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湿润亚热带环境下的气候驱动项目

-减少上海复兴岛城市环境中制冷需求的
设计策略

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**CLIMATE AS A PROJECT DRIVER IN A HUMID
SUBTROPICAL CONTEXT**

**-DESIGN STRATEGIES TO REDUCE COOLING DEMAND IN THE
URBAN CONTEXT OF FUXING ISLAND IN SHANGHAI**

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ABSTRACT

This thesis presents a climate-driven design for Fuxing Island in Shanghai, a hot-humid subtropical context. In this climate, natural ventilation is the most effective passive cooling strategy, and it becomes the main driver for shaping the design forms. The aim is to reduce cooling demand through an integrated approach that works at both urban and architectural scales, using climate-responsive strategies, and to offer a method that can be replicated in other cities with similar climates.

Every design decision responds to the local climate: wind direction, sun path, humidity, and seasonal variation.

Using the City Energy Analyst (CEA) software, the research first identifies a cluster of three highly inefficient buildings. The intervention then extends to the entire waterfront strip, where climate-responsive strategies are applied.

At the urban scale, the masterplan uses open building forms (U-shaped, L-shaped, and courtyard typologies) that let summer winds from the south-east flow through the site. Building heights increase gradually to guide airflow, while the northern side remains compact to block cold winter winds. Light-coloured porous paving, green spaces, and a careful mix of residential, office, and commercial functions reduce heat absorption and balance energy demand throughout the day.

At the architectural scale, a mixed-use courtyard building is designed with its form directly shaped by the sun. The building is elongated east-west to minimise the most exposed facades. Window sizes vary by orientation: large on the north and south, narrow on the east and west. Adjustable aluminium shading devices, vertical sliding fins on east/west facades, horizontal rotating louvers on north/south, are not just functional but become part of the building's architectural language. A ventilated facade with terracotta tiles, XPS insulation, a material that resists moisture better than other insulants in humid climates, a green roof with an *Ilex chinensis* tree, planted balconies, and ivy-covered stairs all work together to keep the building cool.

The design also encourages people to spend time outdoors. The shaded ground floor colonnade, the central courtyard, and the green balconies are comfortable places to sit, eat, or work even on hot summer days. Every hour spent outside is an hour that does not require air conditioning, reducing cooling demand through behaviour as well as building performance.

CEA simulations show a 20-25% reduction in cooling demand compared to the existing condition. This method, using CEA to find a critical cluster, redesigning it with climate-responsive strategies, and simulating the improved scenario, can be used again in other humid subtropical cities. The same principles (letting wind pass through the site, shading from the sun, using vegetation for cooling) are not limited to this specific site. They can be adapted to any place with a hot and humid climate.

Key Words: Climate-responsive design; hot-humid climate; cooling demand reduction; courtyard typology; functional mix; natural ventilation; integration of green; encouraging outdoor hours; City Energy Analyst (CEA).

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CHAPTER 1: INTRODUCTION

1.1 Climate Change and the Built Environment

Climate Change represents one of the most critical challenges faced by contemporary society, and it is within this urgent context that this thesis is developed. The increase in greenhouse gas emissions, principally driven by human activities such as fossil fuel consumption for energy production, has led to a progressive increase in global temperatures and serious environmental impacts (Filonchyk et al., 2024). In particular, these emissions cause frequent and intense extreme weather events, such as rising sea levels, and increasing pressure on ecosystems and human health (Intergovernmental Panel on Climate Change, n.d.).

Over the past decades, global emissions have continued to increase, highlighting the urgency of implementing effective mitigation strategies. Despite international climate efforts such as the Kyoto Protocol and Paris Agreement, current emissions levels remain high and exceed the targets required to limit global warming (Filonchyk et al., 2024).

In the Chinese context, these global challenges are particularly significant, because China is currently the world's largest producer and consumer of coal, which remains a dominant source of energy and a major contributor to greenhouse gas emissions. At the same time, the country has national policy frameworks, including the carbon neutrality goals and the Action Plan for Carbon Dioxide peaking before 2030, which promotes a broader transition towards green and low-carbon development across multiple sectors, including urban and rural construction. (State Council of the People's Republic of China, 2021).

Within this policy and environmental framework, the Chinese context offers a relevant ground for this thesis, as it combines urgent climate challenges with an explicit national commitment to low carbon transformation in the built sector.

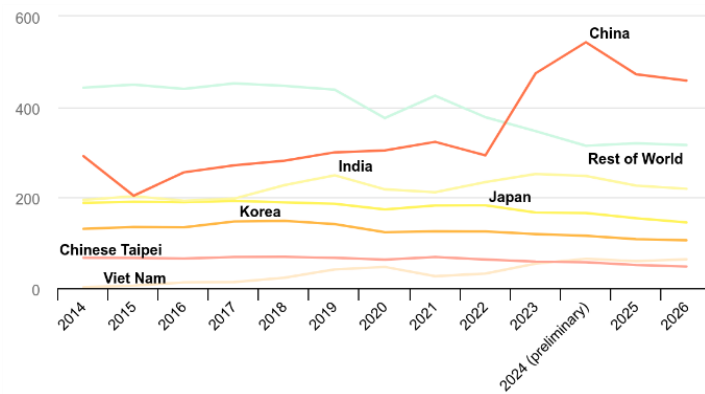


Figure 1: Coal imports of selected countries (2016-2026), highlighting China's dominant role in global coal demand. (International Energy Agency (IEA), 2024).

In this context, the built environment plays a crucial role, with buildings responsible for a significant share of global energy consumption and greenhouse gas emissions, accounting for approximately 35% of global final energy demand and nearly 38% of energy-related CO₂ emissions. This makes the building sector a key area for climate change mitigation strategies (Mastrucci et al., 2021).

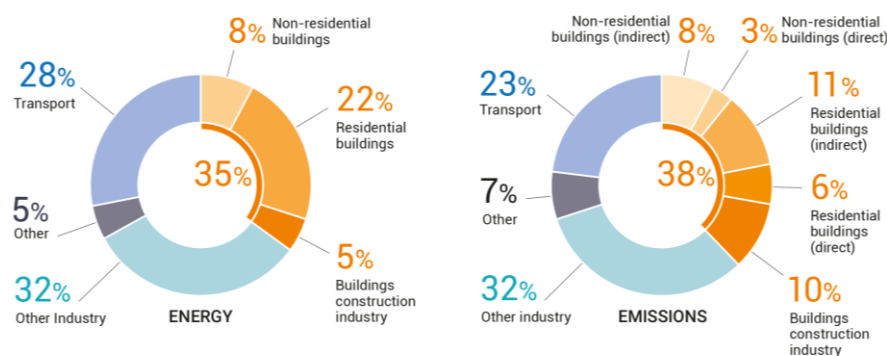


Figure 2: Share of global energy consumption and CO₂ emissions attributable to the building sector. (International Energy Agency (IEA), 2020).

In addition to operational energy use, such as electricity for lighting, heating, cooling and ventilation, buildings also contribute to emissions through construction process, material production, and demolition activities (Mastrucci et al., 2021). This trend is further intensified by population growth and urban expansion, which are increasing the demand for housing, infrastructure, and thermal comfort. According to United Nations projections, the global population is expected to reach around 9.7 billion by 2050, and the consequent concentration of people and activities in urban

areas is placing further pressure on energy demand from the building sector (United Nations Department of Economic and Social Affairs, Population Division, 2022).

As a result, reducing energy demand in the built environment has become a fundamental objective in the transition towards more sustainable and climate-responsive cities.

1.2 Rising Cooling Demand in Hot-Humid Climates

In recent years, rising global temperatures and increasing frequency of extreme heat events have significantly intensified the demand for space cooling, especially in hot and humid regions. According to the International Energy Agency, space cooling is one of the fastest growing end uses in buildings, with global energy demand projected to more than triple by 2050 under current policies (Birol, 2018).

Currently, cooling technologies such as air conditioners and electric systems account for 20% of total electricity consumption in buildings worldwide. This share is expected to increase as economic and demographic growth becomes increasingly concentrated in warmer regions. As incomes rise, access to cooling expands, allowing a larger portion of the population to afford air conditioning. In this context, while this represents a crucial improvement in terms of health, and well-being, it also reveals a significant demand, particularly in developing countries (Birol, 2018). This overlap between rapid population growth and warm climatic conditions is especially critical, as many of these regions are already characterized by high cooling needs, which are expected to increase further, contributing to additional greenhouse gas emissions (Intergovernmental Panel On Climate Change (Ipcc), 2023).

This dynamic is particularly critical in hot-humid climates, where high temperatures combined with elevated humidity levels intensify thermal discomfort and increase dependence on mechanical cooling systems. At the same time, the global number of air conditioning units is rapidly growing, with approximately 1.6 billion units currently in use, more than half of which concentrated in China and the United States (Birol, 2018). This rapid diffusion places increasing pressure on electricity systems, energy use, and contributes to rising greenhouse gas emissions.

Table 1: : Installed stock and annual sales of air conditioners by country, expressed in units and cooling output capacity. (Birol, 2018)

	Installed stock						Annual sales					
	Million units			GW output capacity			Million units			GW output capacity		
	Res	Com	Total	Res	Com	Total	Res	Com	Total	Res	Com	Total
United States	241	132	374	2 295	2 430	4 726	16	8	24	314	129	443
European Union	43	53	97	192	654	847	9	3	12	34	41	75
Japan	116	33	148	407	352	759	9	2	11	47	14	61
Korea	30	29	59	129	220	348	2	2	4	19	15	34
Mexico	7	9	16	40	65	105	1	1	2	5	6	10
China	432	138	569	2 092	607	2 699	41	12	53	305	81	386
India	14	13	27	77	72	149	3	2	4	14	12	25
Indonesia	7	5	12	32	27	59	1	1	2	5	4	9
Brazil	14	14	27	59	68	127	1	0.3	1	5	1.4	6
South Africa	1	1	3	6	15	22	0.1	0.1	0.3	0.9	1.1	2.1
Middle East	30	18	47	147	153	299	4	2	6	29	16	45
World	1 093	529	1 622	6 181	5 491	11 673	94	40	135	848	359	1 207

In addition, indicators such as Cooling Degree Days (CDD), commonly used to estimate cooling needs based on outdoor temperatures, are expected to rise significantly, with global increases of around 25% by 2050 (Birol, 2018). Therefore, the use of air conditioning systems contributes to the urban heat island effect by releasing heat into the outdoor environment and further increasing ambient temperatures, as shown in Figure 3.

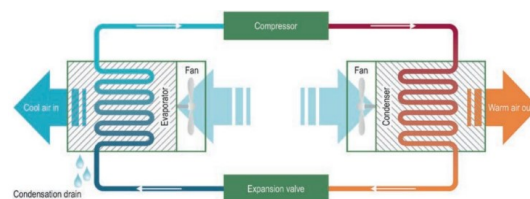


Figure 3: Schematic diagram of a vapor-compression air-conditioning system, which removes heat from indoor spaces and releases it outdoors, contributing to outdoor warming. (Birol, 2018).

In the Chinese context, these dynamics are especially relevant, as cooling demand already represents a major contributor to peak electricity load, in some cases accounting for more than 50% of demand (Birol, 2018). Combined with its rapid urbanization and a strong reliance on coal-based energy production, this trend poses significant challenges for both energy and consequent emissions reduction. In response, national Chinese policies have introduced measures such as Minimum Energy Performance Standards (MEPS), promoting more efficient air conditioning technologies and encouraging a transition from fixed-speed to variable-speed systems (Horowitz, 2023). However, improving equipment efficiency alone is not sufficient to address the rapid increase in cooling demand.

For this reason, this thesis explores design strategies in the hot-humid context of Shanghai, China, that help to improve the local climate, and to lower overall energy consumption and CO₂ emission, key issues addressed in this research.

1.3 Humid Subtropical Climate as a Design Challenge

Humid subtropical climates, classified as Cfa in the Köppen system, are characterized by hot summers, mild winters, and the absence of a distinct dry season, with high levels of humidity throughout the year. These regions are typically located between 20° and 35 ° latitude in both hemispheres and include areas such as Southeast China, the southeastern United States, parts of South America, and eastern Australia. (Hernandez-Ochoa & Asseng, 2018).

Table 2: Overview of the Köppen climate classification, with reference to the Cfa Humid subtropical climate.

Type	Subtype	Letter Code	Characteristics
A—Tropical	Tropical wet	Af	No dry season
	Tropical monsoonal	Am	Short dry season
	Tropical wet and dry	Aw	Winter dry season
B—Dry	Subtropical desert	BWh	Low-latitude dry
	Subtropical steppe	BSh	Low-latitude semi-dry
	Mid-latitude desert	BWk	Mid-latitude dry
	Mid-latitude steppe	BSk	Mid-latitude semi-dry
C—Mild Mid-latitude	Mediterranean	Csa	Dry, hot summer
		Csb	Dry, warm summer
	Humid subtropical	Cfa	Hot summer, no dry season
		Cwa	Hot summer, brief winter dry season
	Marine west coast	Cfb	Mild throughout year, no dry season, warm summer
		Cfc	Mild throughout year, no dry season, cool summer
D—Severe Mid-latitude	Humid continental	Dfa	Severe winter, no dry season, hot summer
		Dfb	Severe winter, no dry season, warm summer
		Dwa	Severe winter, winter dry season, hot summer
		Dwb	Severe winter, winter dry season, warm summer
	Subarctic	Dfc	Severe winter, no dry season, cool summer
		Dfd	Extremely severe winter, no dry season, cool summer
		Dwc	Severe winter, winter dry season, cool summer
		Dwd	Extremely severe winter, winter dry season, cool summer
E—Polar	Tundra	ET	No true summer
	Polar ice cap	EF	Perennial ice
H—Highland	Highland	H	Highland

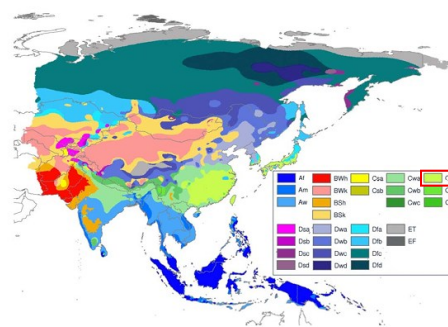


Figure 4: Spatial distribution of climate zones in Asia according to Köppen system, highlighting the Cfa Humid subtropical climate of Shanghai. (Peel et al., 2007).

A key characteristic of this climate is the combination of high temperatures and elevated air humidity, which significantly affects thermal comfort and increases the perceived temperature experienced by users. High humidity reduces the effectiveness of the human body's natural cooling mechanism, such as evaporation through sweating, making outdoor and indoor environments feel warmer than the actual air temperature (Birol, 2018).

In addition, rainfall is generally abundant and often concentrated in specific seasons, particularly in monsoon-influenced areas such as Southeast China, where high precipitation levels and moisture availability contribute to persistent humidity conditions (Hernandez-Ochoa & Asseng, 2018).

Although humid subtropical climates can experience cold temperatures during the winter, the focus of this research is on the extended and uncomfortable combination of heat and humidity. Unlike cold climates, where thermal discomfort comes from low temperatures, these climates present a distinct challenge due to the high levels of humidity that persist throughout the year, amplifying the discomfort caused by heat. This combination, particularly in regions like Southeast China, creates a unique environmental condition that significantly affects both outdoor and indoor spaces. Natural ventilation is very effective in dry climates, and it also remains a key strategy in humid subtropical environments. However, in these contexts, ventilation alone is often not enough to guarantee thermal comfort, because it brings additional moisture that limits its cooling effect (Birol, 2018).

Therefore, this research focuses on how to achieve comfort while dealing with both high temperatures and humidity at the same time. In humid subtropical climates, a single solution is not enough; an integrated design approach is needed. Such an approach should improve local conditions and thermal comfort while also lowering energy demand. For this reason, these climates offer a meaningful context to test climate-responsive design strategies in the built environment.

1.4 Problem Statement

What makes this thesis different from conventional design practices? In the context of the built environment, the design of urban form and buildings cannot be separated from climatic performance, since spatial configuration, solar exposure,

ventilation, vegetation, and envelope choices all influence thermal conditions and energy demand.

Within this framework, this thesis focuses on the urban context of Fuxing Island and investigates how energy demand can be evaluated and addressed not only at the architectural scale, where building performance is more commonly discussed, but also at the district scale, where urban morphology and local climate conditions strongly affect building behaviour. At the same time, general discussions on cooling demand often focus mainly on temperature, while the importance of humidity is less considered, even though it is very important in this climate.

The research therefore explores the relationship between urban and architectural design through an integrated climate-responsive approach, supported by energy assessment tools. Although climate-responsive design offers significant benefits, its implementation is often overshadowed by priorities such as aesthetic expression, construction speed, and cost efficiency. This research, therefore, reconsiders these principles, highlighting their relevance in contemporary dense urban environments such as Fuxing Island.

In addition, although simulation tools are often used primarily as evaluative instruments after design decisions are made, this research takes a different approach. By using energy assessments, such as City Energy Analyst software (CEA) by ETH Zurich, early in the design phase, the research identifies areas with the worst thermal comfort, that would therefore require high energy and cooling demand. This highlights the need for a rethinking of design choices, considering solar exposure, wind directions, and all climatic conditions that can ensure greater comfort. This approach aims to improve local climate conditions, enhance thermal comfort, and reduce cooling demand, addressing a key gap in current design practices.

1.5 Research Objectives and Questions

This thesis explores how climate-responsive approach can guide design decisions within a humid subtropical context. **Using Fuxing Island in Shanghai as a case study, the research develops a pilot design proposal in which climate acts as a driver of transformation.** First, it investigates how the design of the urban context can respond to climatic conditions and improve environmental performance. Then, it

focuses on the architectural scale, where design choices are also aimed at ensuring greater comfort. At this scale, particular attention is given to the building envelope, which represents a crucial interface between the external environment and the building interior. By applying climate-responsive design principles, the envelope plays a key role in controlling heat transfer, enhancing thermal comfort, and reducing the need for mechanical cooling.

The research questions that this thesis aims to answer are the following:

RQ1: How can climatic characteristics of a humid subtropical environment inform urban and architectural design strategies in Fuxing Island?

Each design decision, both at the urban and architectural scale, is justified based on local climatic conditions, such as wind direction, solar exposure, and other environmental factors. The aim is to ensure that climate actively guides spatial configuration, optimizing thermal comfort and reducing energy demand.

RQ2: How can energy assessment at the district scale support the identification of critical areas and guide design decisions?

In this research, energy evaluation tools play an important role in identifying zones where thermal discomfort is most pronounced, leading to high cooling demand. Therefore, instead of just checking existing performance, the simulation allows us to start the design process by pointing out the problems and guiding towards solutions. It allows us to focus on areas that need improvement and apply climate-responsive strategies to reduce cooling demand and enhance comfort.

RQ3: To what extent can an integrated climate-responsive approach improve environmental performance and reduce cooling demand compared to existing conditions?

This question addresses the comparative dimension of the thesis by evaluating the potential effects of the proposed strategies against the current situation. The aim is to assess whether the integration of climate-responsive solutions can lead to measurable improvements in the overall performance of the site.

1.6 Research Methodology

The research follows a multiphase methodology structured into literature review,

analysis, design, and evaluation. In particular, the literature review and the entire research phase are fundamental for building the knowledge base that guides my project, providing understanding to inform the development of climate-responsive strategies.

