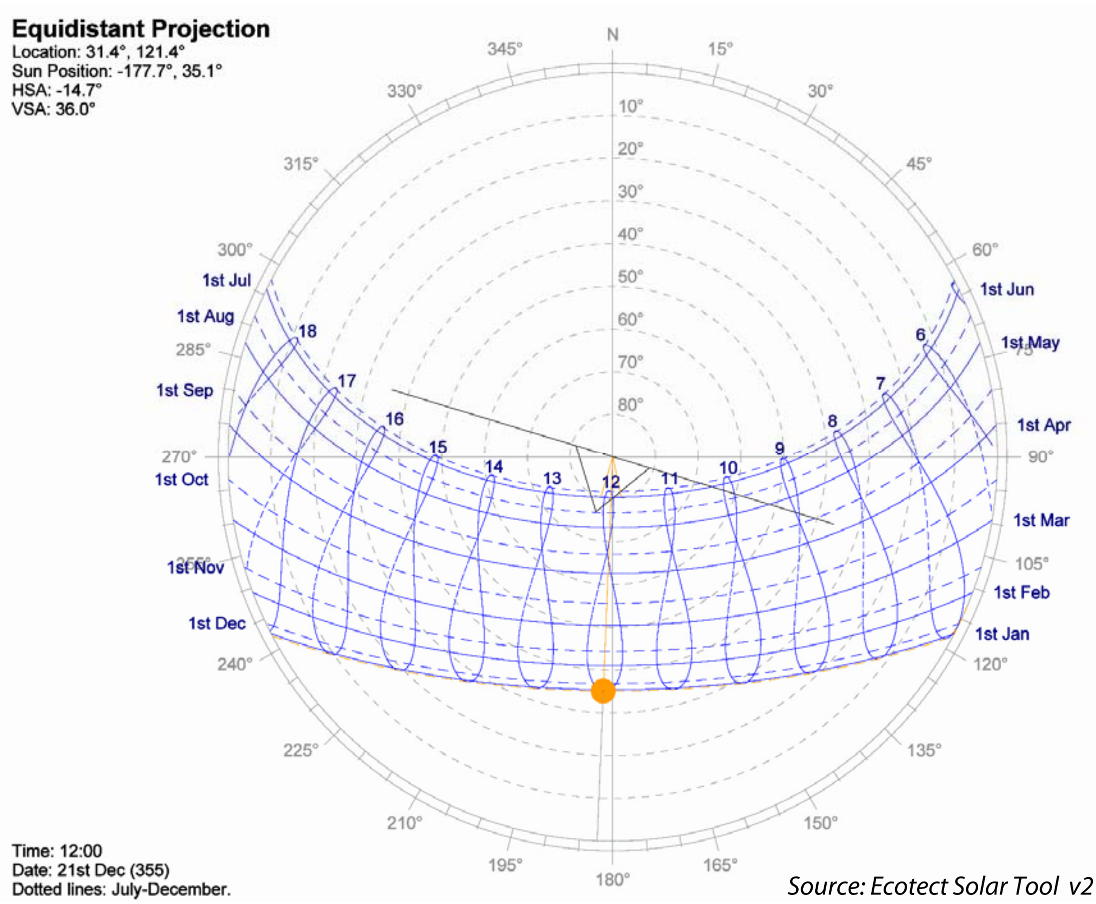
The northern part of China is located in the severe cold and cold zones, where space heating is the predominant end use for buildings. The HSCW zone covers the central part of China, where space heating and cooling are both required for comfort in buildings. The southern part of China, which falls in the HSWW zone, has seen increasing energy demand for cooling during hot summers.

Appendix 3



Source: Ecotect Weather Tool v2

Appendix 4



Source: Ecotect Solar Tool v2

Appendix 5

The equation for the Average Daylight Factor is given by:

$$DF_{avg} = \frac{T \times W \times \Phi}{2A \times (1 - R)}$$

Where:

T = Transmission of glazing (0-1),

W = Total area of glazing (m2),

Ø = Angle of sky subtended at the window (degrees),

A = Total internal surface area, wall, floors ceilings and glazing (m2), and

R = Area weighted average reflectance of surfaces (0-1).

Note: A completely unobstructed window would have a maximum value Ø of 90°