Considering the analysis phase, first of all, the climatic conditions of Shanghai are examined through the official EPW weather file, in order to identify seasonal trends, average values, and peak conditions related to temperature, humidity, solar radiation, and wind. This is followed by an urban analysis of the existing context, including functional distribution, construction periods, building heights, geometry, number of floors, and other parameters required for energy modelling.

These data are used as inputs for City Energy Analyst (CEA), which simulates the cooling demand of the existing scenario required to maintain indoor comfort conditions. Based on the results, the most inefficient cluster is identified according to cooling demand intensity per square meter.

The selected area then becomes the focus of the design phase, considering two scales. At the urban scale, a masterplan is developed, incorporating climate-responsive strategies, that consider the local climate, aimed at improving outdoor thermal conditions. At the architectural scale, the same principles are applied, with particular focus on the building envelope, considering the roof, walls, openings, shading devices, and materials, as well as the integration of open spaces and vegetation, all elements that enhance thermal comfort.

Finally, the proposed urban scenario is simulated again in CEA and compared with the existing condition to assess its impact on cooling demand and overall thermal performance. This iterative process is designed to ensure measurable improvements, with simulation results guiding further design refinement. The integration of climate-responsive strategies is central to this process, demonstrating their potential to enhance thermal comfort and reduce energy demand. This approach not only serves as a case study for the effectiveness of such strategies, but also acts as a pilot project, showcasing how these solutions can be applied in other contexts around the world.

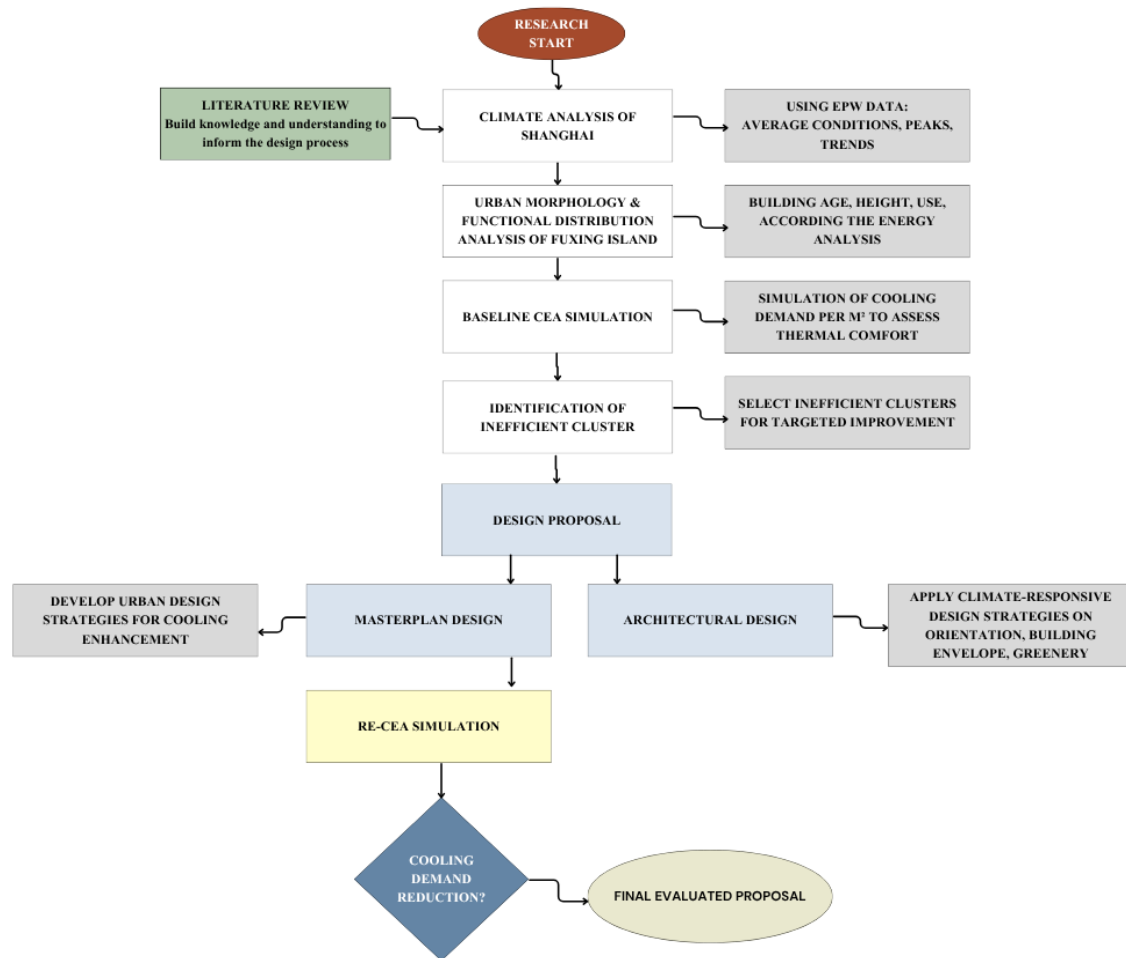


Figure 5: Diagram showing the research methodology of the thesis.

1.7 Thesis Structure

The thesis is divided into nine chapters that develop the research from theoretical background of literature review to design applications and evaluation.

- Chapter 1 presents the introduction, including research background, problem statement, the research objectives and questions, methodology used, and thesis structure.
- Chapter 2 presents the theoretical framework of climate-responsive design, first defining its main principles, benefits, and limitations within the built environment. It then explores how these principles can be translated into design strategies in the humid subtropical context, studied in this research, first at the urban scale and then at the architectural scale. In this way, the

chapter builds a coherent background for understanding how climatic conditions can inform both urban and building design choices.

- Chapter 3 gives case studies selection with relevant design lessons that inform the proposal.
- Chapter 4 describes the research methodology, analytical tools, design process, and overall adopted research framework.
- Chapter 5 is on the site analysis of Fuxing island, which includes urban context, climatic condition, energy performance, and site selection.
- Chapter 6 develops the urban design proposal, presenting the main design choices through the masterplan, which summarises the overall intervention.
- Chapter 7 develops the architectural focus of the project, explaining the main design choices and illustrating them through floor plans, sections, elevations, architectural details and renderings.
- Chapter 8 evaluates the outcomes by comparing the existing urban scenario with the proposed intervention, in order to assess the effectiveness of the project in addressing the identified problem and improving environmental performance, particularly in terms of cooling demand.
- Chapter 9 concludes the thesis by providing a summary of the main findings, contribution of the research and reflections on limitations and possible future developments.

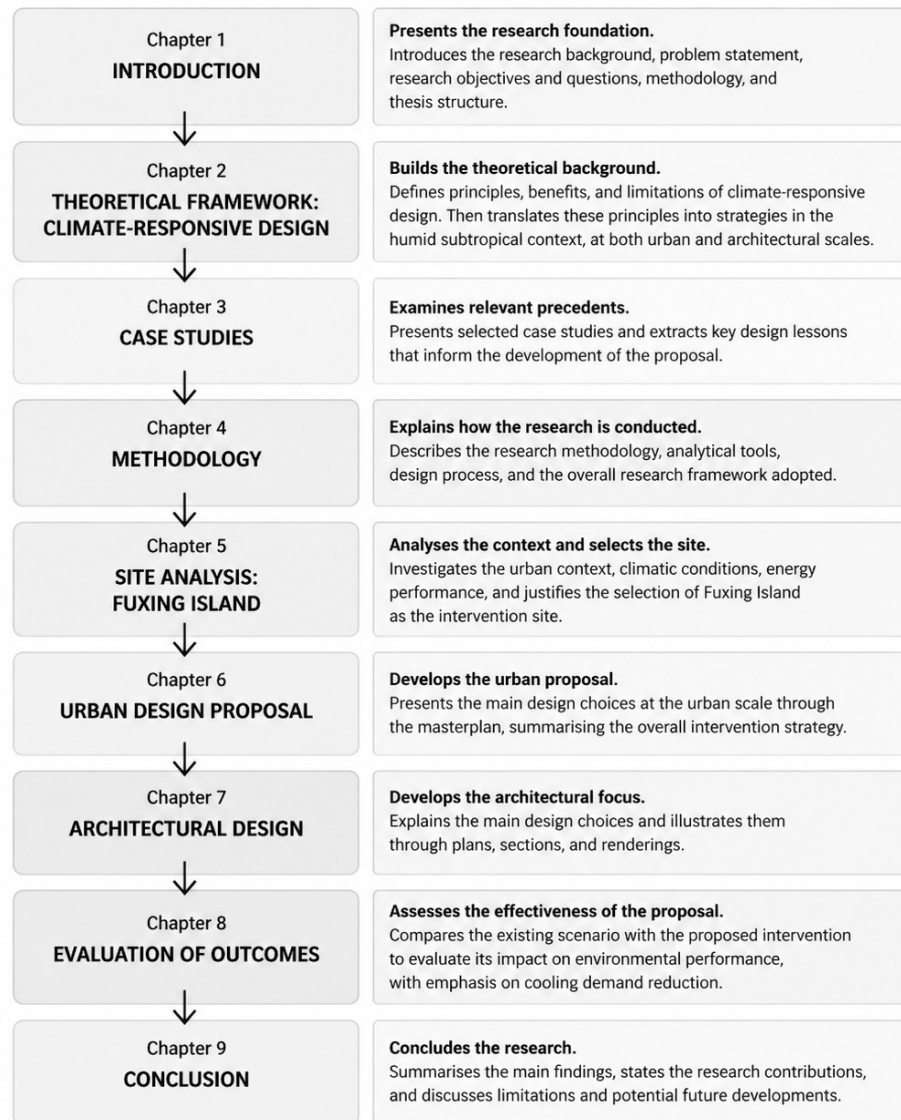


Figure 6: Overall Thesis Structure.

CHAPTER 2: CLIMATE-RESPONSIVE DESIGN FRAMEWORK

2.1 Climate-Responsive Design: Origins and Main Principles

In order to understand climate as a driver of design, it is first necessary to introduce the main architectural approaches that, throughout history, have engaged with environmental and climatic conditions.

From the beginning, architecture was originally developed to create spaces able to protect people from external conditions and provide functional and comfortable indoor environments. Throughout history, in different places and climates, buildings gradually evolved in response to local environmental conditions in order to improve indoor comfort. This long process is closely related to vernacular architecture, which can be understood as: “the collective and place-based response of communities to the specific conditions of their habitat, shaped by climatic, material, cultural, and practical factors” (Wu et al., 2026). In this sense, vernacular architecture represents an early form of climate adaptation, based on the use of local resources and on construction solutions developed in direct relation to the surrounding environment.

In this context, bioclimatic architecture emerged as a more structured design approach aimed at improving human comfort by considering climate, well-being, and environmental performance (Manzano-Agugliaro et al., 2015). Compared with vernacular architecture, which developed gradually through local traditions and practical adaptation to place, bioclimatic architecture adds the consideration of different climatic levels, from the general climate of the region to the specific microclimatic conditions surrounding the building, since both influence thermal behaviour and indoor comfort (Manzano-Agugliaro et al., 2015).

At the centre of this approach lies the concept of thermal comfort, understood as the condition in which people feel satisfied with the thermal environment and do not prefer it to be either warmer or cooler (Manzano-Agugliaro et al., 2015). Bioclimatic diagrams have been used as design-support tools to relate climatic conditions to comfort levels and to identify suitable strategies for improving building performance. Among them, the Givoni diagram is one of the best-known examples, as it relates temperature and humidity ranges to strategies that can help achieve indoor comfort, as

shown in Figure 7.

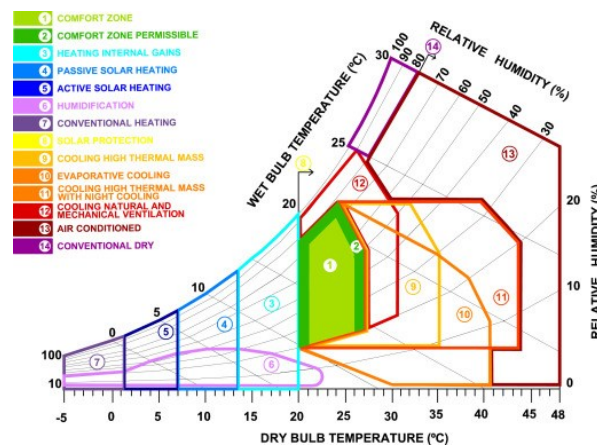


Figure 7: Givoni bioclimatic chart illustrating the relationship between thermal comfort, temperature, and relative humidity, and the corresponding design strategies required under different climatic condition. (Manzano-Agugliaro et al., 2015).

This theoretical background helps explain the context in which climate-responsive design (CRD) later developed. From the second half of the twentieth century, and especially after the energy crisis of the 1970s, architecture began to reconsider the relationship between buildings, energy use, and environmental conditions. In this context, issues such as orientation, window size, shading, ventilation, insulation, and building technology became increasingly important (Krishan, Yannas, Baker, Szokolay, 2001). During the 1980s and 1990s, growing awareness of limited resources and responsibility towards future generations strengthened the idea of sustainability, which gradually became one of the most relevant design concerns, influencing not only individual buildings but also neighbourhoods, cities, and regions (Krishan, Yannas, Baker, Szokolay, 2001).

Therefore, climate-responsive design, built on these concepts, can be understood as an approach that uses climatic knowledge to guide design decisions in order to improve comfort and reduce energy demand. In this sense, it is closely related to bioclimatic architecture, since both address the relationship between climate and human comfort. However, climate-responsive design places stronger emphasis on the translation of climatic data into design choices across different scales, from the urban context to the building envelope (Krishan, Yannas, Baker, Szokolay, 2001).

At the same time, passive and low-energy strategies represent some of the main

tools through which climate-responsive design can be applied in practice. The aim is not simply to reduce energy use through technology, but to modulate environmental conditions through landscape, urban form, building shape, envelope design, materials, and solar control, so that indoor and outdoor spaces remain as close as possible to comfort conditions throughout the day (Krishan, Yannas, Baker, Szokolay, 2001).

Already in antiquity, Vitruvius highlighted that the selection of the site and the shaping of buildings in relation to climatic factors were among the fundamental tasks of architecture for ensuring comfort (Vitruvius Pollio, Marcus, n.d.) . In the same direction, Olgyay (1981) argued that design should work with natural forces rather than against them, using their potential and the available environmental resources to create better living conditions and support human comfort (AIPE – Marco Piana, n.d.). From this perspective, climate-responsive design can be understood as a broader design framework, within which bioclimatic principles and passive strategies play a key role in achieving thermal comfort, reducing energy demand, and promoting more sustainable built environments.

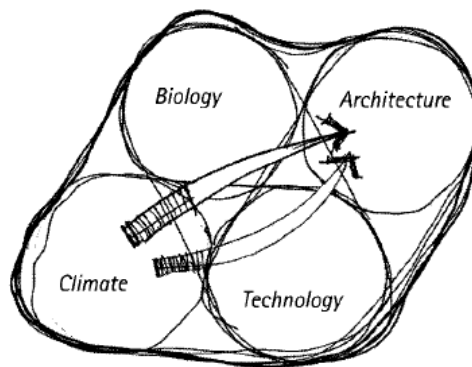


Figure 8: Conceptual diagram showing climate as the starting point for architectural design, in relation to biology and technology. (Richard Hyde, n.d.).

2.2 Climatic Challenges and Design Priorities in Hot-Humid Climates

In order to build the knowledge base that guides the project, it is essential to state that in hot-humid climates no design decision can be separated from a prior understanding of climate. As already discussed in the previous chapter (paragraph 1.3), the challenge of these environments does not depend only on high air temperatures, but on the combined effect of heat, humidity, strong solar exposure, and limited

night-time cooling. For this reason, thermal comfort is particularly difficult to achieve, and the literature does not identify a single solution as sufficient. Instead, it highlights the need for integrated responses based on the combination of several passive cooling measures. In these climatic regions, daily maximum air temperature and relative humidity often exceed 30 °C and 70%, making it difficult for one isolated strategy to maintain acceptable comfort conditions (Nagasue et al., 2024).

In general, passive cooling in hot-humid climates can be understood through three main objectives:

- preventing heat gain, limiting the amount of solar and external heat entering the building through roofs, walls, openings such as windows, and exposed surfaces.
- modulating heat, reducing heat accumulation within the building fabric by means of appropriate materials, insulation, and surface treatments.
- dissipating internal heat, removing heat generated both by outdoor conditions and by internal sources such as occupants, equipment, and daily activities (Nagasue et al., 2024).

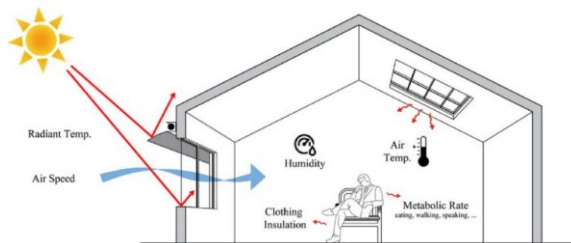


Figure 9: Main factors contributing to indoor thermal conditions and heat gain, including solar exposure and occupant-related comfort variables. (Daemei et al., 2019).

This explains why passive cooling in this climate cannot be reduced to a single technical device but must be understood as a coordinated environmental response.

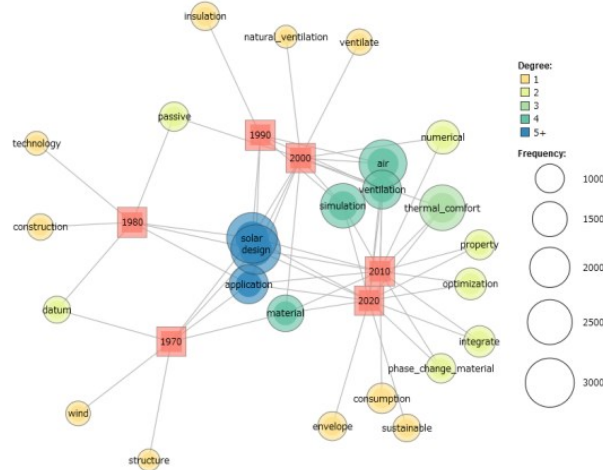


Figure 10: Co-occurrence network showing the evolution of research themes in passive cooling studies, from early concerns related to wind, structure, and construction towards a more integrated focus on ventilation, thermal comfort, simulation, materials and sustainability. (Nagasue et al., 2024).

Within this framework, **natural ventilation** remains one of the most important strategies, since the literature identifies it as a key factor in improving thermal comfort in hot climates. However, in hot-humid regions its effectiveness is greater when combined with other measures, including ceiling insulation, solar shading, and roof-based strategies such as green and cool roofs.

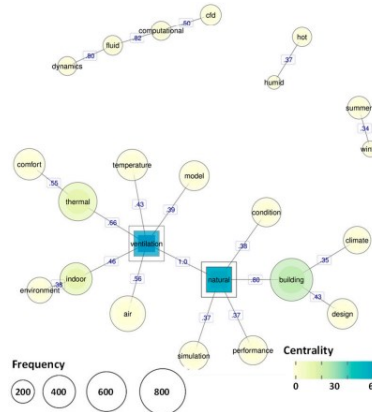


Figure 11: Co-occurrence network of natural ventilation, highlighting its relationship with thermal comfort, indoor conditions, and building performance in hot-humid climates (Nagasue et al., 2024).

At the same time, the design of materials and envelope components, especially roofs, walls, and external surfaces, becomes fundamental because these elements strongly influence heat transfer and indoor thermal behaviour. For example, even after ageing, white roofs are still capable of reflecting 80 % of solar radiation compared to dark roofs, which only reflect between 5 and 10 %, absorbing the heat and letting it enter. In this sense, these strategies do not depend on complex technologies, but on a

“careful control of materials and surfaces” (Birol, 2018).

Vegetation also plays an important role, not only as an architectural device but also as a microclimatic strategy: green roofs and walls help protect surfaces from overheating and mitigate radiation, while their effect becomes more significant at a broader scale when the green coverage ratio increases (Nagasue et al., 2024).

Overall, hot-humid climates require a climate-specific and integrated design approach, in which ventilation, solar protection, envelope performance, material choice, and vegetation are considered together as part of the same environmental response.

2.3 Climate-Responsive Strategies at the Urban Scale

At the urban scale, climate-responsive design addresses the relationship between urban form and local environmental conditions. In humid-subtropical climates, the configuration of streets, blocks, open spaces, surfaces, and vegetation strongly influences solar exposure, airflow and heat accumulation. For this reason, urban design strategies cannot be considered independently from climate but must respond to it through spatial choices that improve microclimatic performance. The following sections examine the main urban parameters that affect this relationship.

2.3.1 Urban Form and Solar Exposure

Urban development and the growth of the built fabric are important factors influencing the amount of solar radiation entering public spaces and the shading between buildings. Solar access depends not only on the position, height, and orientation of buildings, but also on the configuration of the urban block and street section (Ratti et al., 2005).

In this context, an urban canyon is defined as a street space enclosed by buildings on both sides, and its environmental behaviour is commonly evaluated through the H/W ratio, which describes the relationship between building height and street width. A high H/W ratio increases the shading effect within the canyon: the taller the buildings and the narrower the street, the deeper the canyon and the greater the mutual shading. This can be beneficial in climates with strong summer solar radiation, although it also reduces sky visibility and limits natural ventilation. By contrast, a low

H/W ratio usually corresponds to wider streets and greater solar exposure, which can increase solar gains and the risk of overheating. In this climate, it is therefore important to choose the street design according to local climatic conditions, sometimes favouring a denser and more shaded urban form, and sometimes preferring a more open layout that allows better ventilation. (Ratti et al., 2005).

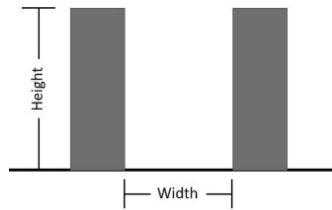


Figure 12: Drawing showing Height to Width ratio concept. (Du et al., 2025).

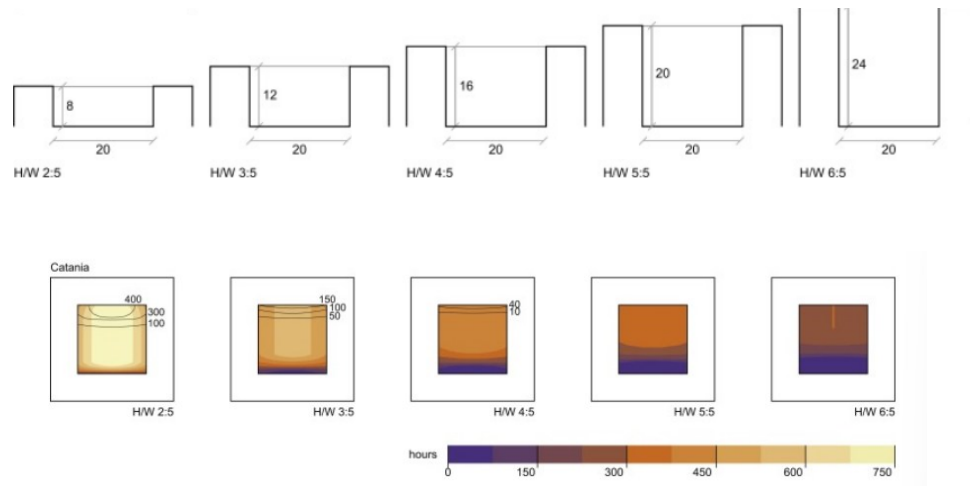


Figure 13: (a) Geometric configuration of urban canyons with different H/W ratios in a humid subtropical climate for the case study in Catania, Italy.

(b) Corresponding annual hours of solar exposure, highlighting how different design choices can change the effect. (Martinelli & Matzarakis, 2017).

Recent studies in humid subtropical Chinese cities confirm that block typology also influences solar availability. In Wuxi, research has shown that setback blocks get the most annual solar irradiation at street level, while courtyard blocks have much lower values due to enhanced mutual shading between buildings. The same study shows that courtyard blocks can reduce solar exposure by around 25% compared with setback and linear blocks, highlighting the strong effect of morphology on urban radiation patterns (Li et al., 2026). Another study in Wuhan revealed that block shape

affects energy consumption, with some articulated and compact urban forms showing better energy efficiency and solar access (Du et al., 2025).

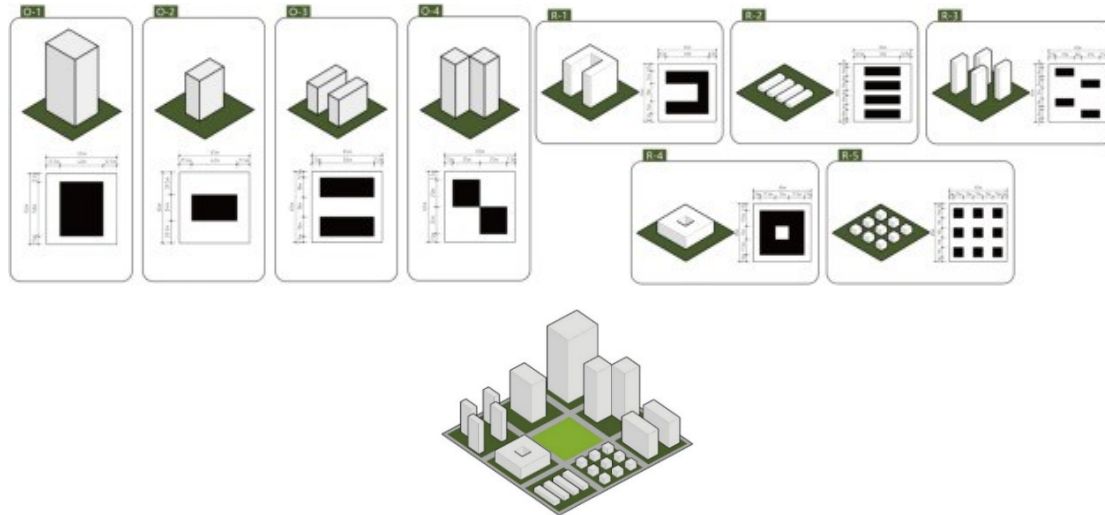


Figure 14: (a) Representation of the urban block configuration analysed in the Wuhan study, where O refers to office, and R to residential buildings.

(b) Three-dimensional schematic representation of the building typologies used in the simulation, each analysed separately. (Du et al., 2025).

Besides geometry, materials and colours also influence solar behaviour. Lighter surfaces tend to reflect a larger portion of solar radiation and therefore absorb less heat, while darker materials tend to absorb more radiations and result in more heating (Sue Ball, 2018). In this sense, the Solar Reflectance Index (SRI) is a useful indicator for understanding how much a surface heats up under solar radiation, as it describes the ability of a material to reflect solar energy and release absorbed heat. In hot-humid climates, it is therefore important to compare material properties through this type of index, especially when choosing lighter and more reflective materials that can help reduce heat accumulation (*OTM Consultants*, n.d.).

Key points for design:

- A higher H/W ratio is essential for creating more shade and reducing direct solar radiation, while a low ratio allows wind to enter.
- Courtyard and articulated block typologies can benefit from mutual shading, which helps reduce excessive solar exposure by preventing direct sunlight from the façade throughout the day.

- Light-coloured materials are effective in reflecting solar radiation and reducing heat accumulation on surfaces.

2.3.2 Urban Ventilation and Wind Corridors

Urban configuration does not only affect solar exposure but also plays a key role in shaping air movement inside the city, which is critical in humid subtropical climates. Outdoor thermal comfort can be improved, accumulated heat can be dispersed, and conditions that aggravate cooling demand can be neutralized by air circulation. In a dense urban area, the velocity and direction of the wind are controlled by the presence of buildings, vegetation, open spaces, and water bodies, and so each urban configuration impacts air flow differently (Erell, Evyatar et al., 2011).

The H/W ratio also influences ventilation patterns. In deep urban canyons, tall buildings create narrow streets that restrict ventilation flow from reaching pedestrian levels, and the winds tend to flow above roofs. This is due to the wind forming above the roof level and not funnelling down to pedestrian level, creating thermal stagnation and enhancing pollutant build-up (Sue Ball, 2018). Wider street sections and more open canyons normally facilitate the penetration of wind currents, reaching also pedestrian levels, thereby improving urban ventilation. For this reason, high H/W ratios may be relevant in providing shading but moderate ratios are more appropriate in humid environments where ventilation is a necessity for dissipating both heat and moisture (He et al., 2025).

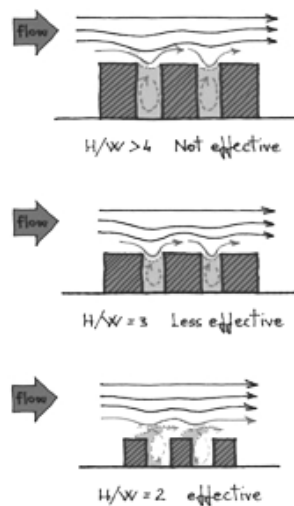


Figure 15: Influence of different H/W ratios on airflow within urban canyons. (Sue Ball, 2018).

In hot and humid cities such as Shanghai, dense built fabrics combined with weak ventilation result in heat trapping at ground level. Therefore, Urban Ventilation Corridors (UVC) represent a crucial climate-responsive planning strategy. Overall, these corridors are connected to open spaces, streets, parks, or waterfronts to let cooler air enter into built districts. Findings in Shanghai emphasize the importance of identifying the main ventilation directions and preserving ventilation corridors in order to support environmental improvements at the district scale. Studies from different Chinese cities highlight roads, riverfronts, and large continuous open spaces as important pathways for air movement (Qian et al., 2025).

Also, urban morphology affects ventilation through building disposition and height variation. Studies suggest that gradual changes in building height can facilitate wind entry and guide airflow more effectively through the urban fabric while very compact and continuous block arrangements tend to obstruct it. This is particularly important in waterfront situations, where the climatic advantages of water can only be secured if the air movement is drawn inland into the city.

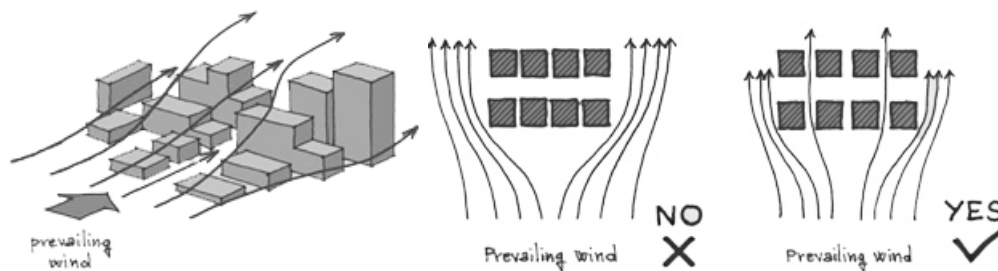


Figure 16: (a) Gradual variation of building heights guiding the prevailing wind.
(b) Comparison between compact and permeable building layouts, to improve wind penetration.
(Sue Ball, 2018).

Key points for design:

- Wind penetration at the street level is not guaranteed with deep canyons and compact forms.
- Ventilation corridors are linked to open spaces and waterfronts can improve airflow within the dense districts.
- Height variation and permeable building layouts of the space can encourage distribution of air across the urban fabric.

2.3.3 Vegetation and Microclimate Cooling

Urban green spaces, such as parks, trees, gardens, green roofs, and green walls, contribute to cooling by providing shade and promoting evapotranspiration, the process by which water evaporates from soil and vegetation, cooling the air. Recent studies confirm that these green spaces can produce significant local cooling effects, with the extent of temperature reduction depending on factors like vegetation type, density, spatial distribution, and the surrounding urban morphology (Soltanifard & Amani-Beni, 2025).

The shape and configuration of green spaces also affect their cooling performance. Cooling is not just about the quantity of green space, but also about its design and connectivity. Studies have suggested that elongated or more distributed green areas tend to spread their cooling effects over a larger portion of the urban fabric compared to compact, isolated patches. This highlights the importance of thinking about vegetation as a spatial climatic system, rather than merely a decorative feature in the urban landscape (Tan et al., 2024).

Trees and vertical greenery are particularly effective strategies because they act directly at the pedestrian level and on building facades. Trees intercept solar radiation, lower surface temperatures, and enhance thermal comfort in streets and open spaces. They can also act as wind barriers when wind intensity is high or when the prevailing wind is particularly strong, helping to mitigate excessive air movement (Z. Ren et al., 2026).

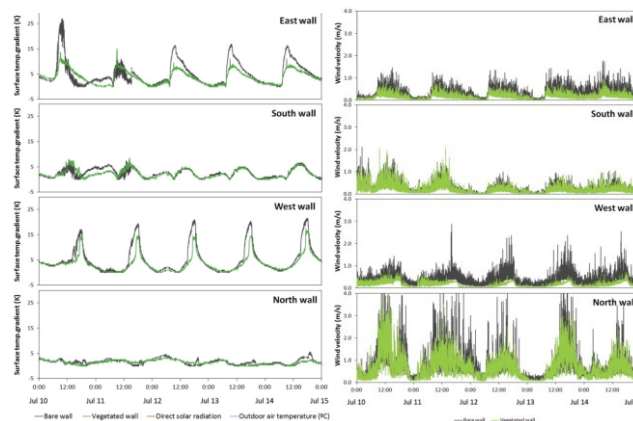


Figure 17: (a) Comparison of air and surface temperatures between bare and vegetation walls on a university building in Chicago, illustrating the thermal efficacy of green walls. (b) Comparison of wind velocity with and without vertical vegetation, highlighting the wind-buffering efficacy of vertical vegetation. (Susorova et al., 2014).

In this context, an attentive design of vegetation, including the selection of suitable plant typologies, is needed. One study measured 17 representative tree species in Shanghai under sunny conditions using a photosynthesis system to compare their cooling and humidifying performance. The results showed clear differences among species, confirming that not all trees provide the same microclimatic benefits. In general, species such as *Magnolia alba*, *Ilex chinensis*, *Cinnamomum camphora*, and *Zelkova schneideriana* showed particularly strong cooling and humidifying effects, suggesting that species selection is an important factor for improving urban thermal comfort in Shanghai's hot and humid climate (Shao Yongchang, 2015).

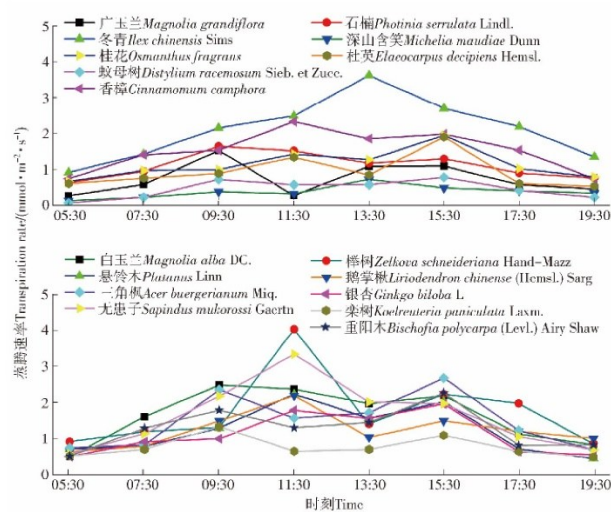


Figure 18: Daily variation of transpiration rates for selected urban tree species in Shanghai during summer, demonstrating the cooling effectiveness of different species.

- (a) *Ilex chinensis* and *Cinnamomum camphora* exhibiting the highest transpiration rates, thereby enhancing evaporative cooling.
- (b) *Zelkova schneideriana* and *Magnolia alba* also showing strong transpiration performance, confirming their suitability for urban heat mitigation. (Shao Yongchang, 2015).

Blue elements can also contribute to local thermal regulation, although their cooling effects should not be overestimated when used alone. Research on small urban water bodies shows that water surfaces by themselves have only limited cooling effects. However, combining water with other elements, such as tree shading, significantly enhances the cooling effect. In this case, the cooling benefit comes not just from the water, but from the combination of shade, green spaces and evaporation. (Cortês et al., 2020).

Key points for design:

- Elongated green forms can extend the cooling influence across a wider portion of the urban fabric.
- Trees and vertical greenery are particularly effective, helping to attenuate solar radiation and intense winds.
- The presence of blue elements, when integrated with open spaces, such as vegetation, provides a valuable contribution of cooling.

2.3.4 Surface Materials and Permeability

Together with vegetation, surface materials and permeability play a significant role in the urban context. Impermeable surfaces such as asphalt and conventional paving absorb and store large amounts of solar heat, while also preventing rainwater infiltration and evapotranspiration. In densely built urban areas, this results in higher surface temperatures and increased runoff during rain events.

Permeable and porous pavements are increasingly recognized as effective strategies because they allow water to infiltrate the ground, supporting evaporative cooling. Studies have shown that these materials can significantly reduce surface temperatures by about 8°C to 25 °C compared to traditional pavements, while also improving stormwater management. This dual benefit makes them particularly relevant in humid subtropical environments, where managing both heat and water is crucial (Zhao et al., 2026).

As explained before, light-coloured surfaces tend to remain cooler than darker ones, as they reflect more of the incoming solar radiation. This suggests that permeability and reflectance should not be seen as separate considerations, but rather as complementary elements in urban design. The best outcomes are achieved when cool materials, permeable pavements, and vegetation are combined as part of an integrated microclimatic strategy (Dalla Mora et al., 2025; Wang et al., 2025).

Key points for design:

- Permeable pavements can reduce surface temperatures and improve water infiltration.
- Light-coloured and reflective materials further assist in heat mitigation.

2.3.5 Functional Mix and Energy Use

The distribution of functions within a district is also an important aspect of urban design, since it influences not only the social and spatial organisation of the area, but also its environmental and energy behaviour. Different building uses are associated with different occupancy patterns and daily activity schedules, which means that their energy demand varies over time. Office buildings usually concentrate their demand during working hours, residential buildings tend to peak in the morning and evening, while commercial spaces often add further demand during the afternoon or evening. For this reason, the way functions are arranged within the urban fabric affects not only urban vitality, but also the temporal distribution of energy use at the district scale (Blanco et al., 2024).

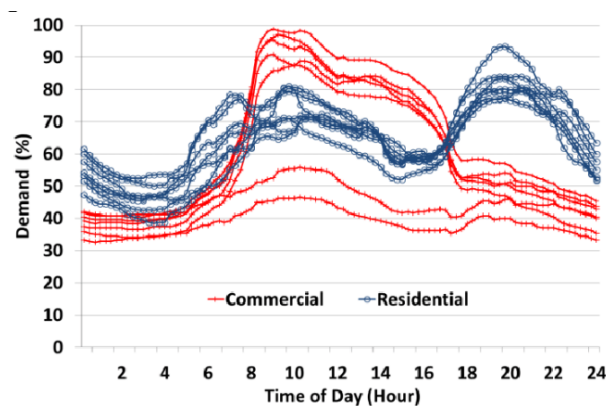


Figure 19: Daily electricity load profiles for commercial and residential users over one week, showing the typical weekday peak demand in commercial buildings and the evening peak in residential buildings, as observed in the study by Joshi & Lakum. (Joshi & Lakum, 2014).

In this sense, land-use planning becomes relevant not only from a social and economic point of view, but also from an environmental one. Although functional mix is not a climatic strategy in itself, it is still part of urban climate-responsive design because it helps organise the district in a more efficient and coordinated way.

At the same time, the location of different functions within the urban fabric should also respond to local climatic conditions. Residential areas, for example, may benefit from proximity to vegetation, shaded open spaces, or water bodies, where local cooling can improve thermal comfort and living conditions. More intensive mixed-use buildings, by contrast, may be more appropriate in denser and better-connected parts of the district, where accessibility is higher and urban activity

is already concentrated (Y. Ren et al., 2025; Tan et al., 2024). This suggests that functional mix should be planned not only according to programmatic needs, but also in relation to the microclimatic qualities of different parts of the site.

Key points for design:

- Mixed-use districts can reduce the intensity of simultaneous energy demand peaks.
- Residential areas may be more appropriate near open spaces.
- Mixed-used buildings can be more suitable in denser areas.

2.4 Climate-Responsive Strategies at the Architectural Scale

At the architectural scale, the same climate-responsive principles are addressed from a more focused perspective, considering the individual building as the main unit of response to climate. While urban strategies operate through the configuration of the wider district, architectural strategies translate these principles into more specific design choices related to the building itself, its envelope, its spatial organisation, and its relationship with the surrounding environment.

2.4.1 Orientation

Orientation is one of the simplest aspects to control during the design phase, and it can already influence the energy behaviour of a building. A correct position of the building on the site can help improve indoor thermal conditions, while an incorrect one can worsen thermal comfort, increase heat exposure, and lead to a greater reliance on mechanical cooling systems. For this reason, orientation should be considered from the beginning of the project, as an important design choice rather than a secondary technical adjustment.

In general, and especially in this climate context, buildings developed along the east-west axis can respond better to local climate, because they reduce the exposure of the east and west façades and create a larger south-facing side. This condition is useful because the south façade is easier to protect through passive devices such as balconies, loggias, overhangs, or shading elements. By contrast, the east and west sides are more difficult to control, since they receive direct solar radiation for many hours, and the west façade is often the most critical because it is exposed when

outdoor air temperatures are already higher in the afternoon. (Serafino, n.d.).

Orientation also affects the internal organization of spaces. The most frequently used rooms can benefit from better exposure and more favourable environmental conditions, while service areas and circulation spaces can be placed in less advantageous positions, like the north side, and act as a buffer. At the same time, the entrance should also be carefully considered, since every opening can create a sudden exchange between indoor and outdoor air. For this reason, transitional spaces or protected entrance zones can help reduce unwanted heat gain and improve the overall environmental performance of the building. In this sense, orientation is not only a question of solar exposure, but part of a broader climate-responsive strategy that connects building form, internal layout, and passive environmental control.

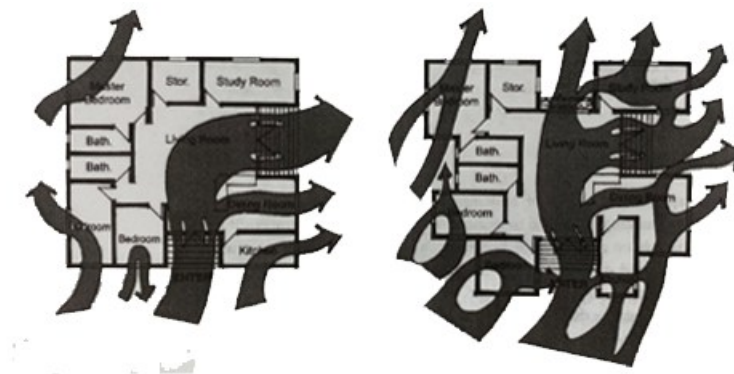


Figure 20: Diagram showing how different plan configuration influence natural ventilation and airflow penetration. The second plan, characterized by a more irregular shape with additional corners, alters airflow patterns. East-west orientation yields better performance. (Givoni, Baruch, 1998).

Key points for design:

- Orientation along the east–west axis to reduce heat gain on critical façades.
- Primary functions located in areas with better environmental conditions.
- Less favourable zones, on the north side, are dedicated to service spaces or vertical circulation systems.

2.4.2 Shading Strategies

In hot-humid climates, shading should not be applied uniformly but differentiated according to façade orientation. East and west façades are the most critical because they receive low-angle solar radiation in the morning and afternoon, which penetrates

more deeply into interior spaces and is more difficult to control than the higher sun on south-facing façades (Palmero-Marrero & Oliveira, 2010).

For this reason, horizontal devices such as overhangs and balconies are generally more effective on south-facing façades, where they can block high summer sun while still allowing daylight. On east and west façades, however, vertical fins and operable louvers, combined with brise-soleil are usually more suitable, since they respond better to low solar angles and provide more effective protection during the most exposed hours of the day (Lau et al., 2016; Palmero-Marrero & Oliveira, 2010). Therefore, the effectiveness of fixed shading devices, depends on their depth and geometry, which should be calibrated according to the sun path and its seasonal variation.

Balconies and loggias can also be understood as passive shading elements integrated into the architectural form. Rather than acting only as circulation or outdoor living spaces, they can reduce direct solar gains on glazing and opaque surfaces, especially when their depth is carefully calibrated in relation to orientation. In this context, recent studies also note that balconies may improve building performance by regulating solar exposure (Loche et al., 2024).

Vegetation should be considered part of the shading strategy as well. Trees, pergolas with climbing plants, green façades, and vertical greenery systems can improve thermal conditions not only by blocking solar radiation, but also through evapotranspiration and the reduction of surface temperatures, as explained in the earlier chapters. In subtropical contexts, the cooling effect of vegetation is strongly influenced by factors such as foliage density, canopy structure, and leaf characteristics, which means that plant selection is as important as placement (Lin et al., 2024).

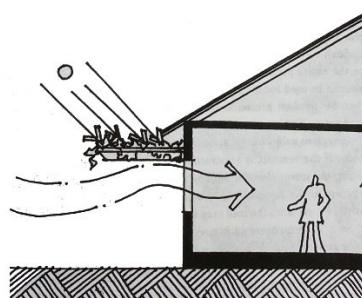


Figure 21: Vegetation placed on the balcony of a building to direct prevailing winds toward the opening (enhancing natural ventilation) and to block solar radiation (reducing heat gain), illustrating the dual benefit of balcony greenery. (Givoni, Baruch, 1998).

Finally, shading devices in these climates should be designed together with ventilation strategies rather than as isolated façade additions. This is particularly important in hot-humid environments, where solar protection must reduce heat gains without preventing air movement. Studies also show that deeper shading devices provide greater cooling benefits, but performance decreases with improper design, and west-oriented shading remains the most critical under peak summer conditions (Lin et al., 2024; Yin & Muhieldeen, 2024).

Key points for design:

- Shading strategies should vary according to façade orientation.
- Horizontal devices are more effective on south-facing façades, while vertical systems work better on east and west exposures.
- Balconies, loggias, and vegetation can also function as integrated passive shading elements.

2.4.3 Natural Ventilation and Window Design

In humid environments the priority shifts towards promoting continuous air movement in order to dissipate heat and enhance evaporative cooling from the human body (Givoni, Baruch, 1998). For this reason, ventilation should not be considered as a secondary technical feature, but as a fundamental design parameter influencing both building form and spatial organization.

The effectiveness of natural ventilation depends primarily on the ability to create a continuous airflow path across the building. Single-sided ventilation, where air enters and exits through the same opening, generally provides limited air exchange and is often insufficient in hot-humid conditions. Cross-ventilation, on the other hand, is significantly more effective, as it allows air to flow between openings located on opposite façades, improving heat removal and indoor comfort (Givoni, Baruch, 1998). To achieve this, openings should be positioned to capture prevailing winds and aligned in a way that facilitates airflow through interior spaces.

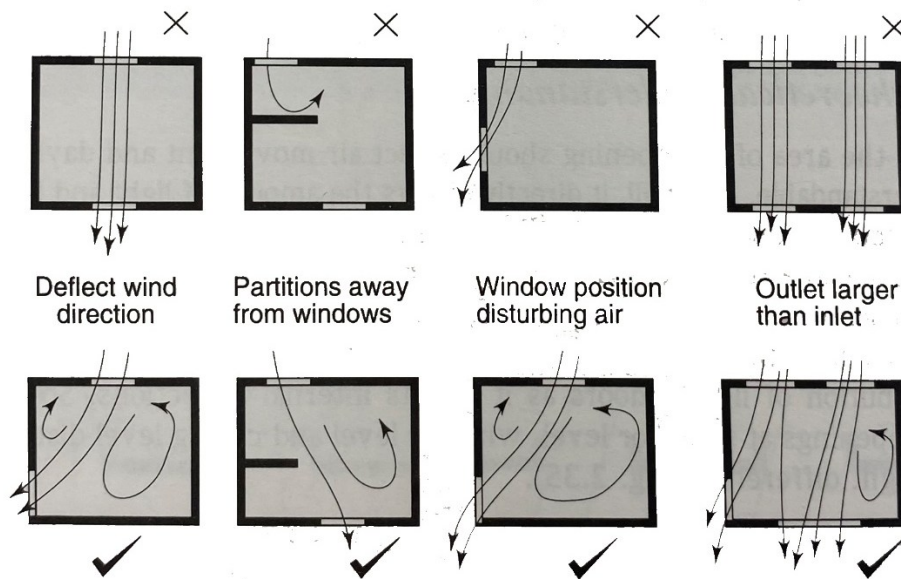


Figure 22: Diagram summarising basic rules for window configuration to improve indoor air movement and cross-ventilation performance. (Krishan, Yannas, Baker, Szokolay, 2001).

Window design plays a critical role in balancing airflow, daylight, and solar heat gains. In this context, the window-to-wall ratio (WWR) becomes a key parameter, as it directly influences both ventilation potential and thermal performance. Higher WWR values can improve air exchange and daylight availability, but they also increase solar heat gains and indoor overheating if not properly shaded. In hot-humid climates, excessively large glazed areas are therefore not always beneficial, and a balanced WWR, combined with effective shading devices, is generally more appropriate to reduce cooling demand while maintaining sufficient ventilation (Benni et al., 2016).

In addition to façade design, internal layout plays a crucial role in supporting ventilation. Deep floor plans and compartmentalized layouts can obstruct airflow, reducing the effectiveness of natural ventilation. In contrast, more permeable configurations, such as open-plan arrangements or spaces connected through aligned openings, allow air to move more freely within the building. This highlights the importance of considering ventilation not only at the level of windows, but as an integrated spatial strategy.

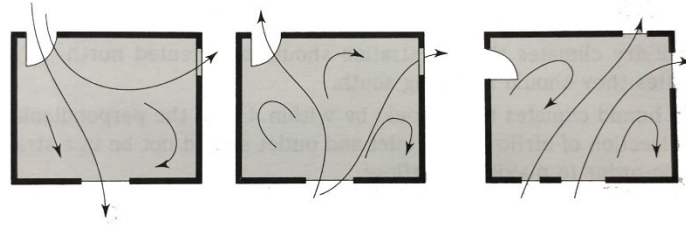


Figure 23: Ideal configuration of openings on two external walls, maximizing cross-ventilation and ensuring uniform air distribution, thereby improving natural cooling effectiveness. (Krishan, Yannas, Baker, Szokolay, 2001).

Overall, natural ventilation in humid subtropical climates requires a coordinated approach that integrates building orientation, façade and windows design, and internal spatial organization. Rather than relying on mechanical systems, ventilation should be incorporated in the design process from the beginning, ensuring that airflow becomes a defining element of architectural strategy.

Key points for design:

- Cross-ventilation is more effective than single-sided ventilation in improving airflow and indoor comfort.
- Internal spatial layout strongly affects airflow, with more permeable configurations supporting better ventilation.
- The window-to-wall ratio (WWR) should be carefully balanced and integrated with shading strategies to optimize airflow while controlling solar heat gains.

2.4.4 Building Envelope and Materials

The building envelope plays a central role in humid subtropical climates because it regulates the relationship between outdoor conditions and indoor comfort. Its performance depends not only on walls and glazing, but also on roofs and the overall configuration of the envelope as a thermal system. In these climates, the envelope must reduce heat transfer from outside to inside, limit solar gains, and at the same time control moisture-related risks. Rather than being understood as a simple barrier, the envelope should therefore be considered as an active interface that integrates solar protection, material properties, and moisture control to improve building performance in a coordinated way. (Hasan et al., 2017; Liu et al., 2022).

In this context, one of the main strategies is thermal insulation, which reduces heat transfer through walls and roofs and helps stabilize internal surface temperatures. A widely adopted solution is the use of multilayer “sandwich” configurations, where different materials are combined to optimize performance. These assemblies typically include an external protective layer, an insulation layer, an air cavity or ventilation gap, and an internal structural or finishing layer. The external layer interacts with solar radiation, while the insulation layer limits conductive heat transfer. The inclusion of air cavities, either static or ventilated, can further improve performance by reducing heat transmission and allowing part of the accumulated heat to dissipate before reaching the interior.

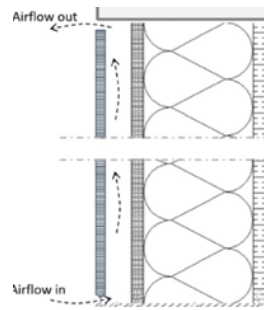


Figure 24: Sandwich wall configuration with, from the left to the right, external layer, ventilated cavity, insulation layer and internal layer, allowing airflow to enter. (Rahiminejad & Khovalyg, 2021).

Among these systems, ventilated façade configurations are particularly effective in hot-humid climates. By introducing a cavity between the external layer and the main wall, these systems allow solar heat to be partially removed through airflow before it penetrates the building. Studies show that, when properly designed, ventilated façades can significantly reduce heat gains and improve summer thermal performance, especially in contexts where passive cooling strategies are essential (Rahiminejad & Khovalyg, 2021).

Within multilayer assemblies, material selection becomes a key factor. Common insulation materials include expanded polystyrene (EPS), extruded polystyrene (XPS), polyurethane foam, and mineral wool, each characterized by different thermal conductivity, moisture resistance, and durability (Hung Anh & Pásztor, 2021). A fundamental parameter in evaluating these materials is thermal conductivity (λ), which describes how easily heat passes through a material. In general, lower conductivity values correspond to better insulating performance, as they limit heat

transfer through the envelope. As shown in Figure 25, materials such as polyurethane and extruded polystyrene typically exhibit lower thermal conductivity values and therefore provide higher resistance to heat transfer.

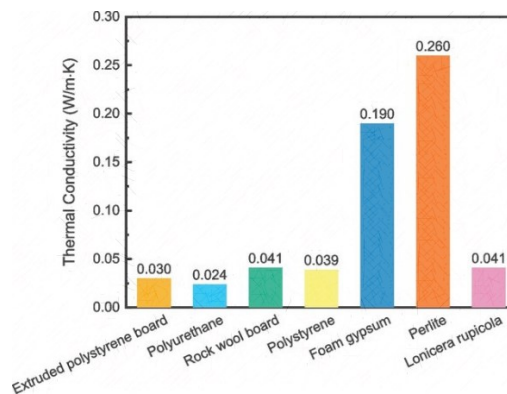


Figure 25: Comparison of the thermal conductivity values (W/m·K) of various insulation materials. The lower the thermal conductivity, the better the insulating performance. (Lu-Xi Lu et al., 2023).

However, this parameter should not be considered in isolation, since the performance of insulation materials may vary depending on temperature and moisture conditions. This is particularly relevant in humid climates, where moisture can reduce insulation efficiency and affect long-term durability (Cai et al., 2017; Hung Anh & Pásztor, 2021).

Therefore, it is important to rethink the building envelope in relation to the local context. In hot-summer regions such as Shanghai, building envelopes are typically based on reinforced concrete structures combined with multilayer wall systems. Insulation is often applied as an additional layer rather than being integrated into the structural system, and materials such as expanded polystyrene (EPS) and extruded polystyrene (XPS) are widely used due to their relatively low cost and ease of application. In humid conditions, however, the moisture behaviour of materials becomes a critical factor, since water absorption can reduce thermal performance and increase the risk of deterioration over time. In general, XPS shows lower water absorption than EPS, while mineral wool may be more sensitive to moisture if not properly protected. (Liu et al., 2022).

Key points for design:

- Multilayer assemblies (sandwich systems and ventilated façades) improve

thermal performance by reducing heat transfer and dissipating solar gains.

- Material selection must consider both thermal conductivity and moisture resistance.
- Expanded polystyrene (EPS) and extruded polystyrene (XPS) are widely used insulation solutions in hot-humid climates.

2.4.5 Integration of Vegetation

As already discussed, vegetation plays a fundamental role in improving microclimatic conditions at the urban scale. However, its importance remains equally significant at the architectural scale, where it can be directly integrated into the building envelope as an active environmental strategy.

Architectural integration of vegetation can take different forms, including green façades and roof gardens. Vertical greenery systems, such as climbing plants or modular green wall systems can help moderate external conditions by increasing local humidity and reducing temperature fluctuations. The effectiveness of green systems depends not only on their presence, but also on factors such as plant type, density and irrigation, rather than being treated as an aesthetic addition (Nikoofard et al., 2011).

When integrating vegetation at the architectural scale, the selection of plant typology and its structural implications must be carefully considered. Climbing plants can be broadly classified into self-clinging species, such as ivy, which attach directly to surfaces, and supported climbers, which require trellises, cables, or secondary structures to grow. While self-clinging plants offer simpler installation, they may affect façade durability over time, whereas supported systems provide better control of growth, ventilation, and maintenance.

In addition, the integration of vegetation on balconies, terraces, and roofs introduces important structural and technical considerations. Unlike vertical greenery systems, which mainly affect façade performance, horizontal vegetated surfaces involve the accumulation of soil, water, and plant mass, significantly increasing permanent loads on the structural slab. As a result, the design must account for load capacity, as well as additional layers such as waterproof membranes, drainage systems, and root barriers.

Key points for design:

- Green façades and roof gardens can improve thermal conditions, but their effectiveness depends on plant selection, density, and irrigation.
- Self-clinging plants are easier to install and require less maintenance, while supported systems need additional structures but provide better control and protection of the façade.
- Green roofs, terraces, and balconies require structural verification and technical layers such as drainage, waterproofing, and root barriers.

CHAPTER 3: CASE STUDIES

3.1 Selection Criteria

The case studies in this chapter are chosen to show specific design decisions that respond directly to climate. Each case was selected because it offers a practical lesson that can be used in the design proposal for Fuxing Island.

The selection follows five main themes, all coming from the climatic analysis of Shanghai: how urban form can improve natural ventilation, how courtyards create shaded and comfortable outdoor spaces, how greenery can be added to balconies, how materials such as terracotta and exposed concrete contribute to thermal performance, and how brise-soleil systems can block solar radiation effectively. Rather than analysing the architectural quality of each building as a whole, the chapter focuses on one or two clear strategies per case.

3.2 Urban Ventilation

3.2.1 Urban Breathing Block, Antalya (Hakan Sabahlar)



Figure 26: Urban breathing block illustrating the design and placement of openings to optimize natural ventilation and airflow distribution throughout the block. (Hakan Sabahlar, n.d.).

At the urban scale, the first challenge in a hot-humid climate is to let wind move through the site. A compact block with no openings traps heat and makes the cooling

demand higher. The Urban Breathing Block project in Antalya, Turkey, offers a clear solution.

Instead of designing one big building mass, the project breaks the program into separated volumes calibrated to prevailing wind directions and solar exposure. Building spacing preserves dominant wind corridors while allowing secondary sea breezes to penetrate the site, improving natural ventilation potential and reducing heat accumulation within the urban block. The ground level is conceived as a fully pedestrianized public realm where shaded streets, courtyards and open passages create continuous urban life. This approach shows how a porous urban system can respond to local wind patterns without reducing density (Hakan Sabahlar, n.d.).

For the design proposal, the lesson is clear: building spacing and orientation must be designed first for wind, not only for program or aesthetics. In addition, when the outdoor spaces at ground level are comfortable thanks to shade and airflow, people tend to spend more time outside. This means fewer hours spent inside air-conditioned rooms, which directly helps reduce the overall cooling demand of the building.

3.3 Courtyard Typology

3.3.1 Ruihong Tiandi – Hall of the Moon, Shanghai (WAA+)

This project is located in Shanghai, the same city as my site, and offers a local example of how the traditional courtyard typology can be adapted to a contemporary mixed-use building. The central courtyard acts not only as a spatial organizer but as a ventilation core, allowing air to circulate vertically and horizontally across the building. (WAA (World Architecture Architecture), n.d.).

The presence of continuous balconies overlooking the courtyard, combined with glass parapets, maintains visual permeability while enabling natural airflow and daylight penetration. This creates a semi-open environment where indoor and outdoor conditions are blurred, encouraging users to occupy transitional spaces rather than relying exclusively on conditioned interiors.

Vegetation integrated along the balconies and within the courtyard, including tree planted in the central space further enhances the microclimate through shading and evapotranspiration, reducing local temperatures and improving air quality. This case

shows how a courtyard can reduce the hours people spend indoors, lowering the overall cooling demand of the building.



Figure 27: Ruihong Tiandi- Greenery on balconies and courtyard integration. (Tianhua Group, n.d.).

3.3.2 New Church and Parish Centre, Cavernago (PBEB Architeti)

This project, located near Bergamo in Italy, combines two strategies that are relevant to the design proposal: a central courtyard with a single tree and the use of exposed concrete as the main building material. The church and the parish house are arranged around a central open space that functions as a shaded meeting point for the community. A single tree is planted in the middle of this space, providing a focal point and a limited but effective cooling effect through shade. This is a modest courtyard, not a large public square, yet the presence of the tree makes the outdoor space usable even during warm hours.

The concrete surfaces absorb heat during the day and release it at night, helping to stabilise indoor temperatures. At the same time, the central tree keeps the courtyard from overheating, creating a transition zone between outside and inside. This shows that even a small intervention, one tree in a small courtyard, can make a difference when combined with the right material choices.



Figure 28: New church and parish center- Concrete treatment in the courtyard. (PBEB Architetti-Paolo Belloni, n.d.)

3.3.3 Cloud 11, Bangkok (Snøhetta)

Cloud 11 is a large mixed-use development in Bangkok, a city with a humid subtropical climate very similar to Shanghai. The project combines offices, retail, restaurants, hotels, residential units, and creative production spaces. Its total floor area is about 250,000 m², which is much larger than the intervention on Fuxing Island. However, the way the project organises its functions around a central outdoor space offers a useful lesson for smaller projects as well.

Large openings between the buildings allow wind to flow through the vegetation, improving natural ventilation. Trees and planted areas provide shade throughout the day, making the outdoor space usable even during hot hours. Restaurants, cafes, and co-working areas are placed along the edges of the courtyard, so that people can work, eat, or relax outside instead of staying inside air-conditioned rooms.

When a building offers a mix of functions located next to a comfortable courtyard, people naturally choose to be outside. This reduces the number of hours they spend indoors, which in turn lowers the cooling demand of the building.

From Cloud 11, the design proposal takes two ideas. First, a courtyard needs the right planting strategy: trees must be selected for their cooling effect. Second, functional mix should be planned together with outdoor spaces. Shops and cafes on the ground floor open onto the courtyard, and residential units above have balconies overlooking it.



Figure 29: Cloud 11- Courtyard greenery that makes outdoor spaces comfortable. (Snøhetta, n.d.).

3.4 Green Balconies

3.4.1 Trudo Vertical Forest, Eindhoven (Stefano Boeri Architetti)

Adding greenery to balconies is a simple but effective way to improve the microclimate around a building without taking up ground space. The Trudo Vertical Forest in Eindhoven is a social housing tower whose facade provides a home to 125 trees and thousands of shrubs and plants. Each apartment includes a 4 m² balcony with one tree and 20 bushes, creating a natural micro-environment that helps counteract atmospheric pollution. The trees absorb over 50 tonnes of carbon dioxide every year.



Figure 30: Trudo Vertical Forest – The custom-designed plant pots create a unique architectural language for the façade while ensuring passive cooling. (Stefano Boeri Architetti, n.d.).

For the design proposal, this case confirms that balconies can do more than just provide outdoor space. With the right depth, orientation, and planting, they become active environmental devices that shade the facade, cool the air through evapotranspiration, and reduce the heat entering the building.

3.5 Terracotta Tiles

3.5.1 Home Studio for an Artist, Montecarotto (Studio Zero85)

This project, located on a hilltop in the Italian countryside, is a combined artist's studio and family home designed by Studio Zero85. The building is covered with bumpy terracotta tiles made from Tavelle, a type of slim hollow brick made from baked clay. The tiles were applied on the facades and the roof, forming a continuous skin that gives the building a rough, earthy texture. The material was chosen for its durability and its ability to react with natural light, changing appearance throughout the day.



Figure 31: Home Studio for an Artist – Terracotta tile cladding. (studio zero85; S. Sarra, n.d.).

Terracotta tiles are a traditional building material in many hot climates, including parts of China. They have low thermal conductivity, which means they do not transfer heat easily from the outside to the inside. They also allow the wall behind them to breathe, reducing moisture buildup, an important feature in humid subtropical climates.

3.6 Exposed Concrete and Brise-Soleil

3.6.1 Couvent Sainte-Marie de La Tourette (Le Corbusier)

Le Corbusier's convent near Lyon, built between 1956 and 1960, is one of the most important examples of how exposed concrete can be used both as a structural material and as a climate-responsive device. At La Tourette, many aspects of Corbusier's architectural vocabulary are visible, including the vertical brise-soleils used with effect in his Indian projects. The brise-soleil loggias topping the building provide passive cooling and solar control, reducing energy loads. When used in its raw, massive form, stone and concrete serve as load-bearing materials with excellent thermal mass properties, absorbing and releasing surplus humidity without degrading.

The design proposal takes two lessons from La Tourette. First, exposed concrete floors, pillars and circulation cores provide thermal mass that helps stabilise indoor temperatures. Second, the brise-soleil is not an add-on but is integrated into the architecture itself.



Figure 32 : Couvent Sainte Marie de La Tourette- Raw concrete used for exposed structural and architectural element. (Le Corbusier, n.d.)

3.7 Brise-Soleil Combinations

3.7.1 La Massana School of Arts, Barcelona (Estudio Carme Pinós)

This fine arts school is located in the historic centre of Barcelona, facing a public square. The challenge was to protect the students' privacy while still allowing them to see out. The solution is a ceramic brise-soleil that covers the exterior, emphasising the building's volume while at the same time protecting the interior from direct views. The ceramic pieces are reminiscent of a traditional brise-soleil but are arranged in different ways depending on the facade orientation. On some facades the system uses

vertical elements, on others horizontal ones, and in some areas both directions are combined. This variation in the placement of the brise-soleil not only improves solar control but also enriches the architectural language of the building, giving it a more articulated and less repetitive appearance.

This case is useful because it shows that a shading device can serve two purposes at once: solar protection and visual privacy. In addition, by mixing vertical and horizontal elements in different parts of the building, it is possible to respond to different solar exposures while also creating a more interesting architectural expression.



Figure 33: Massana School of Arts- Use of brise-soleil arranged both horizontally and vertically.
(Estudio Carme Pinós, n.d.).

3.7.2 Harwell Zeta, Oxfordshire (Allies and Morrison)

The Zeta building at Harwell Campus in the UK is a laboratory building designed to meet net-zero carbon standards. The brise-soleil system is a combination of horizontal and vertical panels, made of aluminum, installed on the east and south elevations. The panels frame the windows in an L-shape, providing critical protection from solar glare.

Aluminum is a particularly suitable material for brise-soleil in hot-humid climates. It is lightweight, which makes it easier to install and reduces structural loads on the facade. It is also highly durable and resistant to corrosion, which is important in a humid environment like Shanghai. Moreover, aluminum has a natural reflective surface that helps to bounce back solar radiation before it reaches the glass, further reducing heat gain. The material can be extruded into complex shapes, allowing designers to fine-tune the angle, depth, and orientation of each louver for maximum

performance.

This case reinforces two important points. First, a combination of horizontal and vertical elements is often the best response, because no single device works equally well on all facades. Second, the brise-soleil does not need to cover the entire facade to be effective; targeted placement on the most exposed elevations can already make a significant difference.



Figure 34: Harwell Zeta – Aluminum shading elements (brise-soleil) reducing solar gain. (Allies and Morrison, n.d.).

CHAPTER 4: CITY ENERGY ANALYST METHODOLOGY

As illustrated in Figure 5, after identifying the relevant literature that supports the theoretical framework of this thesis, it becomes necessary to describe the methodology of the main analytical tool used in the research process. The City Energy Analyst (CEA) is an open-source urban energy simulation platform developed by the ETH Zurich, a leading European institution in engineering and environmental research. The platform is specifically designed to evaluate energy demand and environmental performance **at the district scale**, allowing the analysis of multiple buildings simultaneously and considering their interaction within the urban context. This characteristic makes CEA particularly suitable for this research, where the objective is not only to evaluate a single building, but to understand how urban form influences cooling demand at a broader scale.

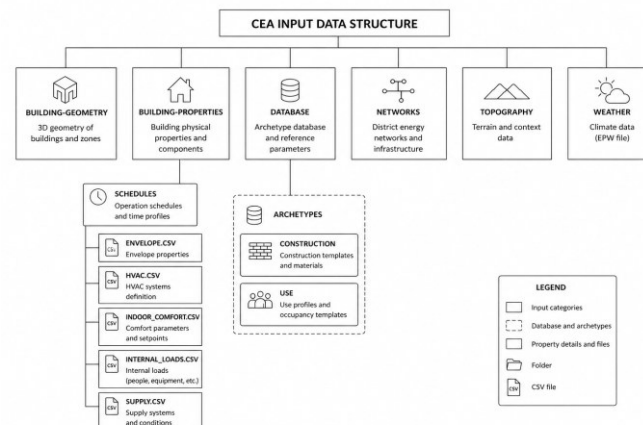


Figure 35: CEA Workflow.

The methodology of CEA is based on the integration of multiple datasets that describe both environmental conditions and physical characteristics of the built environment. The first step in the process is the definition of the study area and the collection of climate data. These data are typically provided through Energy Plus Weather (EPW) files, which contain hourly climatic information such as air temperature, relative humidity, solar radiation, and wind speed and direction. The use of EPW files allows the simulation to reflect realistic climatic conditions over an entire year, which is essential in a humid subtropical context such as Shanghai, where seasonal variations and high humidity levels strongly affect cooling demand.

In addition to climate data, the model requires an accurate description of the site's topography and the geometry of the buildings. This includes not only the buildings selected for analysis, but also the surrounding urban fabric. The presence, height, and spatial arrangement of neighboring buildings influence solar exposure, shading patterns, and air movement, which are all critical factors in determining energy performance. These geometrical inputs are typically derived from GIS datasets and define the three-dimensional structure of the urban environment.

Another key component of the methodology is the definition of building properties. These include several parameters that describe how each building behaves in terms of energy consumption. Additional parameters include HVAC systems (heating, ventilation, and air conditioning), which define how buildings are cooled and ventilated, indoor comfort conditions that establish target temperature ranges, and internal loads. The number of floors is also an important parameter, as it affects both the total energy demand and the distribution of loads within the building.

CEA also uses archetypes to simplify and standardize the representation of buildings. Archetypes are predefined sets of characteristics that describe typical buildings based on their use, construction type, and historical period. These include parameters such as building height, year of construction, material properties, and occupancy profiles. The construction period is particularly relevant, as it reflects different building standards and technologies, which have a direct impact on energy performance. By assigning archetypes to buildings, it becomes possible to simulate large urban areas without requiring excessively detailed data for each individual structure.

In addition to buildings, the model also considers elements of urban infrastructure, such as street networks. Although these do not directly consume energy in the same way as buildings, they play an important role in defining urban morphology, accessibility, and spatial relationships, which indirectly influence energy demand and microclimatic conditions.

All the required data are organized within a structured database that includes GIS files containing the geometry of buildings and surfaces, Excel files that define building properties and archetypes, and EPW files that provide climate data. The organization of these datasets is fundamental for the correct functioning of the model, as each layer contributes to building a comprehensive representation of the urban

system.

Table 3: Table of building data. Underground and above-ground floors with heights, typology Standard01 (archetype), construction year, and observed mono-functional use.

name	floors_bg	floors_ag	void_deck	height_bg	height_ag	year	const_type	use_type1	use_type2	use_type3	use_type1r	use_type2r	use_type3r
B1012	0	2	0	0	6	1980	STANDARD1	INDUSTRIAL	NONE	NONE	1	0	0
B1013	0	2	0	0	6	2024	STANDARD1	MULTI_RES	NONE	NONE	1	0	0
B1014	0	2	0	0	6	1930	STANDARD1	MULTI_RES	NONE	NONE	1	0	0
B1017	0	3	0	0	9	1930	STANDARD1	MULTI_RES	NONE	NONE	1	0	0
B1018	0	3	0	0	9	1930	STANDARD1	OFFICE	NONE	NONE	1	0	0
B1019	0	6	0	0	18	2024	STANDARD1	RETAIL	NONE	NONE	1	0	0

Once all inputs are defined and integrated, CEA processes the data to estimate energy demand, with a particular focus on heating and cooling loads. In this research, the tool is used mainly to analyze cooling demand and to compare the existing condition with the proposed design intervention. It is important to note that **CEA does not aim to provide exact energy consumption values, but rather to simulate the theoretical energy behavior of buildings under specific climatic and operational conditions**. This approach allows the tool to evaluate how design strategies influence thermal performance and indoor comfort, supporting informed decision-making rather than delivering precise real-world consumption data (ETH Zurich, 2023).

CHAPTER 5: FUXING ISLAND SITE ANALYSIS

5.1 Urban Context & Selection of the Site

Why choose Fuxing Island as the site for this project?

Fuxing Island, located in the Yangpu District along the Huangpu River in Shanghai, offers a unique opportunity for urban revitalization. Originally formed through river dredging, the island later developed as an industrial area with warehouses and fuel-related facilities (Jin, C., 1993). Today, many of these structures are abandoned, and the island is largely underutilized. The Shanghai Master Plan 2017–2035 identifies Fuxing Island as a strategic reserve area, recognizing its potential for future redevelopment, particularly as a space for mixed functions and green urbanism (People’s Daily, 2025).

Fuxing Island is chosen for this project as a pilot case study, where the urban design will prioritize climate-responsive strategies. The development will incorporate a mix of functions within the island to ensure energy complementarity. This is particularly important given the island's predominant industrial history, which

presents an interesting challenge in reintroducing residential, commercial, and public spaces while considering their interaction with the local microclimate.

The analysis of Fuxing Island started by mapping the area using Geographic Information System (GIS) tools. Key data, like building geometry, number of floors, building heights, and functional distribution, were collected. The age of the buildings was also considered, along with temporal use patterns, categorizing spaces into those used during the day, at night, or in mixed ways. This analysis showed where energy demand is higher, since commercial areas or residential buildings usually need more cooling or heating.

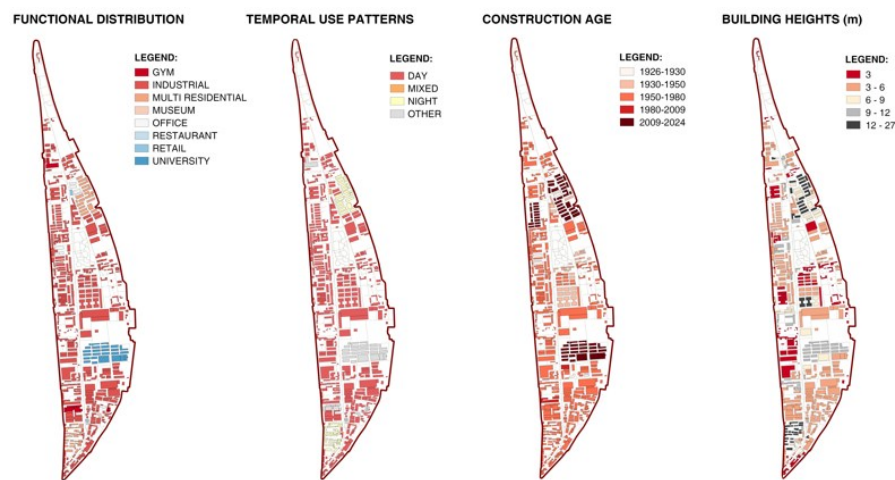


Figure 36: GIS-based mapping of Fuxing Island showing functional distribution, temporal use patterns, construction age, and building heights.

Next, the GIS data was combined with the City Energy Analyst (CEA) tool.

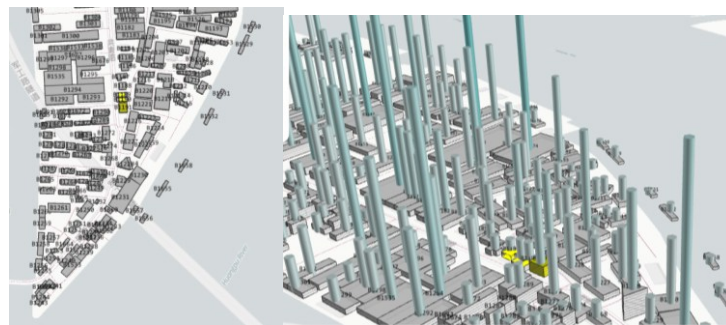


Figure 37: CEA analysis results.

(a) identification of the cluster with highest cooling demand.

(b) blue bars showing total cooling demand, where height is proportional to energy use (not yet normalized per m²).

COOLING DEMAND INTENSITY (KWH/M²)

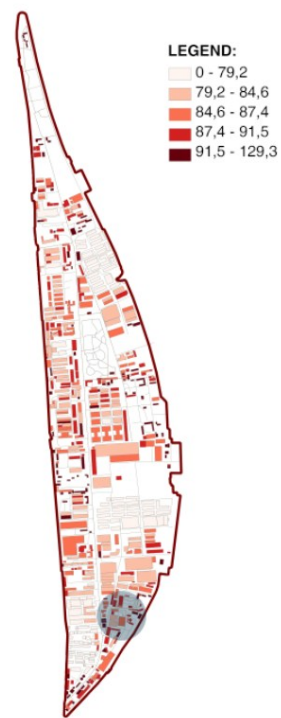


Figure 38: Cooling demand intensity (kWh/m²) map, with the selected high-demand cluster shown in blue, based on a combined GIS and CEA approach.

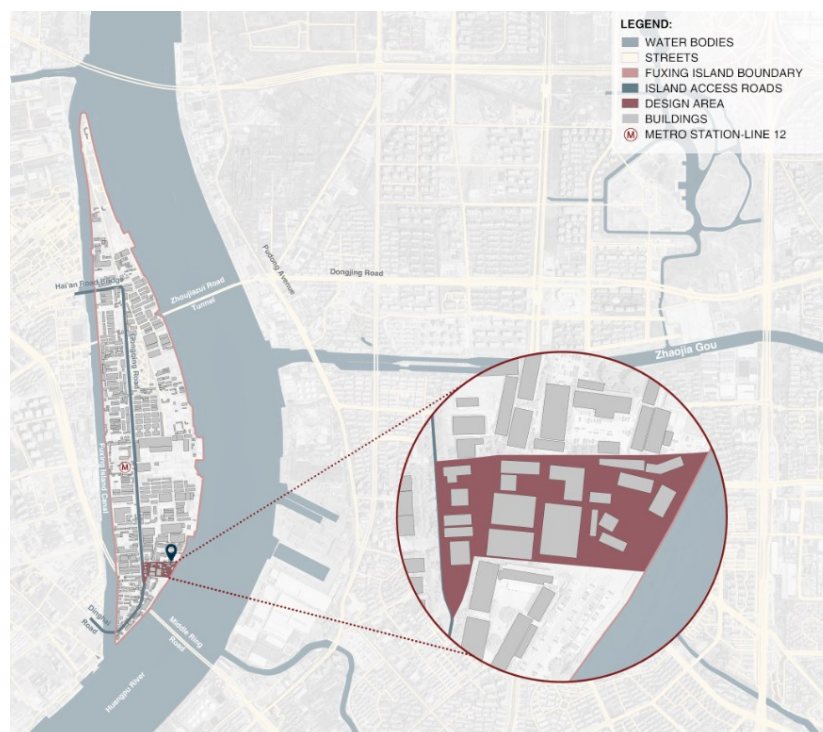


Figure 39: Identified Site Area within the Fuxing Island Urban Context.

Table 4: Cooling demand results for the three selected buildings, showing total cooling energy (MWh), floor area (m²), and normalized cooling demand (kWh/m²).

Building	Cooling MWh	m ²	Cooling kWh/m ²
B1189	14086	108946	129,2934114
B1191	43448	336762	129,0169318
B1190	12774	99551	128,3161395

Using GIS and CEA data, the buildings with the highest cooling demand per square metre were identified. Three buildings in particular (B1189, B1190, B1191) showed values around 129 kWh/m², significantly above the island's average.

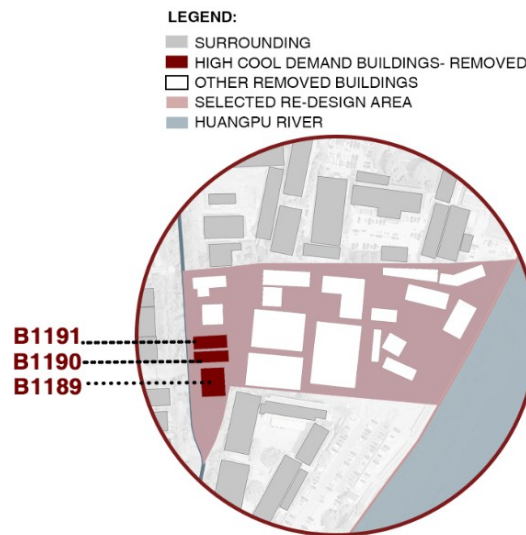


Figure 40: Design Approach.



Figure 41: The three buildings show poor envelope conditions and neglect. Their alignment reveals a critical climatic zone where cooling demand is highest.

Notably, these buildings are not scattered but aligned along a continuous urban strip that extends from the interior of the island down to the riverfront. This alignment

reveals a localized climatic weakness: the existing urban morphology in this specific area traps heat, blocks winds, and increases cooling demand. For this reason, the site was selected as a **pilot case to test climate-responsive design strategies**.

The intervention area is located in the southern part of Fuxing Island, accessed from a road that splits off from the main Gongqing Road. Rather than redesigning only the three inefficient buildings, the project extends the intervention zone to include the entire strip up to the river. This broader boundary is justified because the surrounding buildings share the same poor morphological characteristics; leaving them unchanged would limit the effectiveness of strategies such as wind corridors, permeable surfaces, and open green spaces. **By redesigning this entire critical zone, the project can fully apply both urban and architectural climate-responsive solutions.** The goal is to reduce cooling demand through better building orientation, shading, natural ventilation, and material choices, in line with the overall vision for Fuxing Island.

5.2 Climatic Analysis

The climatic analysis of Fuxing Island, based on data from the EPW climate file (latitude: 31.198° N, longitude: 121.336° E, elevation: 3m), covers the period from 1956 to 2023, reflecting the characteristics of a Köppen Cfa humid subtropical climate. The analysis highlights significant seasonal variations, with the summer months posing the greatest design challenge due to extreme heat and humidity.

5.2.1 Daytime Dry Bulb Temperatures

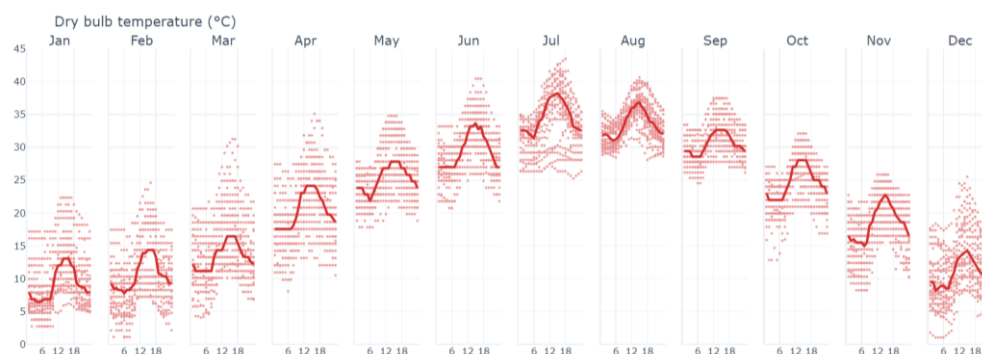


Figure 42: Daytime Dry Bulb Temperatures in Shanghai. (Center for the Built Environment, n.d.).

As illustrated in the Figure 42, peak summer temperatures reach up to 36.8°C in

July, signifying the intense heat typical of the humid subtropical climate. During the summer, temperatures are high both during the day and at night, with nighttime temperatures remaining around 20°C, contributing to a significant demand for cooling. In contrast, winter temperatures are cooler, with minimum values occasionally dropping below 0°C, but the cold season is much shorter than the prolonged summer period. While winter conditions require attention to reduce heat loss and cold air infiltration, the primary concern for design remains summer overheating.

5.2.2 Thermal Stress

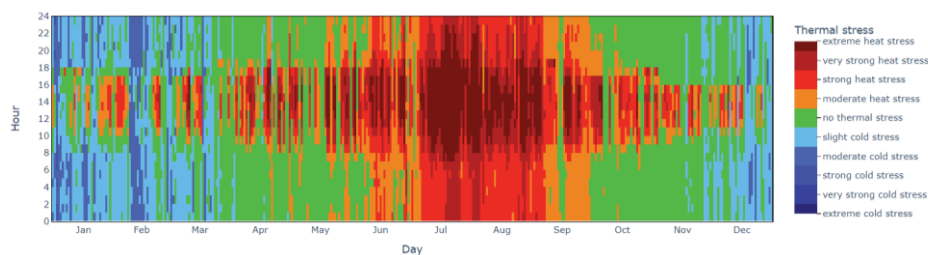


Figure 43: Shanghai's Thermal Stress Analysis. (Center for the Built Environment, n.d.).

Figure 43 presents the UTCI (Universal Thermal Climate Index), which further confirms that summer heat stress is the dominant climatic factor affecting the site. Although winter cold stress does occur, it is less intense and of shorter duration, which directs the focus of design strategies towards mitigating heat during the warmer months.

5.2.3 Sun Path and Solar Exposure

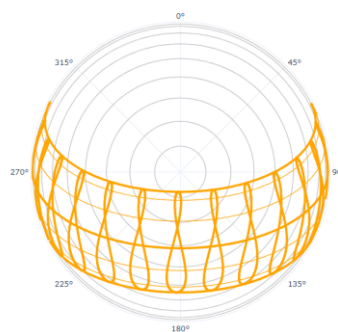


Figure 44: Shanghai's Sun Path. (Center for the Built Environment, n.d.).



Figure 45: Sun path diagram in Shanghai. (SunCalc.org, n.d.).

(a) 21 of July, 12:00.

(b) 21 of July, 15:00.

(c) -21 of December, 12:00.

During the summer months, the sun reaches its highest point at 12:00 on June 21, leading to minimal shadows and intense radiation on horizontal surfaces. This suggests the potential for horizontal shading solutions. As the sun moves towards the west in the afternoon, radiation shifts to impact vertical façades, which have already absorbed significant heat. This further emphasizes the need for vertical shading systems to prevent overheating. Conversely, in winter, the sun remains low at 12:00 on December 21, creating long shadows and limited solar access between buildings, pointing to the potential for solar-responsive design strategies that could enhance indoor comfort in winter while reducing cooling demand in summer.

5.2.4 Wind Patterns and Natural Ventilation

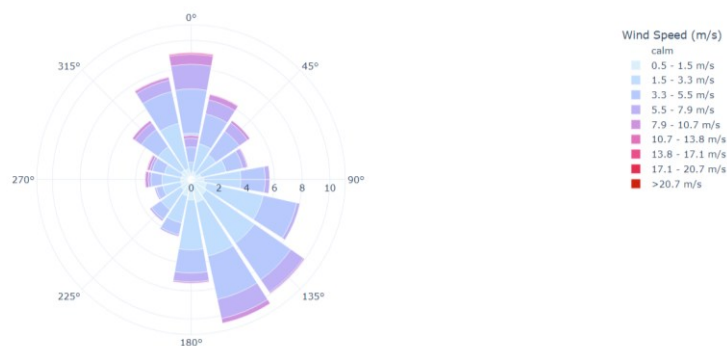


Figure 46: Shanghai's Annual Wind Rose of Shanghai. (Center for the Built Environment, n.d.).

The annual wind rose derived from the EPW dataset shows that the average wind speed on Fuxing Island is approximately 3 m/s, with winds predominantly coming from the north and south-east. The map indicates a predominance of light to moderate

winds (0.5 m/s–5.5 m/s), which can be strategically utilized for natural ventilation.

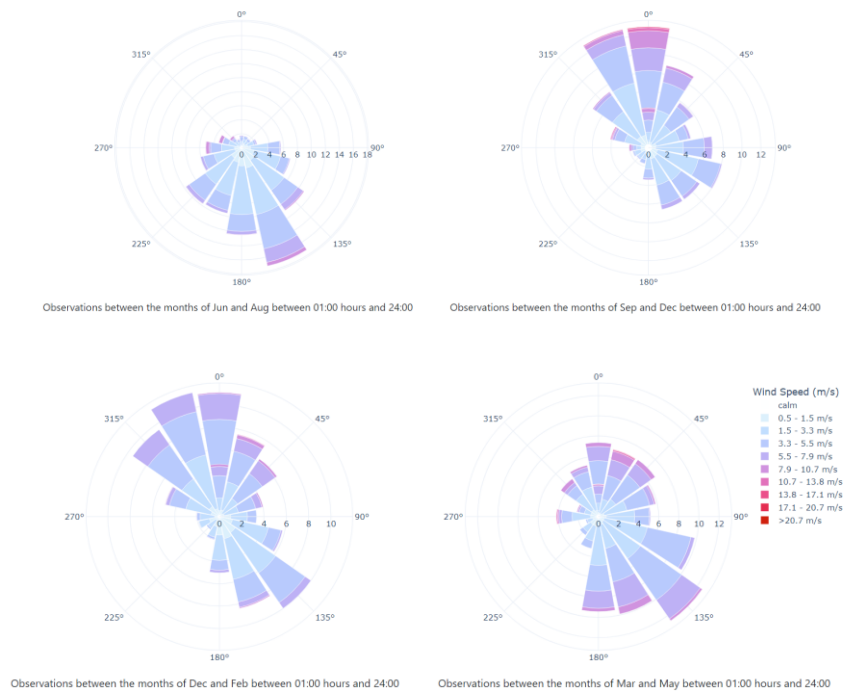


Figure 47: Shanghai's Seasonal Wind Roses of Shanghai. (Center for the Built Environment, n.d.).

Seasonal wind rose diagrams further illustrate that during the winter months (December to February), winds are stronger and primarily from the north and north-west, suggesting the need for design solutions that protect against cold air infiltration. In contrast, during the summer months (June to August), winds are gentler and come from the south-east, offering potential for natural cooling and ventilation strategies.

5.2.5 Humidity and Comfort Considerations

Relative humidity levels throughout the year remain consistently high, with values rarely dropping below 60% and typically hovering around 75-80%.

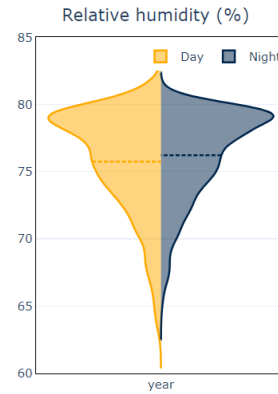


Figure 48: Relative humidity between day and night in Shanghai. (Center for the Built Environment, n.d.).

As shown in Figure 49, the highest humidity levels occur during the summer months, persisting both during the day and at night. This persistent high humidity exacerbates thermal discomfort, as it hampers the body’s ability to dissipate heat naturally.

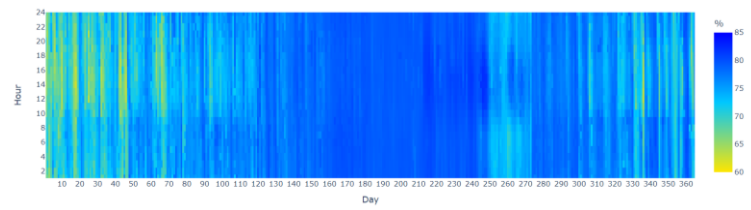


Figure 49: Shanghai’s Relative Humidity Chart. (Center for the Built Environment, n.d.).

The combination of high temperatures and high humidity during most of the summer hours puts the site in the high discomfort zone, further underlining the need for effective ventilation and shading solutions to ensure indoor comfort.

5.2.6 Precipitation

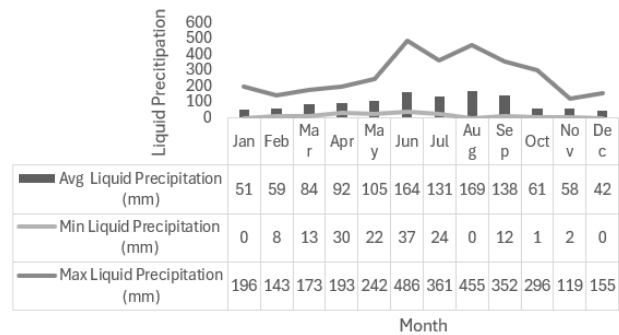


Figure 50: Shanghai’s monthly precipitation trends based on EPW data, highlighting seasonal variation and peak rainfall during summer months.

The precipitation analysis reveals a marked seasonal pattern, with rainfall increasing significantly from spring and peaking during the summer months of June to August, where recorded values exceed 450 mm. This high rainfall, characteristic of the humid subtropical climate, suggests the importance of permeable surfaces and green areas capable of absorbing stormwater, as part of the design solutions to manage excess rainwater and prevent flooding. The integration of open green spaces and sustainable urban drainage systems would help mitigate the impact of heavy rainfall while enhancing the environmental quality of the site.

In conclusion, the climatic analysis of Fuxing Island reveals that summer overheating and high humidity are the main challenges that need to be addressed in the design process. Solar-responsive strategies, natural ventilation, shading devices, and permeable surfaces are key elements to be considered for reducing cooling demand and improving indoor comfort, both at urban and architectural scale.

CHAPTER 6: URBAN DESIGN PROPOSAL

6.1 Design Objectives

The urban design proposal is driven by the need to respond directly to the climatic conditions analysed in Chapter 5. The main objective is to reduce cooling demand while improving outdoor and indoor thermal comfort.

A key objective is to enhance natural ventilation across the site. The design captures and guides prevailing summer winds from the south-east into the island, allowing airflow to penetrate the urban fabric instead of being blocked. At the same time, the configuration provides protection from colder winter winds coming from the north, using built volumes and tree rows as barriers. This dual strategy creates a balanced microclimatic response, improving comfort throughout the year.

Another important objective is to integrate a functional mix that supports energy complementarity. By combining commercial, office, and residential uses, the project distributes energy demand across different times of the day, reducing peak loads and improving the overall efficiency of the system. In parallel, the design prioritises permeability, vegetation, and open spaces, contributing to cooling through shading, evapotranspiration, and reduced surface heat absorption.

6.2 Masterplan Strategy

The masterplan is structured to maximise environmental performance through a combination of spatial organisation and surface strategies. The built footprint occupies a limited portion of the site, while a large percentage is dedicated to open and permeable spaces.



Figure 51: Masterplan Design.

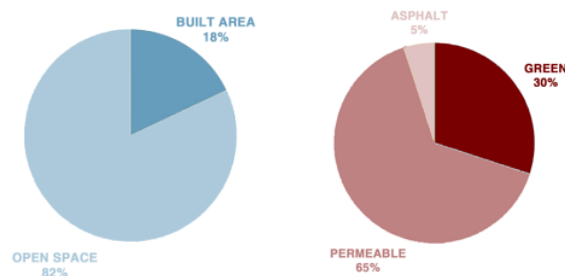


Figure 52: (a) Pie chart illustrates the ratio between built area and open space in the urban design.

(b) Pie chart showing ground cover composition: green areas, asphalt, and permeable surfaces.

As shown in the diagrams, approximately 82% of the area remains open space, while only 18% is built, ensuring low density and high environmental permeability.

The masterplan also responds to climatic flows. The overall layout is oriented along an east–west axis, allowing summer winds to enter from the south-east and move across the site. Green spaces are placed near the river and along the south-eastern edge, where airflow first enters. These open areas give the wind room to

cool down before reaching the buildings. Instead of creating enclosed blocks, the design maintains open corridors that facilitate airflow, ensuring that ventilation is not obstructed but rather guided through the intervention. On the northern side, a more compact built form and rows of trees block the cold winter winds, reducing heat loss from the buildings behind.

6.3 Urban Form and Block Configuration

6.3.1 Building Typologies and Their Climatic Logic

The project introduces different building typologies; each selected according to its functional program and its ability to respond to the local climate.

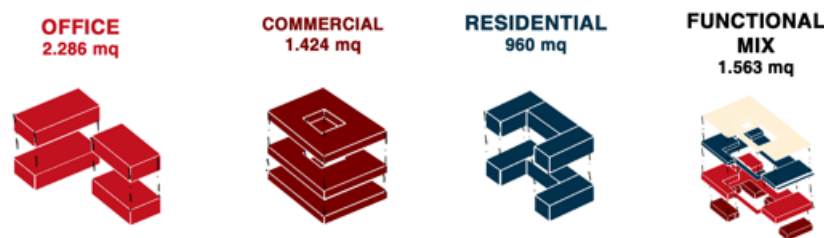


Figure 53: Building typologies, number of floors, function, and floor area (mq).

For residential functions, the design uses U-shaped blocks. These are composed of two elongated wings facing each other, with an open courtyard in between. This configuration gives each apartment good exposure to natural light and cross-ventilation, while the central open space provides a shaded and semi-private outdoor area for residents. The residential units are arranged in a north-south orientation, with the long sides facing south and north, so that the prevailing summer winds from the south-east can flow between the blocks.

For office functions, the design uses L-shaped blocks. These are also elongated along two directions, with an empty corner (a "hole") at the inner angle of the L. Offices benefit from this layout because the open corner reduces heat accumulation and provides natural ventilation to the workspaces on the lower floors.

For the commercial functions and for the functional mix building that will be studied in detail in Chapter 7, the design adopts a courtyard typology. As shown in the case studies (Ruihong Tiandi and Cloud 11), the courtyard creates a shaded and

ventilated outdoor space that remains comfortable even during hot summer days. This encourages people to spend time outside, reducing the number of hours spent inside air-conditioned rooms and therefore lowering the cooling demand of the building.

6.3.2 Height Graduation and Wind Flow

Building heights are not uniform across the site. Following the principles of urban ventilation discussed in section 2.3.2, the design introduces a gradual increase in height. Near the river and the south-eastern edge, where summer winds first arrive, buildings are kept lower (two storeys). Moving westwards and towards the existing urban context of Fuxing Island, heights increase to three storeys. This gradual change helps wind to enter the site smoothly, without creating strong turbulence or blocking the airflow.

6.3.3 H/W Ratio and Shading

Near the courtyard building that is the architectural focus of this thesis, the H/W ratio reaches values of 0.9 in some directions and 0.46 in others. These higher values produce deeper street canyons and more mutual shading between buildings, which is beneficial for reducing solar exposure during summer. In contrast, the other buildings in the masterplan have lower H/W ratios (0.23 and 0.46) because they are located near large open green spaces. In those areas, the open space itself provides cooling, so deep canyons are not necessary. The decision to give the courtyard building a higher H/W ratio is intentional: it creates a shaded microclimate around the building, making the outdoor courtyard and the ground floor commercial spaces more comfortable during hot hours.

6.4 Functional Mix and Energy Complementarity

The functional mix plays a central role in the project. The distribution of functions is not random but carefully designed to create a complementary energy profile. As shown in the masterplan, the residential area is located near the large green open space on the western side of the site, where the cooling effect of vegetation improves living comfort. The offices are positioned along the northern edge and near the main access road, where they benefit from good visibility and easy access.

The courtyard building, which is the architectural focus of Chapter 7,

concentrates commercial functions on the ground floor, facing the internal pedestrian streets. The upper floors of the same building contain a mix of office spaces and residential units. This vertical mixing within a single building is particularly effective because it allows people to live, work, and shop in the same place, reducing the need to travel and spreading energy demand throughout the day.

This temporal distribution reduces simultaneous energy demand peaks. Offices use most of their energy during daytime working hours, while residential buildings peak in the morning and evening. Commercial spaces add demand during lunchtime and late afternoon.

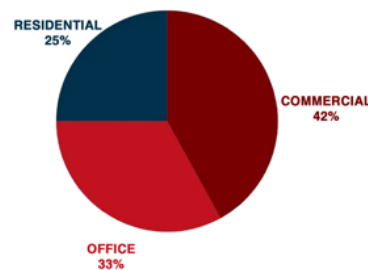


Figure 54: Percentage of Functional Mix.

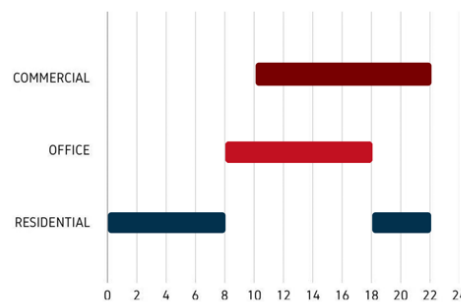


Figure 55: Time profile of functional mix showing the distribution of commercial, office, and residential activities throughout the day, highlighting complementary usage patterns.

6.5 Open Spaces and Vegetation

Open spaces and vegetation are not treated as residual elements, but as active components of the climate-responsive strategy. Two main green open spaces are visible in the masterplan. One is located near the residential sector on the western side, providing a shaded area and acting as a cooling reservoir for the surrounding

buildings. The other is placed along the riverbank on the south-eastern side, for a main residential use, precisely where the prevailing summer winds first enter the site. This riverside green space serves two purposes: it cools the air through evapotranspiration, and it gives the wind an open area where it can slow down and spread before being channelled through the building corridors.

Vegetation is also strategically positioned in other key areas. Trees and planted strips are concentrated near the main entry points of prevailing summer winds, and along the pedestrian paths that connect the river to the interior of the site. Rather than blocking wind, vegetation works together with the built form to channel and filter airflow, creating a more controlled and comfortable microclimate. Trees reduce surface temperatures and provide shaded spaces, which are especially important during the hot summer months.

Pedestrian paths, green corridors, and open plazas are interconnected, allowing both people and air to move freely across the site.

6.6 Surface Materials and Permeability

As discussed in section 2.3.4, the choice of surface materials has a direct impact on local temperatures and stormwater management. In this design, all pedestrian areas, including pavements, private courtyards, and the open spaces around buildings, use light-coloured porous paving. This material reflects a large portion of solar radiation, reducing heat absorption, and allows rainwater to infiltrate the ground, supporting evaporative cooling. The light colour also improves outdoor comfort for pedestrians during sunny days.

The car parking area is also made permeable, using grass grids or porous blocks that let water pass through while providing enough structural strength for vehicles. The only non-permeable surface in the masterplan is the main car access road, which uses concrete. This road is limited to a single-entry point and a short loop, minimising its impact on the overall water balance and heat absorption of the site.

By combining permeable paving, green areas, and limited use of asphalt and concrete, the design ensures that most of the ground surface contributes to cooling and drainage, rather than storing heat and creating runoff.

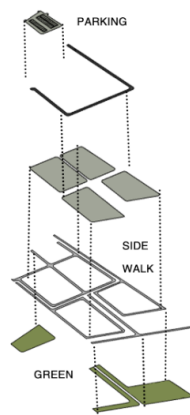


Figure 56: Exploded view diagram of the surface layering strategy.

CHAPTER 7: ARCHITECTURAL DESIGN PROPOSAL

7.1 Building Concept

The building concept is grounded in the integration of climate-responsive strategies at the architectural scale. In coherence with the urban design strategy described in Chapter 6, the building is oriented along an east-west axis, with the main volume elongated in that direction. This choice reduces the length of the east and west facades, which receive the most intense sunlight during the morning and afternoon. By keeping these facades shorter, the building limits the amount of solar radiation that enters the interior, while the longer north and south facades can be used to capture natural light and ventilation more easily.

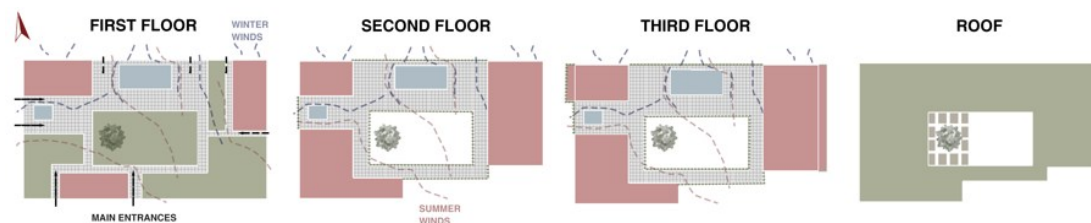


Figure 57: Architectural concept showing openness between floors, letting the wind enter or stop. Red lines represent summer winds, while blue one the winter winds.

The staircase is placed along the north side, not as an external feature but as a horizontal circulation element that acts as a buffer against cold winter winds. At the same time, open spaces between the building volumes allow summer winds from the south-east to enter the courtyard and cross-ventilate the interior. Vertical circulation (stairs and elevators) is located along the perimeter of the building, rather than in a central core. This arrangement avoids trapping warm air inside and helps airflow move freely from the ground floor up to the roof terrace. This concept aligns with the overall objective of reducing cooling demand, improving thermal comfort, and ensuring that the building responds efficiently to local climate conditions.

7.2 Mixed-Use Program

Commercial spaces are concentrated on the ground floor, designed to accommodate high-traffic activities during the daytime, while residential spaces and offices are distributed in a way that complements the building's operational hours.

The residential units are primarily located on the upper floors, benefiting from natural shading from the surrounding volumes. These units also have access to green courtyards and open spaces that encourage outdoor activities and improve overall quality of life. The office spaces, on the other hand, are placed strategically to benefit from the controlled airflow and natural lighting provided by the building's design.

7.3 Spatial Organization

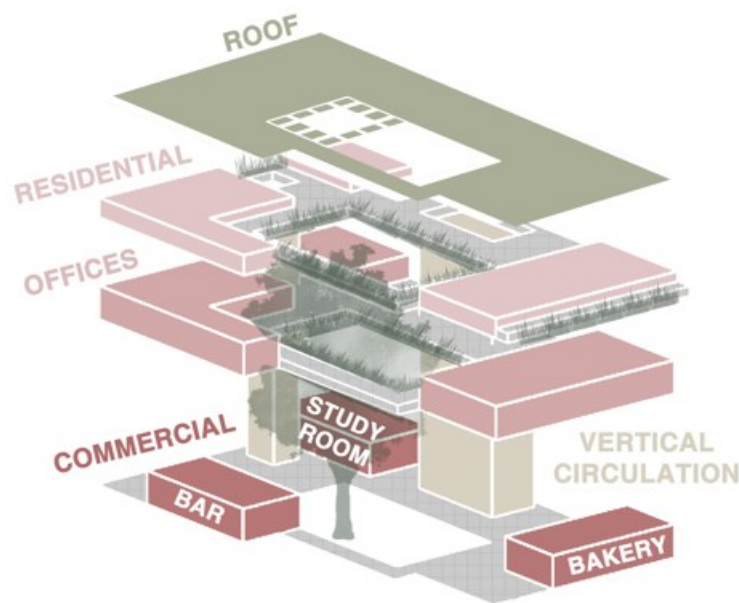


Figure 58: Internal functional distribution.

The spatial organization of the building focuses on creating functional areas that promote both efficiency and comfort. The commercial spaces on the ground floor are arranged to maximise accessibility and create a welcoming atmosphere. These areas, including a bakery, study rooms, and a public courtyard, are designed to be open and interactive, with large openings to the outside that invite natural ventilation.

On the first floor, the offices are organized around the central courtyard, creating a semi-public zone that encourages circulation and interaction. The offices are designed to maximise natural light and provide views of the surrounding green areas. The residential spaces on the upper floors are designed with privacy in mind, while still benefiting from the building's natural ventilation strategies.

The integration of vertical circulation elements, such as stairs and elevators, is designed to allow for efficient movement through the building while supporting its natural ventilation system. This integration ensures that air can move freely throughout the building, from the ground floor up to the roof terrace.

7.4 Design Strategies

The architectural design of the building incorporates a series of passive design strategies, focusing on natural ventilation, shading, thermal mass, and green integration.

7.4.1 Orientation

As mentioned in section 7.1, the building is elongated along the east-west axis. This orientation minimises the area of the east and west facades, which are the most difficult to shade because they receive low-angle sun in the morning and afternoon. The longer north and south facades face directions where shading is easier to achieve with horizontal devices. This layout also allows the central courtyard to receive indirect light without being overheated, keeping the outdoor space comfortable for longer hours.

7.4.2 Natural Ventilation and Window Design

Natural ventilation is the primary passive cooling strategy. To maximise airflow, the building uses cross-ventilation: windows are placed on opposite sides of each room, allowing air to flow through. The effectiveness of this strategy was verified by calculating the ratio of openable window area to floor area for each room. Following the Chinese National Standard (GB), the design targets a ratio of at least 8% in hot-humid climates (Ministry of Housing and Urban-Rural Development of the People's Republic of China, n.d.).

Table 5: Openable-to-floor area ratios for different rooms in residential floor. In all cases, the ventilation ratio exceeds 8%, confirming compliance with minimum ventilation standards and supporting effective natural ventilation performance.

Room	Floor mq	Openable mq	Ventilation Ratio (%)
Single Small Room	10	4,2	42
Single Big Room	19	5,04	27
Apartment	31	5,46	18

Window dimensions vary according to facade orientation:

- On the north and south facades, windows are larger: 200 cm wide and 210 cm high. These facades receive less direct solar radiation, so larger windows bring in daylight and allow good airflow without causing overheating.
- On the east and west facades, windows are narrower: 40 cm wide and 210 cm high. These reduced dimensions limit solar heat gain during the intense morning and afternoon sun, while still providing enough light and ventilation for the rooms behind them.
- On the ground floor, where commercial activities take place, the openings are 180 cm x 120 cm to encourage interaction between inside and outside. All openings are designed to be operable, so occupants can control airflow manually.

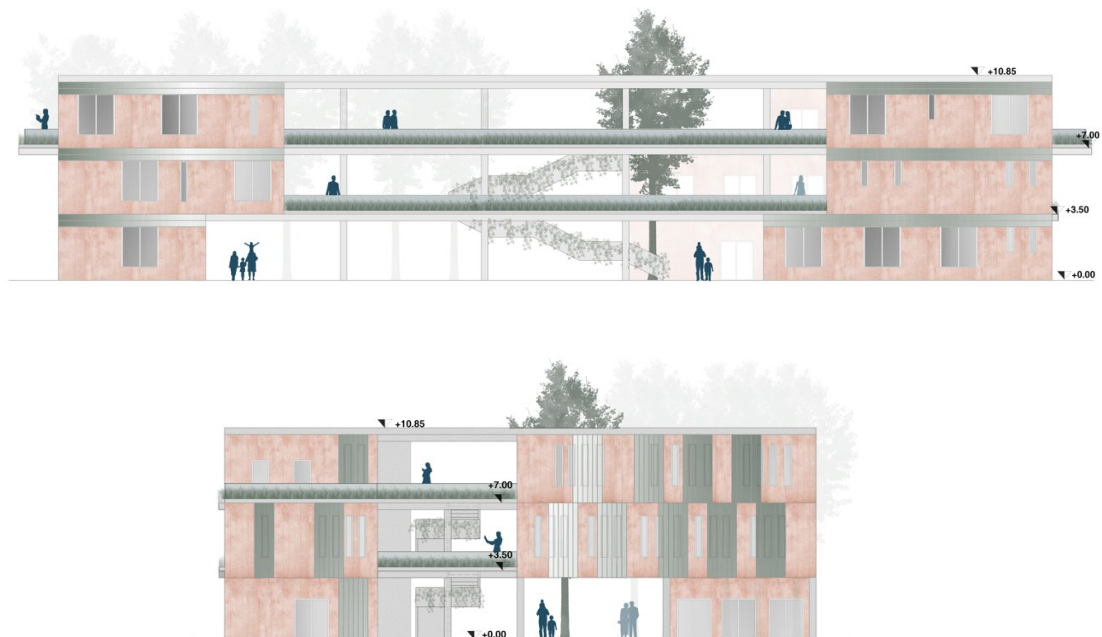


Figure 59: (a) North elevation showing large openings enhancing natural light and ventilation. (b) West elevation illustrating thin, tall windows, with greenery present on both elevations.

7.4.3 Shading Strategies (Brise-Soleil)

Shading devices are made of aluminium, chosen for its light weight, durability,

resistance to corrosion, and natural reflectivity. Aluminium reflects a large portion of solar radiation, reducing heat gain through the glass. The devices are painted green to blend with the vegetation, but the material itself remains aluminium.

The type of brise-soleil varies by facade orientation, following the principles discussed in section 2.4.2:

- On the east and west facades, vertical aluminium fins are installed. These fins slide on a horizontal track, so occupants can adjust their position manually. When the sun is low in the morning or afternoon, the fins can be closed to block direct radiation; when the sun is not a problem, they can be opened to allow light and views.
- On the north and south facades, horizontal aluminium louvers are used. These louvers rotate on a central pivot, from 0° (fully open) up to 90° (fully closed). They can be adjusted to block high summer sun while allowing lower winter sun to enter. When fully opened, they create a small canopy or balcony-like projection above the window, adding usable outdoor space.



Figure 60: Drawing showing the size of the shading systems and the different grid patterns. North and south façades with horizontal elements, east and west façades with vertical elements

The combination of vertical and horizontal shading devices ensures that each facade gets the most effective protection. The adjustable nature of both systems gives occupants control over their environment, which is important for comfort and acceptance of passive strategies.

7.4.4 Building Envelope and Materials

The building envelope is designed as a ventilated facade system. In particular, XPS was selected because it has low thermal conductivity and, more importantly, very low water absorption. The ventilated air cavity (4 cm) that allows air to flow between the insulation and the outer cladding, removing heat before it can penetrate the building.

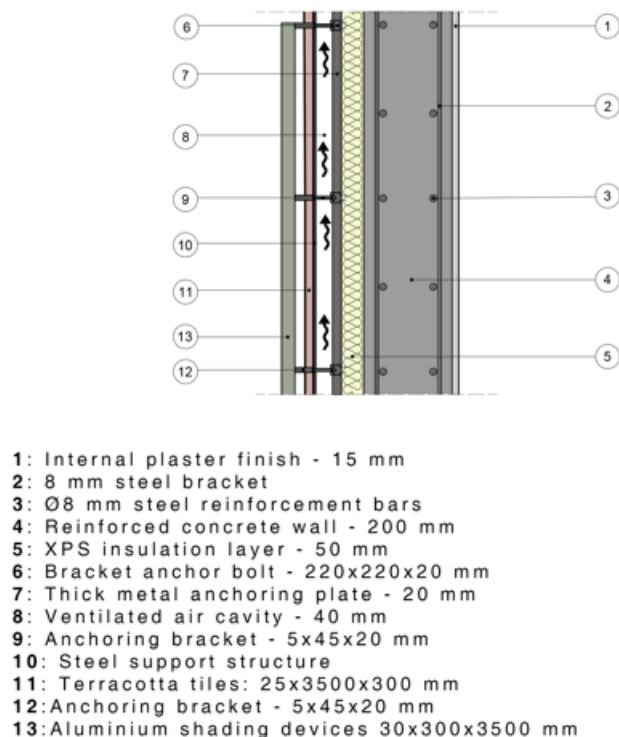


Figure 61: Architectural detail of the ventilated façade.

Terracotta tiles were chosen for several reasons. They are made from baked clay, a natural material with low embodied energy. They have low thermal conductivity, so they do not transfer heat easily. They are durable, require little maintenance, and allow the wall behind them to breathe, reducing moisture buildup. Additionally, terracotta gives the building a warm, earthy appearance that changes with the light.

The tiles are not all the same size. Near the windows, the most critical points for solar gain, the tiles are larger and more widely spaced. This change in rhythm acts as a visual warning that these areas are more exposed to the sun and require careful design. The varied tile pattern also enriches the architectural language of the facade.

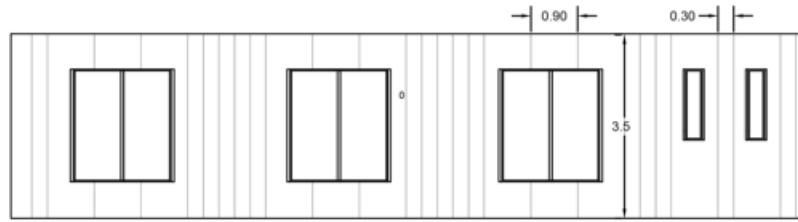


Figure 62: Terracotta Tiles Rhythm on Façade. Terracotta tile façade – tile dimensions vary at window openings.

The structure itself is made of exposed concrete for the pillars, slabs, and staircases. Concrete has high thermal mass: it absorbs heat during the day and slowly releases it at night, helping to stabilise indoor temperatures. The raw concrete surface also looks and feels cool, which matches the building's climate-responsive identity.

The integration of structure and envelope creates a cohesive system where thermal mass, insulation, and ventilation work together to regulate indoor conditions. Additional elements such as glass parapets and vegetation integrated on slab edges further contribute to the overall environmental strategy.

7.4.5 Green Roof, Tree, and Balconies

A green roof covers the top of the building. It provides additional insulation, cools the roof surface through evapotranspiration, and acts as a sound buffer for the residential units below. Above the green roof, a perforated steel canopy is installed. The canopy is organised in a grid, with a central opening that allows a tree to grow through it.

The tree species is *Ilex chinensis*. Local studies have shown that *Ilex chinensis* has one of the highest transpiration rates among common urban trees in Shanghai, meaning it provides strong cooling and humidifying effects (Shao Yongchang, 2015). The tree grows tall enough to surpass the canopy structure, emerging above the grid. The canopy itself shades the roof surface and the courtyard below, while the opening lets the tree receive full sunlight.

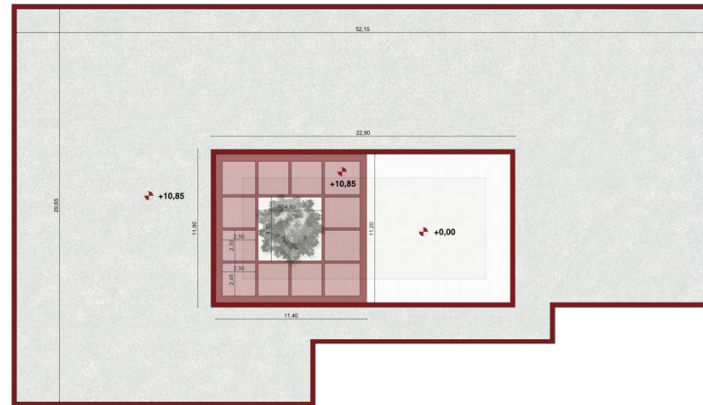


Figure 63: Roof plan showing the green roof with a canopy structure and *Ilex Chinensis* central tree, designed to provide shading and improve the microclimate.

Green balconies are present both on the internal courtyard facades and on the external balconies of the residential units. The balconies are deep enough to accommodate planters with shrubs and small trees. These plants shade the facade, cool the air through evapotranspiration, and improve air quality. The stairs are covered with climbing ivy (a self-clinging species), which further shades the circulation areas and reduces the heat absorbed by the concrete.

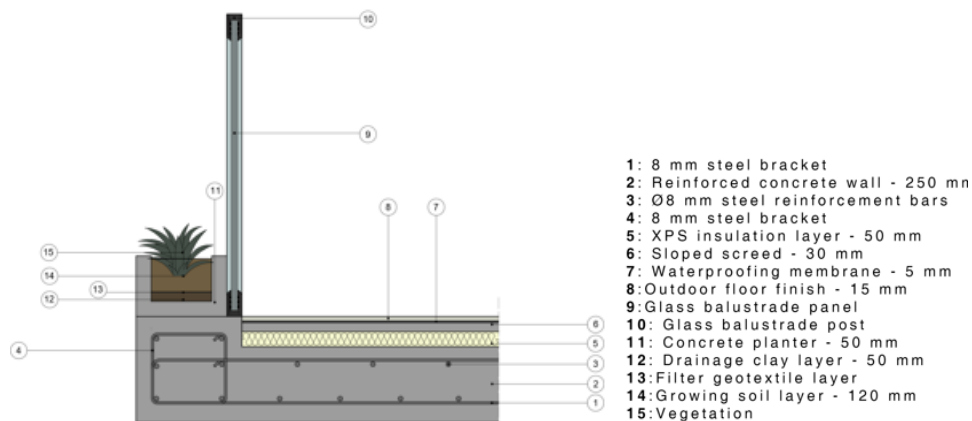


Figure 64: Balcony construction detail – plants and XPS insulation.

7.4.6 Encouraging Outdoor Hours: The Shaded Ground Floor

A key aim of the design is to reduce the hours people spend inside air-conditioned spaces by making outdoor areas comfortable. The ground floor, which contains commercial functions such as a bakery, study rooms, and a public courtyard, is completely shaded. The building volumes above project over the ground floor, and the pillars that support them create a colonnade effect. This overhead construction blocks

direct sunlight throughout most of the day, while still allowing air to circulate freely. As a result, the ground floor remains cool and inviting even during summer afternoons. People can sit, eat, work, or meet outside without needing air conditioning. This directly lowers the cooling demand of the building, because activities that would normally happen indoors are moved to shaded outdoor spaces.

The same principle applies to the central courtyard and the balconies. By providing shade, vegetation, and natural ventilation, the design encourages users to stay outside whenever possible, aligning with the overall climate-responsive strategy.

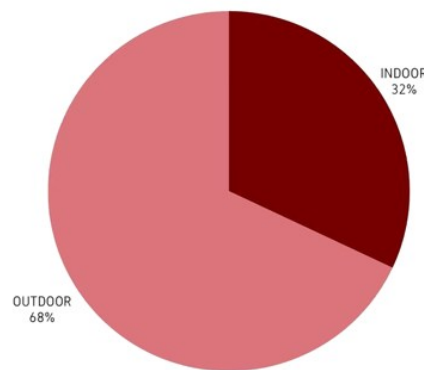


Figure 65: Example of hypothetical temporal use for the ground floor commercial space based on the proposed design, suggesting predominant use of outdoor spaces.

CHAPTER 8: DESIGN OUTCOMES AND EVALUATION

8.1 Comparison between Existing Condition and Design Proposal

Following the definition of the masterplan, the new buildings were first designed according to the climate-responsive design strategies discussed in Chapters 6 and 7. The new urban layout reflects a more permeable configuration, with controlled density, improved spacing, and orientation aligned with prevailing wind directions.

The geometries were then exported into a GIS environment, where the attributes of the buildings were updated: existing data related to construction year, number of floors, and use were replaced with new parameters consistent with the proposed scenario. Building heights were calculated assuming an average floor-to-floor height

of 3.5 metres, ensuring consistency across the dataset.

Functional uses were reassigned according to the new mixed-use strategy, integrating residential, office, and commercial programmes in order to balance energy demand over time. Each building was associated with a simplified archetype, as required by the simulation tool.

Because CEA works with simplified geometries, internal courtyards and complex volumetric details were not modelled. Instead, the overall building footprint and volume were used to approximate the energy behaviour. This is a limitation of the tool, but it still allows a consistent comparison between the existing and proposed scenarios.



Figure 66: GIS workflow for cooling demand calculation of new buildings.

(a) Removal of existing buildings.

(b) Insertion of new volumes. Courtyards are not included, as simplified geometries are required for compatibility with CEA.

Table 6: Updated typology table for the new scenario, including the new defined buildings. Building B1, the architectural design focus, is classified as mixed-use, with functional ratios assigned according to the floor area of each use. Commercial spaces occupy the smallest share, while residential and office areas have equal proportions.

name	floors_bg	floors_ag	void_deck	height_bg	height_ag	year	const_type	use_type1	use_type2	use_type3	use_type1r	use_type2r	use_type3r
B1	0	3	0	0	11	2026	STANDARD1	MULTI_RES	OFFICE	RETAIL	0,39	0,39	0,22
B2	0	3	0	0	11	2026	STANDARD1	COMMERCIAL	NONE	NONE	1	0	0
B3	0	2	0	0	7	2026	STANDARD1	RESIDENTIAL	NONE	NONE	1	0	0
B4	0	2	0	0	7	2026	STANDARD1	OFFICE	NONE	NONE	1	0	0
B5	0	2	0	0	7	2026	STANDARD1	OFFICE	NONE	NONE	1	0	0

The updated GIS model was then exported into City Energy Analyst (CEA) to generate a new design scenario. This allowed a direct comparison between the existing condition and the proposed intervention at the district scale.

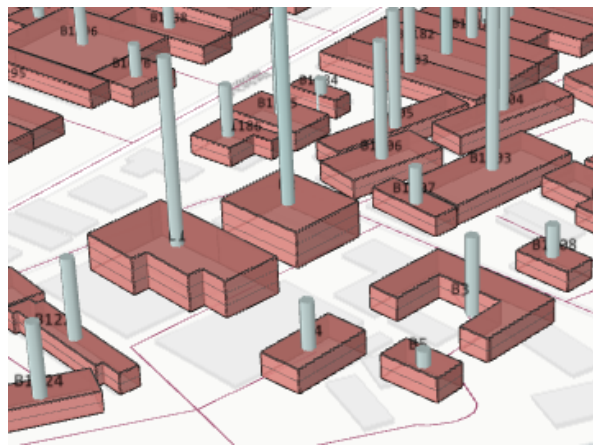


Figure 67: Visual representation of cooling demand intensity (kWh/m²) for the proposed buildings.

Table 7: Cooling demand values for the proposed buildings, compared to the lowest value among the three most inefficient buildings in the existing scenario, confirming the effectiveness of the climate-responsive design strategies.

Building	Cooling MWh	m2	Cooling kWh/m2	(min)Cooling kWh/m2(BEFORE)
B1	92,586	1187	78	128,3161395
B2	63,55	775	82	128,3161395
B3	35,904	528	68	128,3161395
B4	31,5	420	75	128,3161395
B5	26,25	350	75	128,3161395

In the proposed design, cooling demand values dropped significantly, with most buildings recording figures below 100 kWh/m². This reduction is visible across the entire site, not only in the redesigned cluster but also in the surrounding areas, due to the improved urban permeability and shading.

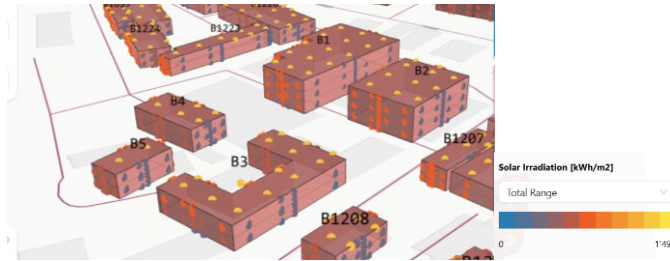


Figure 68: Solar radiation distribution on the four facades (north, south, east, west).

Beyond cooling demand, the software also allowed an investigation of solar radiation received by each facade orientation. The simulation confirmed that different facades behave differently under the same climatic conditions. The north-facing facades received the lowest amount of solar radiation throughout the year, making them the coolest and most stable in terms of thermal comfort. This finding confirms the design choice of placing service spaces and vertical circulation on the north side, as explained in Chapter 7. The south, east and west facades showed progressively higher radiation levels, with the west facade experiencing the most intense afternoon exposure. These results support the differentiated shading strategies applied in the project: horizontal louvers on the south facade, and vertical fins on the east and west facades.

8.2 Microclimate Improvements and Cooling Demand Reduction

The proposed masterplan introduces several modifications that directly influence the microclimatic conditions of the site.

At the urban scale, the reconfiguration of building volumes improves air permeability. This was achieved by adjusting building spacing, orientation, and height graduation. The software did not directly model trees or green spaces, but it read the open spaces and the H/W ratios between buildings. These parameters alone were enough for CEA to understand that the new layout allows better airflow and reduces heat accumulation, without needing to simulate every single tree.

Vegetation plays a central role in the microclimate strategy. The integration of a large central green area, together with distributed planted surfaces and green roofs, contributes to evapotranspiration and surface cooling. However, it is important to note that CEA does not directly account for evapotranspiration or tree shade. The reduction

in cooling demand observed in the simulation comes mainly from the improved building geometry, orientation, envelope properties, and the presence of open spaces. This means that even without modelling every green detail, the software already captured the benefits of a more permeable urban form.

At the architectural scale, shading strategies significantly reduce solar gains. The use of vertical and horizontal shading devices, and ventilated façades limits direct solar radiation, particularly on east and west orientations, which are more exposed in a humid subtropical climate. For the simulation, the key inputs were the building's orientation, window sizes, and envelope construction (ventilated facade with XPS insulation and green roof). These characteristics were enough to tell CEA that the building performs better than the existing one. The software calculated lower cooling demand as a result.

Again, CEA does not simulate wind flow in detail, but it does consider the building's geometry, window placement, and orientation. By inputting the correct window-to-wall ratios and openable areas, the software could estimate that natural ventilation would be effective.

The combination of these strategies results in a noticeable decrease in cooling demand, not only at the individual building scale but also across the entire district. The intervention demonstrates how climate-responsive design can translate into measurable energy benefits. **What the simulation shows is that even a simplified model, based on building shape, orientation, envelope, and functional mix, can capture the positive effects of a climate-responsive design.** Adding more details like trees or green balconies would likely improve the results further, but the current simulation already proves the effectiveness of the approach.

8.3 Discussion of Research Questions

The results of the design process allow a direct reflection on the initial research questions.

RQ1: How can climatic characteristics of a humid subtropical environment inform urban and architectural design strategies in Fuxing Island?

The project demonstrates that climatic parameters can effectively guide both urban and architectural decisions. In particular, solar exposure and prevailing wind

directions influenced building orientation, spacing, and form. The integration of vegetation and permeable surfaces responded to the need for cooling and humidity control, while shading systems and façade design addressed solar radiation. Climate was therefore not treated as a constraint, but as a generator of spatial and formal solutions. The simulation confirmed that orientation alone made a significant difference: buildings aligned along the east-west axis recorded lower cooling demand than the existing misaligned structures.

RQ2: How can energy assessment at the district scale support the identification of critical areas and guide design decisions?

The use of district-scale energy analysis enabled the identification of areas characterised by high cooling demand in the existing condition. This informed the selection of the intervention site and guided the design priorities. Although based on simplified models, the energy assessment provided a comparative framework to evaluate different scenarios and to support decision-making throughout the design process. Without CEA, it would have been difficult to pinpoint exactly which buildings were the most inefficient and why. The software made the design process more objective and data-driven.

RQ3: To what extent can an integrated climate-responsive approach improve environmental performance and reduce cooling demand compared to existing conditions?

The comparison between the existing condition and the proposed design indicates a clear improvement in environmental performance. The reduction in cooling demand across all buildings suggests that the integration of climate-responsive strategies at both urban and architectural scales can significantly enhance energy efficiency. The most inefficient existing buildings had cooling demand values around 129 kWh/m². In the proposed design, most buildings fell below 100 kWh/m², which represents a reduction of roughly 20-25%.

Rather than relying on a single intervention, the project demonstrates that the combination of multiple strategies, urban form optimisation, vegetation integration, shading, natural ventilation, and high-performance envelope, produces cumulative benefits. This confirms the effectiveness of an integrated approach in addressing the challenges of hot-humid climates. Moreover, the simulation showed that functional

mix also played a role. By assigning different uses to different buildings (residential, office, commercial), the software could account for different occupancy schedules, which helped balance the energy demand across the district.

CHAPTER 9: CONCLUSION

9.1 Summary of Findings

The design of Fuxing Island was guided by the need to improve thermal comfort and reduce cooling demand, addressing the specific challenges posed by the humid subtropical climate of Shanghai. Through the integration of climate-responsive strategies, both at the urban and architectural scales, the proposed intervention demonstrates significant improvements in environmental performance.

At the urban scale, modifications in building volumes and configurations allowed better airflow and improved natural ventilation. The introduction of permeable surfaces, vegetation, and green roofs contributed to local cooling through evapotranspiration and shading. What is important to note is that the used software did not need to model every single tree or green balcony to see an improvement. Simply by changing the building layout, orientation, and H/W ratios, and by assigning the correct functions and envelope properties, CEA showed a clear drop in cooling demand. This means that the urban design choices, spacing, height graduation, and porosity, were already effective on their own.

At the architectural scale, the use of shading devices, improved building orientation, and cross-ventilation strategies contributed to a reduction in cooling demand, helping to decrease the reliance on mechanical cooling systems. These architectural choices work together with the urban strategies described above, creating a combined effect that improves the overall thermal performance of the building.

The comparative analysis between the existing and proposed conditions confirmed that the integration of climate-responsive strategies at both scales significantly reduced energy consumption. These findings support the hypothesis that climate-driven design, combined with advanced energy assessment tools like CEA, can effectively enhance thermal comfort and contribute to energy efficiency in humid subtropical contexts. The project shows that even a relatively small intervention, three

buildings replaced and the surrounding strip redesigned, can have a measurable impact on the district's overall performance.

9.2 Research Contributions

The key contribution lies in the development of a design proposal that combines passive design strategies with energy simulations, illustrating the potential of early energy assessments to guide design decisions effectively. One specific contribution is the demonstration that functional mix matters. The simulation required precise inputs for each building's use, including the percentage of floor area dedicated to residential, office, and commercial activities. This shows that energy demand is not only about geometry and materials but also about how people use the building throughout the day.

Another important contribution of this research is that the design was not just about applying technical strategies from the literature review. The thesis went further by translating those strategies into a coherent architectural form. **Every design decision, the elongation of the building along the east-west axis, the placement of vertical circulation on the perimeter, the differentiation of window sizes by facade orientation, the choice of exposed concrete for its thermal mass, and the integration of the courtyard as a shaded social space, was made with the local climate in mind. This means that climate did not just influence the performance of the building; it shaped its very appearance and spatial quality.** The result is an architecture that looks and feels like it belongs to its environment, not a generic building with added technical devices.

Beyond numbers and simulations, the design also addresses a human aspect that is often overlooked in technical studies. The courtyard, the shaded ground floor colonnade, the green balconies, and the accessible green roof are not just passive strategies; they are places where people actually want to spend time. By designing spaces that are comfortable without air conditioning, cool, shaded, and ventilated, the **project encourages users to stay outside.** This is important because every hour spent outdoors is an hour that does not require cooling indoors. The design therefore reduces energy demand not only by improving the building's thermal performance but also by changing how people use the building. This dual approach, technical

efficiency plus behavioural change, makes the proposal more realistic and effective than a purely technological solution.

Furthermore, the research emphasizes the importance of integrating vegetation, shading, and natural ventilation, offering a holistic approach to reducing cooling demand while enhancing the quality of life in urban environments.

9.3 Limitations and Future Developments

Despite the promising results, this research is subject to some limitations. The reliance on simplified geometric models and archetypes in CEA simulations means that the results are indicative rather than precise. More detailed simulations, incorporating specific materials and HVAC systems, could provide a more accurate estimate of energy performance.

A specific limitation of this study is that CEA does not directly model trees, green balconies, or evapotranspiration. Therefore, the cooling effect of the *Ilex chinensis* tree in the courtyard or the ivy on the stairs was not captured in the numbers. The simulation results come mainly from building geometry, orientation, envelope, and functional mix.

An interesting next step would be to focus on the architectural scale with higher precision: using a building energy simulation tool to model the courtyard building in detail, including the green roof, green balconies, the central tree, and the adjustable shading devices. This would give a more accurate picture of how much each passive strategy contributes to cooling reduction.

Further research could also explore the scalability of the proposed strategies to other areas of Shanghai and beyond, particularly in regions with similar climatic conditions. The method used in this thesis, identifying inefficient clusters, redesigning them with climate-responsive strategies, and simulating again, could be applied to other parts of Shanghai or to other humid subtropical cities. The design principles (orientation, porosity guaranteed by the open spaces created between the building forms, shading, ventilation, green integration) are not site-specific; they can be adapted to different contexts as long as the local climate is analysed first.

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RINGRAZIAMENTI

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